Learning inquiry and the nature of science through undergraduate research: Mentoring matters

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Abstract

Undergraduate research experiences (UREs) have the potential to involve students in authentic, cutting-edge scientific inquiry. While research has shown that UREs can be effective in recruiting and retaining students and increasing students' confidence to do research, the literature on science-learning through undergraduate research is scant. My research investigated what students learned about the practice of scientific inquiry and the natures of scientific knowledge (NOS) and inquiry (NOSI) through participation in summer UREs in cutting edge biotechnology laboratories. I also explored the types of research projects and intern-mentor transactions taking place in the UREs to explain students' learning outcomes. I employed a mixed-methods approach involving a pre-post assessment of gains and an exploratory investigation of the laboratory research situations. In general, interns' independent practice of inquiry was of the most basic skills, though their guided practice included many of the more advanced inquiry skills important in developing scientific thinking. While few interns made gains in understandings about NOS, many made gains in understandings about NOSI. NOSI gains were associated with greater autonomy and independent practice of advanced inquiry skills. The exploratory investigation found that mentors played a critical role in determining the type of research project and in driving the intern-mentor transaction. These in turn, contributed to intern's learning outcomes. For example, multifaceted research projects (both observational and hypothesis-driven) provided more opportunities to practice advanced aspects of inquiry. Interns engaged in more indeterminate projects, where methods were less prescribed and outcomes less predictable, generally made greater gains in understandings about NOSI.

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Introduction

As the world-wide demand for a scientific workforce increases, US students perform poorly in international rankings of scientific literacy and US undergraduate science and engineering programs suffer from low enrollments, low diversity and high attrition (Seymour & Hewitt 1997; National Science Foundation [NSF], 1998; National Science Board [NSB], 2006; National Research Council [NRC], 2007). Numerous calls for undergraduate science education reform have been issued over the past 20 years, with increasing urgency (e.g. NSB 1986; Boyer Commission, 1998; NRC, 1999 & 2003; Project Kaleidoscope [PKAL], 2006 and references therein). The most recent synthesis of this reform literature issued the following "recommendations for urgent action":

- use inquiry-based teaching and learning techniques to develop interest in science and engineering fields for all students,
- foster a "deep understanding of the nature of science,"
- provide authentic experiences that reach out into the real world of scientific careers,
- provide learning experiences that are interdisciplinary and that reflect what is on the cutting edge of both scientific and educational research. (PKAL, 2006, pg. 1)

Undergraduate research experiences (UREs) have the potential to address all of these recommendations and are at the forefront of current reform efforts (Fortenberry, 2000, Boyer Commission, 2002). A large body of exhortative and descriptive literature promotes UREs for attracting and retaining a talented and diverse pool of undergraduates in science career pathways; learning the process and nature of scientific research through inquiry; and bridging undergraduate and graduate education (e.g. Boyer Commission, 1998; NRC 1999, 2003). The National Conferences on Undergraduate Research (NCUR) and the Council on Undergraduate Research (CUR) jointly endorse this type of experience as a collaborative, investigative pedagogy integrating teaching and research to provide students with an enriched inquiry-based learning experience (NCUR, 2005). Through active engagement in authentic scholarly work under the guidance of an established member of the discipline, students may develop thinking and reasoning skills as well as knowledge of subject matter and the process of science.

Though undergraduate research programs are expanding rapidly under the encouragement of major funders such as the NSF and the Howard Hughes Medical Institute (HHMI), there is little empirical evidence describing what and how students learn through participation in these experiences.

Therefore, the purpose of this study was to explore what students learned about the practice of inquiry and the nature of science through participation in undergraduate research. The context of this study was a ten-week summer internship in biotechnology and genomics. My research addressed the questions: What do students actually learn about the practice of science, the nature of scientific knowledge (NOS) and the nature of scientific inquiry (NOSI) when they participate in a URE, what are the means by which this learning occurs, and what factors appear to limit learning? A deeper understanding of student learning in UREs will permit the science education community to better develop and integrate meaningful research experiences into undergraduate science education and to build more effective bridge programs between undergraduate and graduate training in science.

What Do We Know About UREs and How They Have Been Studied?

The Council on Undergraduate Research defines undergraduate research as “an inquiry or investigation conducted by an undergraduate student that makes an original or creative contribution to the discipline” (CUR, n.d). In the sciences, undergraduate research typically involves participation in a laboratory (including the computer lab) or field research project under the guidance of a mentor (graduate student, researcher or faculty member). An URE involves significant mentoring by a member of the field; results in the student making a meaningful contribution to the field; involves the student in the actual techniques of the field; and culminates in some form of dissemination of a tangible product by the student to the scholarly community (Hakim, 1998).

In order to establish what is known about the benefits and qualities of effective science UREs, Seymour, Hunter, Laursen, and Deantoni (2004) reviewed the available literature. Two major themes emerged from that review: preparation for a career in science and developing a sense of belonging. Research subsequent to Seymour et al.’s review provides further empirical support for these themes and strongly support claims that UREs can help to retain talented and interested students in graduate pathways, support minorities and women in science, and inspire some new students to pursue an advanced science degree (Bauer & Bennett, 2003; Seymour et al., 2004; Lopatto, 2004, 2007; Russell 2005a, 2005b, 2006; Hancock & Russell, 2008).

What is still lacking, however, is a substantial body of empirical literature outlining the benefits of undergraduate research in terms of students’ learning about doing science. Only one study to date has focused explicitly on the learning of specific research skills. Kardash (2000) developed a list of 14 such skills from recent literature on assessing UREs and from discussions with faculty research mentors. The list of skills reflected aspects of the NRC’s (1996) list of important inquiry abilities, as well as general understanding of concepts related to the student's research project. Kardash asked 57 URE alumni to rate their abilities to perform the research skills before and after their participation in the URE and the degree to which they felt their skills had been enhanced. She triangulated her findings by also asking the research mentors to rate students' abilities at the end of the research experience.

The skills that students felt were most enhanced through their research experience were: oral communication of results, observing and collecting data, relating results to the bigger research picture, and understanding contemporary concepts in the field. What Kardash termed the "higher order skills involved in doing science" (identifying a question for investigation, designing a test of an hypothesis, and reformulating an hypothesis based on experimental results) were rated as being enhanced only "somewhat." Kardash concluded that these findings

> …suggest that although UREs are clearly successful in enhancing a number of basic scientific skills, the evidence is less compelling that UREs are particularly successful at promoting the acquisition of higher order inquiry skills that underlie the foundation of critical, scientific thinking. (p. 196)

The study focused on participants' perceptions of learning. It revealed nothing about the characteristics or qualities of the students' research experiences to help in understanding why the more advanced inquiry skills were not enhanced. The study also did not attend to developing understanding of NOS or NOSI.

The work of Ryder, Leach and Driver (1999) represents the only published investigation, to my knowledge, of changes in undergraduate science students' views about NOS and NOSI[1]

[1] Ryder *et al.* did not distinguish between NOS and NOSI. One of the aspects they discussed (nature of lines of scientific inquiry) would fall under the rubric of NOSI as described by Schwartz. (2004). The other two aspects they investigated (relationships between knowledge and data and social dimensions of science) span both NOS and NOSI.

through participation in undergraduate research. This study involved semi-structured interviews with 11 British undergraduate students working on their final-year research projects in several science fields. Interviews were conducted early in the research experience and again near the end of the experience and focused on three aspects of NOS/NOSI: relationships between knowledge and data, the nature of lines of scientific inquiry, and the social dimensions of science.

These authors found that most students maintained a view of scientific knowledge as distinct from data and provable, though they did note an increased emphasis on the distinction between knowledge and data and on empirical validation of claims from pre to post. Students' views about the nature of lines of scientific inquiry appeared to change under the influence of their research experience. Ryder et al. found a marked increase in emphasis on theoretical guidance of scientific questions in students' statements between the early and later interviews. Ryder et al. found no shifts in students' thinking on the social dimensions of science. In their discussion, Ryder et al. pointed to exposure to "a culture of research practice," as well as the nature of the research project as two mechanisms for influencing students' thinking:

> …we found that students whose project had an epistemological focus (e.g., relating data to knowledge claims) tended to show developments in their epistemological reasoning. By contrast, students whose projects involved making experimental techniques work with novel materials tended to show limited development in their reasoning about data and knowledge claims. (p. 215)

Some of the work conducted after Seymour et al.'s (2004) review has attempted to develop links between students' reported learning gains, elements of the research experience and persistence in science. For example, Lopatto (2004) developed the Survey of Undergraduate

Research Experiences (SURE) to evaluate UREs supported by the HHMI. Lopatto derived his survey questions from the literature on the purported benefits of UREs and from early findings shared by Seymour et al. (2004), whose work is described below. The SURE survey was completed by 1,135 URE participants from 41 different undergraduate institutions (response rate of 74%). Students reported large gains on items regarding learning of laboratory and research skills (which included a selection of inquiry abilities and understandings), independence, and personal development. In particular, “learning laboratory techniques” and “understanding the research process” were rated highest overall. Lopatto also found that a small number of URE participants claimed new-found interest in pursuing graduate education in research (3% of his sample) and an equally small number of URE participants who decided to turn away from a research career. Lopatto’s data showed that these two groups (those more likely to pursue grad school and those less likely) were widely divergent in their mean overall self-ratings of learning gains and satisfaction with their research supervisor.

Another example is Russell’s (2005a) evaluation of the NSF’s Research Experiences for Undergraduates (REU) program. This extensive work went further to link student’s self reports of learning and satisfaction with elements of the research experience. Her evaluation targeted participants of a variety of NSF sponsored programs involving undergraduate research; approximately 4,500 undergraduate researchers (response rate of 75%) completed her web-based survey. Survey items were derived from review of other evaluation surveys and discussions with NSF program officers. Participants rated their perceptions of how much the research experience increased their understanding of various elements involved in planning and conducting research, confidence in their research skills, and awareness of what graduate school might be like. The two highest rated items were “understanding the nature of the job of a researcher” and "understanding how to conduct a research project." Russell found a link between increased interest in a research career and increased confidence in research skills. Confidence gains were linked to autonomy and mentoring, being highest in those students who were involved in designing their research project, gained independence in their work, developed a better understanding of the bigger research picture, and who felt they had sufficient contact with their research mentor. She also found that the satisfaction related to a mixture of student and program attributes: the student's reported enthusiasm for research, feeling prepared going into the research experience, being involved in decisions and design of the project, and the amount of time spent in research activities with the faculty mentor.

Seymour et al. (2004) used interviews to conduct their own investigation of how students benefited from participating in summer UREs, conducting interviews with 76 undergraduate researchers. Their analysis of student's interview transcripts developed six categories for benefits, with 73% of the observations falling into: "thinking and working like a scientist" (27-28%), "personal-professional development" (27-28%), and technical "skills" (19%).
Another component of this study involved interviewing 55 of the students' faculty mentors. Hunter, Laursen, and Seymour (2008) analyzed the transcripts from the mentors' interviews and compared these findings with those of Seymour et al. (2004). The list of faculty observations about the benefits of UREs closely matched the list of student observations. However, the two groups differed in the importance that they placed on different gains, and offered different perspectives about students' development into scientists. Hunter et al. reclassified the codes among the categories to reflect these differing perspectives, creating a new category, "becoming a scientist."

Though laboratory and research skills feature prominently in much of the URE literature reviewed above, the picture of the URE as an experience in learning to do inquiry remains incomplete. Students reported developing confidence and proficiency through practicing certain inquiry skills, but it seems that these were, for the most part, the simpler skills (Kardash, 2000; Seymour et al., 2004). This may be due to the difficulty in mastering more advanced inquiry skills in the short duration of the typical URE, or it may be that students were afforded fewer opportunities to practice such skills in UREs. Though they did not explicitly focus on inquiry, Seymour et al.'s (2004) interview study uncovered students' and mentors' views of the benefits of learning through inquiry. Their findings suggest the ways in which students developed greater knowledge and understanding of scientific theories and concepts as they engaged in research activities: problem solving, explaining their research and its findings, and interacting with peers and mentors. These interactions also appear to have contributed to students' feelings of confidence and their self-identification as young scientists. Russell's (2005a) work also indicates that interactions with mentors, along with involvement in the research design and independent work contributed to students' satisfaction and confidence in their abilities to do science. However, her work did not address how involvement or independence might have been developed through practice, or how these factors might have interacted with student learning.

Only the work of Ryder et al. (1999) attended to students developing knowledge about NOS or NOSI, although some of the items in Lopatto's (2004) and Russell's surveys reflected important understandings about NOS and NOSI, in particular, understanding the research process or how research is conducted. Lopatto also included the item "Understanding how knowledge is constructed." These items were all rated highly by survey participants in both studies. However we know nothing about how these understandings developed, or if students were able to articulate these understandings. Seymour et al. (2004) and Hunter et al. (2008) reported that only a very small percentage of students' or mentors' observations referred to developing understandings about NOS or NOSI. Ryder et al. were able to demonstrate that students participating in UREs can develop more sophisticated views of the relationship between knowledge and data, the importance of empirical processes of validation, and the guiding influence of theory on the direction of research, and that development of certain views may be linked to aspects of the research experience.

This review of the relevant literature demonstrates the small body of empirical work supporting UREs as experiences in which students learn abilities and understandings about inquiry and the scientific enterprise. There is evidence to suggest that undergraduate researchers make some gains in laboratory research skills (Kardash, 2000) and understandings of two aspects of NOS and NOSI (Ryder et al., 1999), and begin the enculturation process into the social world of science practice (Seymour et al., 2004; Hunter et al., 2008). Sadler, Burgin, McKinney and Ponjuan (2010) reviewed a larger body of literature (53 studies) incorporating apprentice-style research experiences for high school students, undergraduate students, pre-service teachers and in-service teachers. These authors reached similar conclusions regarding learning science through research experiences.

Inquiry, Nature of Science and Nature of Scientific Inquiry

The American Association for the Advancement of Science established scientific literacy as a central goal in science education in *Science for All Americans* (Rutherford & Ahlgren, 1989). This document recommended teaching more effectively by focusing on scientific literacy, rather than trying to teach an ever-increasing body of facts that makes up a general knowledge of science. Key among the recommendations was an understanding of the nature of "the scientific endeavor." Understandings about both NOSI and NOS are important learning goals in *Science for All Americans*. Though the authors admitted that scientific inquiry is so varied as to be most difficult to define, they highlighted several aspects of its nature: inquiry requires evidence, logic and imagination and aims to explain and predict; scientists work to avoid bias; and science is not authoritarian – i.e. no scientist has special access to the truth. These authors strongly recommended that science teaching reflect the nature of scientific inquiry by actively engaging students with science-related hands-on, minds-on activities directed by scientific questions and focused on collecting and using evidence: "[d]o not separate knowing from finding out." In this way it is believed that students can construct desired understandings about the scientific endeavor that are situated in the practice of science-process skills.

The *National Science Education Standards* (NRC, 1996) followed *Science for All Americans* in viewing inquiry not only as something that scientists do, but also as an active process through which students learn about science. Though the focus in *The Standards* is primarily on secondary science education, it made the following distinction important to learning inquiry at all educational levels. Students should develop not only *abilities to do* scientific inquiry but also *understandings about* scientific inquiry (i.e. aspects of NOSI and NOS; NRC, 2000). Student *abilities* reflect research and reasoning skills used by scientists in their work: identify testable questions; design and conduct investigations around such questions; use evidence and logic to frame, revise and defend scientific arguments and explanations; recognize and evaluate alternative explanations; effectively communicate findings, and use math and technology to generate, store, manipulate, analyze and communicate data (NRC, 1996). The student should also have fundamental *understandings* that reflect the philosophical and socio-historical nature of scientific endeavors: scientific investigations are undertaken for a variety of reasons (confirmation, explanation, discovery, testing prediction) and are guided by the principles, knowledge and theory of the day; in executing this work scientists rely on technology and mathematics; scientific explanations must adhere to criteria that are determined by the community of practitioners; scientific results are communicated so that they may be subject to critical review by the scientific community (NRC, 1996).

Instruction that integrates both abilities and understandings of inquiry provides students with a framework for understanding the scientific endeavor (i.e. scientific literacy): what and how scientists actually do their work and what forces shape or influence that work and its products. Thus, students can begin to develop an appreciation for both the promise and limitations of scientific knowledge as they learn the reflective, reasoning, and argumentation skills involved in the construction and elaboration of that knowledge. Such skills transfer to real-life situations of problem solving and decision making, and are an important step in educating a citizenry that can make informed decisions about scientific and technological issues. Lederman (2004) and Schwartz and Crawford (2004) point out that there is a synergism between practicing inquiry and understanding the nature of scientific inquiry and scientific knowledge. As Lederman (2004) wrote:

> …it is useful to conceptualize scientific inquiry as the process by which scientific knowledge is developed, and by virtue of the conventions and assumptions of this process, the knowledge produced necessarily has certain unavoidable characteristics (i.e., NOS). (p. 308)

These authors, and many others, recommend explicitly addressing NOS and NOSI within an inquiry context, and providing students with opportunities for discussion and reflection in order to promote deep understandings of these concepts. Undergraduate research can provide an authentic inquiry context in which to develop these understandings.

Methods

This investigation aimed to describe what students learned, and to explain some factors that appeared to contribute to learning, through participation in mentored, laboratory research. The aspects of student learning focused on were: practicing scientific inquiry and developing understandings about NOS and NOSI.

Research Questions

Descriptive questions about learning gains.

1a. What experience with inquiry and research skills did interns gain compared to their prior education?

1b. What inquiry and laboratory research skills did interns practice both independently and with guidance from their mentor?

2. What gains, if any, did interns develop in understanding aspects of NOS and NOSI?

Explanatory questions about how interns develop understandings.

3. Did practical experience relate to understandings about NOS and NOSI?

4. What attributes of the intern or the research experience might explain change or lack of change?

   a. Prior research experience?

   b. Nature of the intern's research project?

   c. Nature of the intern-mentor relationship?

Setting

This research investigated one cohort of interns and mentors involved in an NSF-supported summer REU in the field of plant biotechnology and genomics. The Summer Internship Program (hereafter referred to as the Program) was in its seventh year and administered by Research University with very high research activity (RU/VH)[2]. The goals of the Program were to provide students with 1) broader knowledge of the field's research 2) a better understanding of authentic scientific research 3) and preparation for future academic work in this field through "mentored, independent research."

This URE provided interns with an intense experience, offering the opportunity to participate in highly advanced research in sophisticated settings, and to learn and apply new technologies, techniques and advanced molecular/genetics concepts. Interns were immersed in laboratory culture as they worked 40 hours or more weekly for ten weeks, without distraction from coursework or other obligations. The intern's research project was directly related to the on-going work of the laboratory and often contributed to a lab member's dissertation, grant proposal or publication, affording opportunities for interns' learning to go beyond aspects of inquiry to the social dimensions of research practices and the development of scientific knowledge (i.e. NOS and NOSI).

Participants

Interns. The program supported 15 – 20 interns each summer, selected from a pool averaging 300 applicants. As an REU, this program strove to meet the NSF's recommendations in its intern-selection process: gender balance; at least 30% minority participation; and inclusion of younger undergraduates and students from small undergraduate and 2-year institutions (NSF, 2007). The program achieved all of these selection goals with the 2009 summer cohort (Table 1). Other criteria for selection included GPA, interest in the field and prior research experience. In selecting from the pool of applicants, the Coordinator for the Program collaborated with PIs to balance interests in accepting more experienced interns with the NSF's recommendations described above. The result was a diverse cohort of interns from a variety of educational

[2] Carnegie Classification

backgrounds. Some interns had completed only a single semester of biology coursework and had no prior research experiences. Other intern had completed advanced coursework in molecular biology and several semesters of undergraduate research. These factors may have influenced the intern's practical experiences and learning in the laboratory by determining such things as starting points for the research project and training, the intern's comfort level with independence, and the trajectory of the intern's progress.

Wherever possible, interns were matched with laboratories by interest. They were assigned to a mentor who provided a research project and training. Interns worked at the lab bench, on the computer, in the greenhouse and in the field to conduct their own work and to participate in the work of lab-mates. Some PIs recruited additional interns that were not covered by the NSF funds. The additional interns worked alongside the NSF-supported interns, attended program seminars and social events, wrote a proposal and prepared final posters for the student symposium. However, they were not housed with the NSF-supported interns. Of the 24 interns in the 2009 cohort, five were not NSF-supported.

Mentors. Mentors were selected on an individual basis by the laboratory's PI. Mentor selection was an informal process based on some combination of availability, suitability of their laboratory work for an intern, and prior experience mentoring students. English language skills were also an important consideration as many mentors were non-US citizens. The 2009 mentor cohort included research assistants, graduate students, postdoctoral researchers, and PIs. Though 14 of the 24 mentors were new to the Program in 2009, most of these had mentored a high school, undergraduate, or graduate student in laboratory research prior to participating in the Program. Only three had no prior mentoring experience (Table 2).

Table 1: Interns Participating in the Summer Internship Program 2009. Bold text indicates interns who participated in field observations.

Pseudonym	Year (rising)	Semesters* Prior Research	URM†	Major	Home Institution Carnegie Classification‡ (VH = very high research activity H = high research activity)
Angela	So.	0	X	Biology	Associate's (large rural)
Tanis	So.	0	X	Biology	Tribal College
Heather**	**So.**	**0**		**Plant**	**Research University (VH)**
Wanda**	**So.**	**0**		**Biology**	**Research University (VH)**
Todd	So.	3		Bioche	Doctoral/Research
Betty	Jr.	0		Genetic	Research University (H)
Claire	Jr.	1.5		Biology	Baccalaureate College
Elliot	**Jr.**	**3**		**Biology**	**Baccalaureate College**
Elyssa	Jr.	4	X	Biology	Master's University
Abraham	Sr.	0		Biology	Baccalaureate College
Bart	Sr.	0		Biology	Research University (H)
Lisa	Sr.	0		Biology	Baccalaureate College
Shanell	**Sr.**	**0**	**X**	**Biology**	**Master's University**
Vicky	**Sr.**	**1**		**Biology**	**Research University (H)**
Jake§	**Sr.**	**1.5**		**Biology**	**Associate's (large rural)**
Gene	Sr.	2		Bioche	Baccalaureate College
Hans	Sr.	2		Biology	Baccalaureate College
Helen	Sr.	4		Bioche	Research University (VH)
Monique	**Sr.**	**6**	**X**	**Biology**	**Master's University**
Quinn	**Sr.**	**5**		**Biology**	**Research University (H)**
Ricky	Sr.	7		Biology	Research University (H)
Eddie**	Postbacc	1		Biology	Master's College
Minnie**	5th yr.	4		Pre-Vet	Master's University
Taylor**	**5th yr.**	**4**		**Bioche**	**Master's University**

*Summer research experiences were counted as one semester.
†Students from minority groups underrepresented in US science.
‡Carnegie Classification (http://classifications.carnegiefoundation.org/descriptions/)
§Jake was an older-than-average student returning to complete the remaining credits for his 4-year degree.
**Interns not supported by NSF funds.

The program provided no training or formal guidelines for mentors although they were required to attend a 1-hour orientation meeting during which they were made aware of the program's goals for interns, expectations for mentoring, and suggestions for developing a good working relationship with their intern. Mentors were expected to provide interns with a research project attending to the program's goals that could be accomplished within the ten-week timeframe. Mentors were also expected to guide the intern in lab work, writing a research proposal and preparation of a PowerPoint (© Microsoft Corp.) presentation for the student symposium in the final week of the Program. Mentors constructed the intern's research project, though sometimes in consultation with the PI, and took primary responsibility for the intern's research experience. Mentors were also primarily responsible for teaching interns about their project: the underlying biology, the bigger research picture, the techniques entailed, how the data were to be collected and analyzed, and what the results meant. Mentors made the important decisions about the progress and/or direction of the project throughout the summer and were the ultimate determinants of how independent and autonomous the intern's practice would be. Mentors provided feedback on interns' laboratory practice, writing and final presentation. Mentors also served as tour- and safety-guides to the laboratory, the facilities, and in some cases the campus and larger community. Thus, interactions between intern and mentor shaped the intern's practical experiences, engagement with authentic research, and learning.

Design and Analysis

The research involved two components: a pre-post single group design (Trochim, 2006) to investigate change, and an exploratory, qualitative investigation of factors that might be related to change, or lack of change (Creswell, 2009; Krathwohl, 2009). I used pre- and post-program assessments involving a variety of instruments and follow-up interviews to address questions about interns' practice of inquiry skills, change in understandings of NOS/NOSI, and personal epistemology. To explore relationships among these elements, intern's prior experience and aspects of the URE, I employed ethnographic methods, using in-depth interviews, field observations, and interns' written work to construct explanatory vignettes (Stake, 1995). Table 3 summarizes the schedule for data collection, the data sources, and the relationship between data sources and research questions.

Table 2: Mentors Participating in the Summer Internship Program 2009. Bold text indicates mentors who participated in field observations (RA = research assistant, Grad = graduate student, Post Doc = postdoctoral researcher, PI = primary investigator).

Pseudonym	**Status**	**New Mentor** (X = new to the Program XX = 1st time mentor)	**Non-US Citizen?**
Bernard	**RA**	**XX**	
Lijuan	Grad	XX	Asian
Arthur	Grad	X	
Mandy	**Grad**	**X**	
Tim	Grad	X	
Selena	Grad		Latin American
Harry	**Grad**		
Midori	Post Doc	XX	Asian
Priya	**Post Doc**	**X**	**S Asian**
Jinsong	Post Doc	X	Asian
Dick	Post Doc	X	
Ajay	**Post Doc**	**X**	**S Asian**
Xiang	Post Doc	X	Asian
Pierre	Post Doc	X	N American
Guy	Post Doc	X	
Young	**Post Doc**		**Asian**
Nancy	**Post Doc**		
Franck	Post Doc		European
Christiaan	**Post Doc**		**European**
Marisol	Post Doc		Latin American
Grant	Post Doc		Austral Asian
Faith	**Post Doc**		
Gabriella	PI	X	E European
Qiao	PI		Asian

Pre-post assessment of interns. Interns completed a written questionnaire during the week prior to the program, and then participated in a follow-up, semi-structured interview during the first two weeks of the program. The pre-program questionnaire incorporated a Likert surveyof practical experiences with aspects of inquiry and questions about NOS/NOSI[3] (see Appendix A). The Likert survey was that of Kardash (2000) modified to more closely align with the abilities and features of inquiry outlined in the NSES (1996). Interns completed the survey prior to the interview and then were invited to discuss their interpretation of the survey items and the rationale behind their ratings during the follow-up interview in a retrospective think-aloud process (Sudman, Bradburn & Schwartz, 1995). The NOS/NOSI portions of the questionnaire and follow-up interview were developed from the Views of Nature of Science (VNOS) instrument of Lederman et al. (2002) and the Views of Scientific Inquiry (VOSI) instrument of Schwartz (2004). In their recent work, Schwartz & Lederman (2008) have conducted research in which they have combined the VOSI and the VNOS to more fully describe participants' conceptions of inquiry and scientific knowledge. The two instruments overlap in several areas. I collaborated with a colleague versed in the use of the VNOS to combine questions showing strong overlap, make modifications where appropriate (Schwartz, pers. com) and to preserve the 8-question structure of both instruments (See Appendix B).

The follow-up interview reviewed interns' responses to the questionnaire, covered the remaining questions from the combined VNOS/VOSI and included additional questions about the intern's prior research and science education background (Appendix B). Interns were interviewed again during the last two weeks of the program. In these late interviews, interns were asked complete a similar Likert survey, to review their earlier responses to the questions

[3] The pre-post assessment also incorporated Baxter Magolda's (1992) Measure of Epistemological Reflection instrument to investigate change in interns' epistemological thinking. These data are discussed in another paper and will not be described here.

about NOS/NOSI, and to comment on how their views may or may not have changed through participation in the program. Interns were also asked to answer questions about their research experience, autonomy in the lab and mentor.

Together, the pre-program questionnaire and early interview served as a pre-assessment. The late interview served as a post-assessment. These datasets were compared to identify elements of change and factors in the interns' experiences that might account for that change. Mentors were also interviewed and asked to complete the Likert survey based on their interactions with the intern (Appendix C). These data were used to triangulate intern's self reports.

Engagement with inquiry. The ordinal scale and small sample size (N=24) in this study meant nonparametric statistical approaches were most appropriate for comparing individual survey items (Göb, McCollin & Ramalhoto, 2007). I computed a median rating and interquartile range[4] (IQR) for each survey item. I then ranked items in descending order, to sort frequently practiced skills from infrequently practiced skills, for interns' pre- and post-surveys. I conducted the same analysis for mentors' post-surveys to compare results between the two groups of participants.

The summed survey score is a continuous variable, meaning that parametric statics were most appropriate for comparisons between intern's summed independent and guided scores and between interns' and mentors' surveys. The grand sum of these ratings on the post-survey reflected the intern's overall experience, or engagement with aspects of inquiry as a participant in the Program (Thorndike & Thorndike-Christ, 2005), incorporating both independent and guided practice. Twenty mentors also completed the survey. I combined these two perspectives

[4] Median and interquartile range are nonparametric analogs to the mean (an estimate of location) and standard deviation (a measure of variability).

by averaging the two grand sums produced by each intern-mentor pair. This produced a single, conservative score describing the intern's overall engagement with inquiry as a participant in the program; this is the program inquiry score.

Autonomy. Two additional items on a Likert scale addressed the intern's feelings of autonomy in the research experience. These items were summed and then averaged for each intern-mentor pair to produce a conservative score describing the intern's autonomy in conducting his or her project. Autonomy scores were used in conjunction with program inquiry scores to graphically represent the variability in inquiry experiences in a manner similar to Brown *et al*.'s (2006) inquiry continuum. A low autonomy score reflected a highly prescribed, mentor-directed project. A high autonomy score reflected a more open, intern-directed project.

Correlations. I performed a number of regression analyses to test ideas about interns' practical experiences with inquiry and gains in understanding about NOS and

Calculation of numerical scores for understandings of NOS and NOSI are described below.

Understandings about NOS and NOSI. Written responses to the VNOS/VOSI and the transcripts from this portion of the interviews were analyzed to describe interns' pre and post understandings of aspects of NOS and NOSI. I worked with a colleague who was also using the combined VNOS/VOSI to develop a scoring rubric for this instrument. We used descriptions and examples provided in Lederman et al. (2002), Schwartz (2004) and Schwartz & Lederman (2008) to define the upper (more informed) and lower (naïve) bounds for each aspect of NOS and NOSI. Though Lederman et al. (2002) scored three categories of response (naïve, intermediate, and more informed), we found that four worked better for the finer grained analysis necessary to detect small amounts of change expected from a short-duration intervention. We split the intermediate bin into "emerging" and "informed," using examples from our own datasets to describe each of these categories. We then reclassified all of our participants' responses. The resulting rubric was a 4 point scale (naïve = 0, emerging = 1, informed = 2, and more informed = 3) and can be found in Appendix D.

Exploratory Investigation

The second component of this research project involved an exploratory investigation through naturalistic and ethnographic inquiry approaches. The purpose of this second component was to generate a more detailed understanding of some of the factors that might have contributed to interns' research learning experiences and perhaps explain why or how interns gained (or failed to gain) from the experience. Aspects of the second component were also designed to help triangulate some of the findings from the pre-post design component.

Early and late interviews with interns. Early interviews with interns included open-ended questions about the intern's science education background (prior research experiences, classroom laboratory experience, and science coursework), expectations for the summer internship, and perceptions of the Program so far (see Appendix B). Late interviews with interns included other open-ended questions about their experiences as a summer intern, the research project, mentoring, and the laboratory atmosphere.

Additional artifacts. Interns' application materials included personal statements, letters of recommendation, and transcripts. These materials helped me to triangulate self-reports about prior research and coursework. All interns were required to write a research proposal in the early weeks of the program and a final symposium presentation or poster (non-NSF). These items provided information about the research project's design, the bigger research picture, the techniques employed during the research, and the subject matter knowledge necessary to

Table 3: Data Collection Summary Schedule. Summary of Data Sources, Schedule of Data Collection, and Relationship to Research Questions (research questions, instruments and protocols are described in the text).

	Data Source	1 Wk Pre	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9	Wk 10	1-10 Wks Post	Research Questions
Interns	**Application Materials**	●—●												**5**
	Pre-Program Questionnaire • Likert Survey of Inquiry Skills • Views of Nature of Science /Scientific Inquiry • Measure of Epistemological Reflection	●—●												**1-3**
	Early Interviews • Follow-up to questionnaire • Intern's background and expectations • Perceptions of the research setting		●——	——●										**1-5**
	Research Proposals			●●										**1** and **5**
	Longitudinal Observations				●——	——	——	——	——	——●				**1-5**
	Late Interviews • Likert Survey of Inquiry Skills • Views of Nature of Science /Scientific Inquiry • Measure of Epistemological Reflection • Perceptions of the research experience, setting, and mentor										●——	——●		**1-5**
	Research Presentations												●●	**1** and **5**
Mentors	**Post-Program Interviews** • Likert Survey of Inquiry Skills (Intern's Practice) • Mentor's background and expectations • Perceptions of intern and the research experience												●—●	**1** and **5**

understand all of these things. Proposals and presentations were helpful in understanding the different aspects of the intern's research project, and in developing a typology of research projects for the 2009 Program.

Post-program interviews with mentors. Interns' mentors were invited to participate in a post-program semi-structured interview during the ten week period after the program. Four of the 24 mentors declined to be interviewed. The interview protocol for mentors (Appendix C) included questions in three areas: 1) perceptions of the intern's experience and learning, 2) philosophy and approach to mentoring, 3) and perceptions of the program and its contribution to students' science education. The mentor interview helped to characterize the mentoring relationship for each intern-mentor pair and triangulate the intern's characterization of the research project and interactions with the mentor.

Longitudinal observations. To develop fuller understanding of what interns and mentors actually did during the URE than can be obtained from interviews, I observed nine intern-mentor pairs throughout the summer. Pairs were selected on a voluntary basis to ensure my visits were as non-disruptive as possible. Interns and mentors in bold text in tables 1 and 2 were observed. Though they were not purposefully selected, the group of volunteers reflected some of the diversity found in both sets of participants: intern prior research experience, gender, and minority status; and mentor status, prior mentoring experience, gender, and nationality. I observed each of these nine intern-mentor pairs on three or four occasions for a two-hour period during the middle weeks of the program (Table 3).

Qualitative analysis. To provide a detailed description of what each intern's experience in the laboratory was like, I developed vignettes from analysis and triangulation of application materials, early and late interviews, mentor interviews, research proposals, symposium presentations and field observations. I used ATLAS.ti (2010) to code and sort the data, employing the Likert survey items as an initial coding framework (Miles & Huberman, 1984) for interns' practice of inquiry, and developed additional codes as various elements of the interns' practice emerged as important (for example laboratory techniques and tools, notebooks, and information resources). Memoing also helped to expand and refine the coding framework. I developed a short list of sorting codes to differentiate between independent and guided work: "Independent Work", "Teaching About" and "Teaching to do/use." I also created the sorting codes: "Intern asks a question" and "Mentor asks a question" to focus in on instances of teaching and learning through questioning.

Writing the vignettes was an act of in depth interpretation of the intern's work in the lab, the nature of the research project, and the intern's interactions with her mentor. I began by analyzing the intern's research proposal and symposium presentations, cross-referencing with these portions of the interviews, to produce a description of the intern's research project: research question, hypotheses (if appropriate), techniques, and anticipated outcomes. I then reviewed portions of the interviews addressing the research experience and mentoring relationship to describe how participants experienced these aspects of the program. I cross-referenced and pulled examples from field observations where available.

From the vignettes, I was able to develop a typology of research projects and a continuum of intern-mentor transactions. I was also able to generalize overall positive and negative outcomes from both the interns' and mentors' perspectives. The vignettes were also useful in discerning patterns between aspects of interns' learning investigated through pre-post assessments, and their experiences of mentored laboratory research.

Results

Pre and Post Assessment Findings

Pre-program inquiry experience. Interns were asked to rate the frequency with which they had independently practiced each of the survey items in their prior science education, including both laboratory course-work and prior research, if applicable. Fifteen of the interns had one or more semesters of prior research experience (ranging from one to seven semesters, see Table 4.1). Most of these experienced interns were rising juniors or seniors. The remaining group of nine interns, research novices, included as many rising sophomores as rising seniors. Pre-program survey results were tallied separately for the two groups to distinguish those skills commonly gained through laboratory course-work from those skills more commonly gained through undergraduate research (Table 4). The group of novices rated eight survey items at a median of 2 or above (i.e. practiced more than "once or twice"): summarize data, formulate an explanation for evidence, develop and defend an argument, troubleshoot, connect to scientific knowledge, relate results to the bigger picture and read primary literature. As these students had no prior research experience, these skills must have been gained through laboratory and other coursework. All of the remaining survey items were rated more highly by the group of Interns with prior research experience than by the group of research novices: pose a testable question, select/design methods, determine what data to collect, modify an hypothesis, formulate alternative explanations, and present results. The higher rating by the experienced group suggests these skills were more likely to be gained through either advanced coursework (these were mostly older students) or research experience.

Program inquiry experience. During their late interviews, interns were asked to rate the frequency with which they had independently practiced each of the survey items as participants in the Program. Interns rated a small set of inquiry/research skills at a median of 2 or above (i.e. practiced more than just “once or twice,” Table 5): formulate an explanation for evidence, read primary literature, troubleshoot, connect to scientific knowledge, and formulate alternative explanations. The first four items of this list were among those skills listed above as commonly gained through laboratory coursework.

Mentors were also asked during their interviews to rate the frequency with which they believed their own intern had independently practiced each of the survey items as participants in the Program. Mentors, though more conservative in their ratings than interns, were in general agreement with interns about those skills practiced more than just “once or twice” (Table 5). Two exceptions were formulating alternative explanations (mentors rated this slightly lower than interns) and summarizing data (mentors rated this slightly higher than interns). Summarizing data was also among the list of skills more commonly gained through coursework.

Participants were also asked during late interviews to rate the frequency of guided practice for each of the survey items. Guided practice was defined as being instructed by, or participating with, the mentor in the execution of a task. Interns rated more inquiry/research skills at a median of 2 or above than they did for their independent practice (Table 5). Additional skills practiced with guidance included: select/design methods, determine what data to collect, relate results to the “bigger picture” and develop an argument. The results from the mentors’ surveys also added pose a testable question to the list of skills interns practiced more than just “once or twice” and with guidance. These items were among those listed as more commonly gained through prior research than through coursework.

Table 4: Pre-program, Independent Practice of Inquiry and Research Skills. Median ratings for independent practice of inquiry and research skills in interns' prior science education. Interns rated the frequency with which they had independently practiced each item on a 5-point scale ranging from 0 (never) to 4 (very often).

	Novices (n=9)		**Experienced** (n=15)	
Pre-program Survey Item	**Median**	IQR	**Median**	IQR
Read/use primary literature (scientific journals)	**2.0**	2.5	**4.0**	1.0
Decide how to summarize collected evidence (in a graph, figure or table, or statistically).	**3.0**	2.5	**3.0**	2.0
Formulate an explanation for the evidence (data analysis or interpretation).	**3.0**	2.5	**3.0**	0.0
Form connections between your explanations and existing scientific knowledge.	**2.0**	3.0	**3.0**	1.0
Figure out what went wrong in an investigation and attempt to fix it (trouble-shoot).	**2.0**	2.0	**3.0**	2.0
Develop a reasonable and logical argument to communicate your explanation.	**2.0**	2.0	**3.0**	1.0
Defend your argument (respond to written or oral questions/criticism/critique).	**2.0**	1.5	**2.0**	1.0
Relate results to the "bigger picture" in your field.	**2.0**	2.0	**2.0**	1.0
Determine what evidence to collect (and then collect it).	**1.0**	1.0	**2.0**	2.0
Pose a testable question to pursue through scientific investigation (and then test it).	**1.0**	1.5	**2.0**	2.0
Select or design the methods for a scientific investigation.	**1.0**	1.5	**2.0**	2.0
Formulate alternative explanations based on data/evidence.	**1.0**	2.0	**2.0**	2.0
Modify a hypothesis based on new evidence or ambiguous data	**1.0**	2.0	**2.0**	1.0
Present results of a scientific investigation (orally/poster)	**1.0**	2.0	**2.0**	0.5

Engagement with inquiry. To develop a single score describing the intern's overall engagement with inquiry in the Program, surveys were summed, and scores for intern-mentor pairs were combined as described in the data analysis section above. Program scores variedwidely, ranging from 29.5 to 77 out of a possible 112 (mean = 49.1 ± 10.4, n = 20[5]). These program scores were used to investigate relationships between interns' overall engagement with inquiry, understandings about NOS and NOSI, and personal epistemologies. Autonomy scores measured the degree of the intern's involvement in designing or developing his or her research project. Autonomy scores were also calculated and combined for each intern-mentor pair as described above. These scores varied from zero to seven out of a possible 8 (mean = 3.25 ± 1.9, n = 20). Program inquiry and autonomy helped to describe the variability in interns' UREs (Figure 1). Most interns' projects fell within the bottom left quadrant of the plot, indicating more prescribed projects with limited opportunities to engage in all aspects of inquiry. Four projects were heavily prescribed, partial inquiries. Three projects were less prescribed. Only one of these UREs, that of Elliot, was more self-directed, and closer to full inquiry than any of the others.

[5] Four mentors declined to be interviewed and therefore did not complete a survey for their intern. Only interns with a mentor score were included in this portion of the analysis.

Table 5: Post-program Survey of Inquiry and Research Skills. Median ratings for interns' independent and guided practice of inquiry/research skills during a ten-week summer research internship. Each intern and mentor completed the same survey separately, rating the frequency with which the intern had practiced each item on a 5-point scale ranging from 0 (never) to 4 (very often).

	Independent Practice				**Guided Practice**			
	Interns(n=24)		**Mentors**(n=20)		**Interns** (n=24)		**Mentors**(n=20)	
Post-program Survey Item	**Median**	IQR	**Median**	IQR	**Median**	IQR	**Median**	IQR
Formulate an explanation for the evidence (data analysis or interpretation).	**3.00**	1.75	**2.00**	1.75	**3.00**	1.75	**3.00**	1.00
Read/use primary literature (scientific journals)	**3.00**	1.38	**2.00**	1.88	**2.00**	1.00	**2.00**	1.75
Figure out what went wrong in an investigation and attempt to fix it (trouble-shoot).	**2.50**	2.00	**2.00**	3.00	**3.00**	2.00	**3.00**	2.00
Form connections between your explanations and existing scientific knowledge.	**2.00**	2.00	**2.00**	3.00	**2.00**	2.00	**2.75**	1.00
Formulate alternative explanations based on data/evidence.	**2.00**	2.50	**1.50**	2.00	**2.00**	1.00	**2.00**	1.75
Decide how to summarize collected evidence (in a graph, figure or table, or statistically).	**1.50**	2.00	**2.00**	2.00	**1.00**	2.75	**2.00**	1.00
Select or design the methods for a scientific investigation.	**1.00**	2.00	**0.50**	2.00	**3.00**	1.00	**3.00**	0.88
Determine what evidence to collect (and then collect it).	**1.00**	3.00	**0.00**	2.00	**3.00**	1.75	**2.25**	1.00
Relate results to the "bigger picture" in your field.	**1.25**	1.00	**1.00**	2.38	**2.00**	1.75	**2.00**	2.00
Develop a reasonable and logical argument to communicate your explanation.	**1.00**	1.00	**1.00**	1.75	**2.00**	2.00	**2.00**	1.13
Pose a testable question to pursue through scientific investigation (and then test it).	**0.50**	2.00	**0.50**	1.00	**1.50**	2.00	**2.75**	2.00
Defend your argument (respond to written or oral questions/criticism/critique).	**1.00**	0.00	**1.00**	1.75	**1.00**	1.00	**1.50**	1.00
Present results of a scientific investigation (orally/poster)	**1.00**	0.75	**1.00**	0.00	**1.00**	0.75	**1.50**	1.00
Modify hypothesis based on new evidence/ambiguous data	**0.00**	2.00	**1.00**	1.00	**0.00**	2.00	**1.75**	1.75

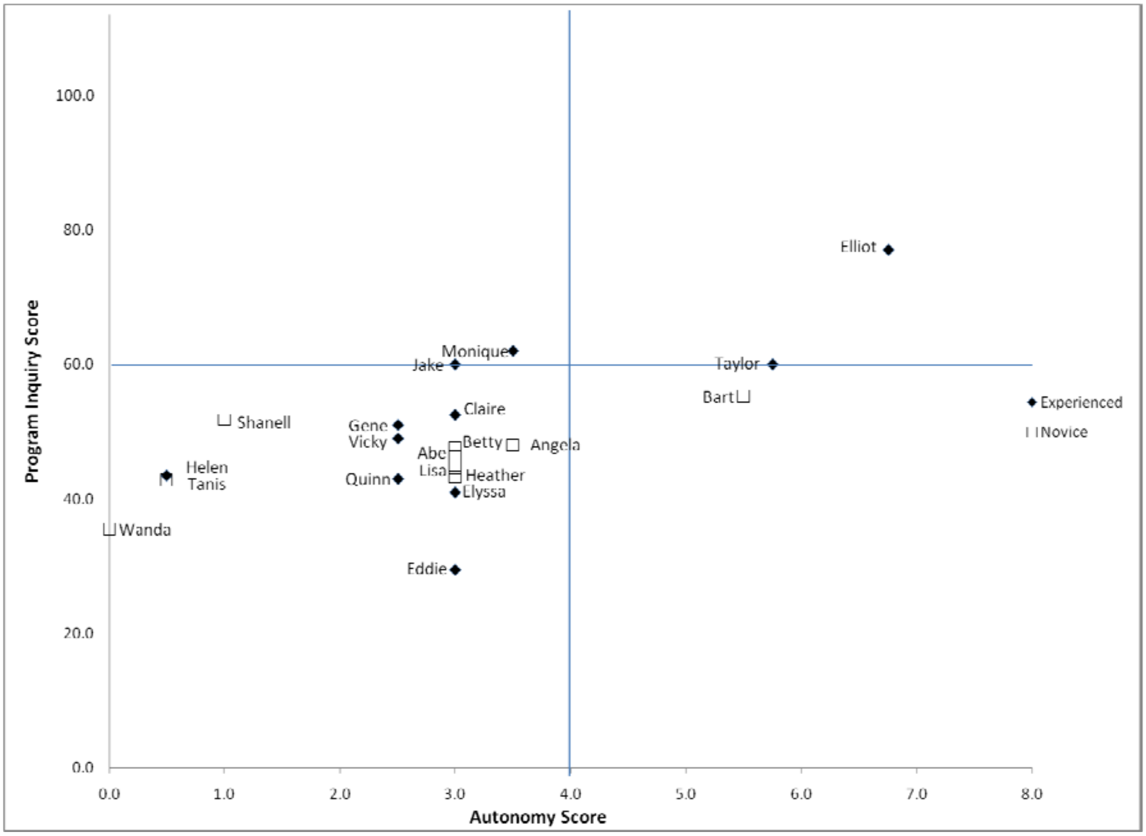

Figure 1: Inquiry vs. Autonomy. Scatter plot of interns' scores for program inquiry and autonomy. Experienced students had 1 or more semesters of prior research. Novice interns had no prior research experience (n=20).

Understandings about NOS and NOSI. Prior to the program, most interns held naïve or emerging conceptions of nearly all aspects of NOS investigated, especially empirical NOS, validity of observational science, and theory laden NOS (Table 6). For example, Ricky, a rising senior with seven semesters of prior research, struggled to articulate a distinction between science and other disciplines in his early interview:

> It's difficult to verbalize [what science is]. It's more of an area. Being nonbiased. For science it's very difficult not to get personally involved but if you can investigate a problem, examine all the facts – well, you can't examine all the facts… I think in a lot of ways, historians do use a scientific approach, social

science. They have to be nonbiased. When they are hunting for evidence and things from the past they have to use good research. They don't necessarily design an experiment though. I guess science would be taking an investigation and making it your own. I feel like you have to be investigating some, I guess you could say part of the natural world, but that's vague too, and social science would be an investigation of our man made world. I'm sure they use a lot of scientific approaches when they investigate literature. I don't know, I feel like the scientific method is something that people use in their day to day lives. (Ricky, Early Interview)

Table 6: Pre-post Change in Interns' Understandings about Aspects of NOS and NOSI. Percent of the intern cohort holding informed/robust views about aspects of NOS and NOSI at the beginning and end of the Program (n=24)

	% informed/robust	
Aspects of NOS	**Pre**	**Post**
creative	42	67
empirical	8	22
experiment	75	75
observational	25	29
socio-culturally embedded	54	63
tentative	33	38
theory	42	46
theory change	50	50
theory laden	29	33
Aspects of NOSI		
anomalies	33	46
community of practice	54	75
data vs. evidence	58	63
justification	42	50
multiple purposes	68	67
scientific	38	42
scientific methods	21	25

Ricky's view of empirical NOS was emerging, and did not change pre to post-program: science is non-biased investigation of the natural world (versus the man-made world). He seemed to understand that the purpose of investigation is to collect evidence in a systematic way in order to make a claim, and that these activities are not exclusive to natural science. However he clung to experimentation and the scientific method as the main approaches that scientists take to investigate phenomena.

Two areas where more interns held informed or robust views were interns' understanding of socio-culturally embedded NOS and, in particular, an experiment. Nearly all of the interns with prior research experience articulated an informed or robust view of an experiment.

Post-program, the majority of interns continued to hold naïve or emerging conceptions of most aspects of NOS. However, there was a shift toward more informed/robust understandings of creative NOS, and a slight shift toward more informed/robust understandings of socio-culturally embedded NOS. Bart, a senior with no prior research experience, had an emerging pre-program view that creativity was important in developing methods for an investigation, citing the invention of the Polymerase Chain Reaction as an example. An excerpt from his late interview illustrates how Bart's view of the role of creativity in science had been expanded by his internship experience:

MRP: Creativity in science - is it important? Is there room for it?

Bart: Yeah I think so. Because I've seen, and I'll show you tomorrow, the chart of all the QTLs[6] that are known for this grain species - and I mean there are infinite other ones. Any trait that you can measure you can find QTLs that are theoretically [in this genome]. Just the fact that people thought to

[6] Quantitative trait loci (QTLs) – areas of the genome that determine quantitative variation in phenotype. In this case, the desired phenotype is improved grain yield.

measure these different traits and then look for the regions in the genome that would contribute to that, like making those connections to [crop] yield.

MRP: Do you see room for creativity in other aspects of science than that one you just described, like do you see room for creativity in the data collecting or data analysis phases?

Bart: Yeah, I mean if people can think of different ways to show data, compare data, and present it as evidence, then yeah. I mean if you put it in a new kind of graph together somehow, it will make things more clear, and the way you choose [to organize it]. (Bart, Late Interview)

The most common view of the socio-culturally embedded NOS both pre- and post-program was that religious and social movements (via political processes) can influence the kinds of research that get funded, and therefore the direction that young scientists might consider pursuing for their graduate career. For example, Alyssa, a rising senior with four semesters of prior research, changed from an emerging view that a person's religious convictions and ethical sensibilities caused them to shun certain areas of science (for example stem cell research), to an informed view by learning more about the rationales behind the work of her lab mates, for example developing genetically modified crops for developing countries or as new sources of biofuel.

Figure 2 demonstrates a wide range in interns' NOS scores and a narrow range for change in NOS scores. Participation in the Program yielded small pre-post change in most interns' understandings of one or two aspects of NOS. Only two interns, Elyssa and Hans, improved their understandings of three aspects of NOS pre to post.

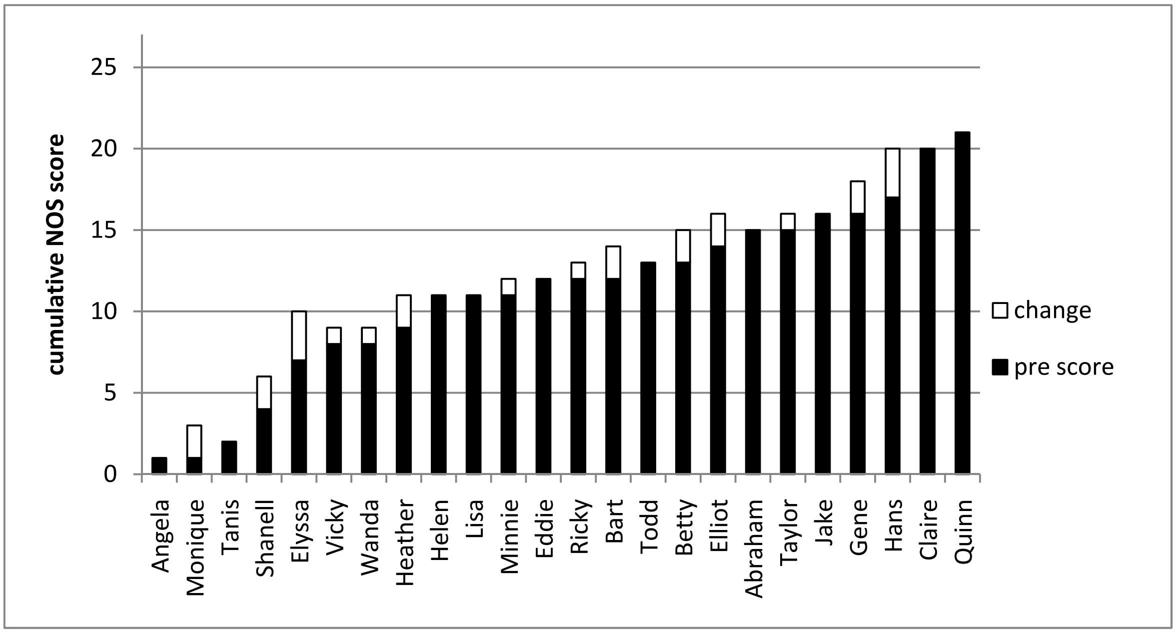

Figure 2: Interns' Pre- and Post-program NOS Scores. Mean pre-program NOS score = 11.2 ± 5.5; mean post-program NOS score = 12.3 ± 5.4 (maximum possible score = 27).

As with NOS, most interns' conceptions of many aspects of NOSI were naïve or emerging prior to the Program (Table 6). However, a slight majority of interns held more informed or robust pre-program conceptions for three aspects: the community of practice, the distinction between data and evidence, and scientific methods. Most interns with prior research experience understood the contribution of the scientific community in setting standards and

criteria for investigations and in communicating information, particularly in the form of primary literature. Likewise, most interns with prior research experience understood that data were amassed and/or interpreted to produce evidence for or against a claim. However, research novices tended to demonstrate confusion between the every-day use of the word evidence and its use in scientific practice. For example:

> I think evidence is factual information that is – it can be tested as many times as possible and is still going to be the same. I consider fossils to be evidence. Even though they died a long time ago they are still going to show what the animal was

> like. I see data as more as written information.
>
> …
>
> As for evidence I see more actual, like touchable, not information but um – I don't know how to explain it. Data is just like collected information. Data is just something that's written somewhere. (Angela, Early Interview)

Though Angela distinguished between the two concepts, she had a limited view of each. Evidence was something physical, and left behind – several interns used a crime-scene analogy to explain their thinking here. Angela viewed data as collected and written bits of information. She did not invoke the ideas of analysis or supporting/refuting a claim in her naïve explanation of these terms or elsewhere in her interview.

Post-program, most interns continued to hold naïve or emerging views of most aspects of NOSI (Table 6). However, there was at least a slight pre-post shift toward informed or robust views for all of the NOSI aspects. The greatest shifts occurred for: the role of anomalies, the community of practice, and multiple purposes of investigation. For example, Taylor, a rising 5th year senior with four semesters of prior research, held the emerging view that it was important to report when findings did not match expectations in her early interview. In her late interview she demonstrated an informed view of the role of anomalies in science when describing the importance of creativity in science:

> But yeah, because you need [to be creative] to look at data and see something you didn't expect and interpret it in a different way. If you see something that doesn't fit into your categories, you have to be able to look at it and see what is there – like maybe it's wrong, but maybe you're seeing something you never expected. That's the thing about molecular biology there are so many things you never

imagined. Like, we didn't figure there'd be an intron stuck in the middle of [our allele]. (Taylor, Late Interview)

Taylor's experience investigating an anomaly and discovering that it did not arise from an error on her part, but was in fact something important, lead her thinking and her research in a new direction from what had been originally planned. The experience also helped to elaborate her views on creative NOS. Other interns who demonstrated improved understanding of the role of anomalies also linked their new understanding to some element of their own research. Hans' experience was noteworthy because it also helped to reshape his views of tentative NOS and theory change. Hans was a rising senior.

Hans: (*thinks*) Um. (*thinks*) I guess…I don't know the difference between theories and

MRP: That's ok. But I'm sure you do because of what you said

Hans: No. I don't. And that's the point! (*laughs*) Sorry. So there were some difficulties for me and I thought that this was accepted and an undebatable point: that SAS[7] was reduced in modern breeding. But what I found was that it wasn't. In a way I disproved the theory with my limited data and so I was in this no-man's land feeling like, "I thought this was already established. Somebody, no we just disproved it in a way. What does this mean? Is there a god?"

MRP: (*laughs*) And how does he feel about shade? I think that's a fantastic learning experience.

Hans: And I thought, "Oh, what I thought was the case wasn't the case and

[7] Shade avoidance syndrome (SAS) is a suite of morphological changes that occur in some plants in response to limited light conditions.

> everybody had based an idea off of that assumption. Crap! Do we need to redo something that we already thought we had solidified?" So that was sort of a productive exercise. And I guess in the beginning I wish I had formalized by talking to [my mentor] and talking to [my PI], whether or not, like what exactly <u>is</u> really known and what ideas have they been pushing out there. (Hans, Late Interview)

Later, when discussing the certainty of knowledge found in text books, Hans explained how his experience helped him to shift from *learning* that scientific knowledge is tentative to *knowing* that scientific knowledge is tentative:

> One has these theoretical classes on science and you have discussions about what is science, what is theory a lot of times. But I've never had something first hand come at me where I thought something was established, where I'd wish that it had been clearer to me what we really do know and what we don't know. It makes you feel insecure, like Oh man, these facts weren't true, that I based assumptions on, so, where are we going here? … You know I was only mildly attached to this thing because I was only working on it for ten weeks. Even so, it was sort of (*laughs*), sort of a shock. Like, it shook me to the core that something wasn't as sure as I thought it would be. So that was neato. (Hans, Late Interview)

Figure 3 demonstrates a wide range or NOSI scores and a wide range for pre-post change in NOSI scores. Participation in the program influenced some interns' understandings of aspects of NOSI to a greater degree than NOS (Figures 2 and 3). Ten interns improved their understandings of one or two aspects of NOSI, and four interns improved their understandings of 3 or 4 aspects. The patterns in Figure 3 suggest that interns with a more limited understanding of aspects of NOSI at the beginning of the program were more likely to make pre-post gains in this area. However, no such pattern emerges for pre-post gains in understanding aspects of NOS.

Correlative relationships. Prior research and pre-program independent inquiry scores estimated interns' engagement with aspects of inquiry before participating in the program. Program inquiry scores estimated interns' engagement with aspects of inquiry through participation in the Program. Prior and program inquiry scores were used to investigate correlative relationships between interns' experiences with inquiry and their understandings about aspects of NOS and NOSI. I sought to discern whether deeper engagement with inquiry resulted in gains in understandings about aspects of NOS and NOSI.

Interns' prior research experience ranged from 0 to 7 semesters (see Table 1). Pre-program independent inquiry scores ranged from 1 to 45 out of a possible score of 56 (mean = 29.9 ± 10.6, n=24). Amount of prior research showed a very weak but non-significant, positive relationship with pre-program independent inquiry, and no relationship with program inquiry (Table 7).

To test if inquiry experience influenced interns' post-program understanding of NOS and NOSI, I compared program inquiry scores with post-program NOS and NOSI scores, and pre-post change in NOS and NOSI scores (Table 8). Program inquiry did not correlate with post NOS or change in NOS scores. Program inquiry showed no relationship with interns' post NOS or NOSI scores or pre-post change in NOS. However, program inquiry showed a strong, significant, positive relationship with pre-post change in NOSI. Program inquiry scores explained 42.4% of the variability in pre-post change in NOSI (Figure 4).

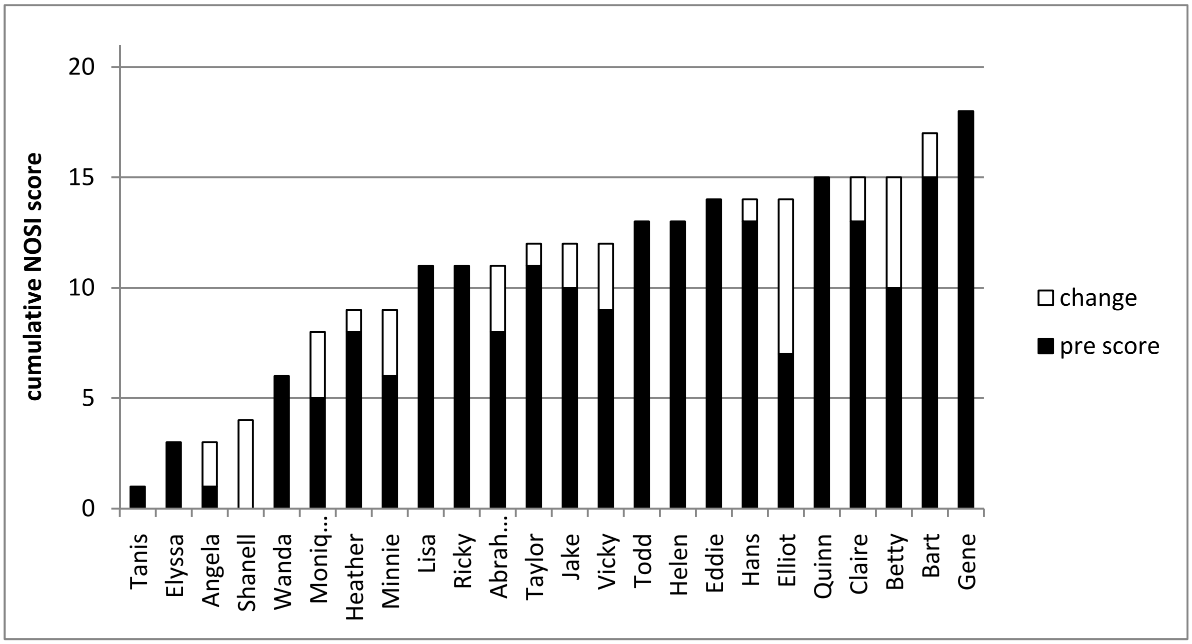

Figure 3: Interns' Pre- and Post-program NOSI Scores. The mean pre-program NOSI score was 9.2 ± 4.8; mean post-program NOSI score was 10.8 ± 4.6 (maximum possible score = 21).

Table 7: Correlation for Prior Research, Prior Independent Inquiry and Program Inquiry Scores.

Dependent variable	Independent variable	r^2	df	P
Pre-program independent inquiry	Semesters prior research	0.13	23	0.083
Program inquiry	Pre-program independent inquiry	0.10	19	0.174

Table 8: Correlation Between Program Inquiry and Post-program NOS and NOSI (n=20). Results from multiple linear regressions analysis. Independent variables in bold text indicate a significant relationship with the dependent variable.

Dependent variable	Independent variable	*F*	P
Program inquiry	Post NOS score	0.58	0.455
	Change in NOS score	1.42	0.249
Program inquiry	Post NOSI score	1.03	0.324
	Change in NOSI score	**13.26**	**0.002**

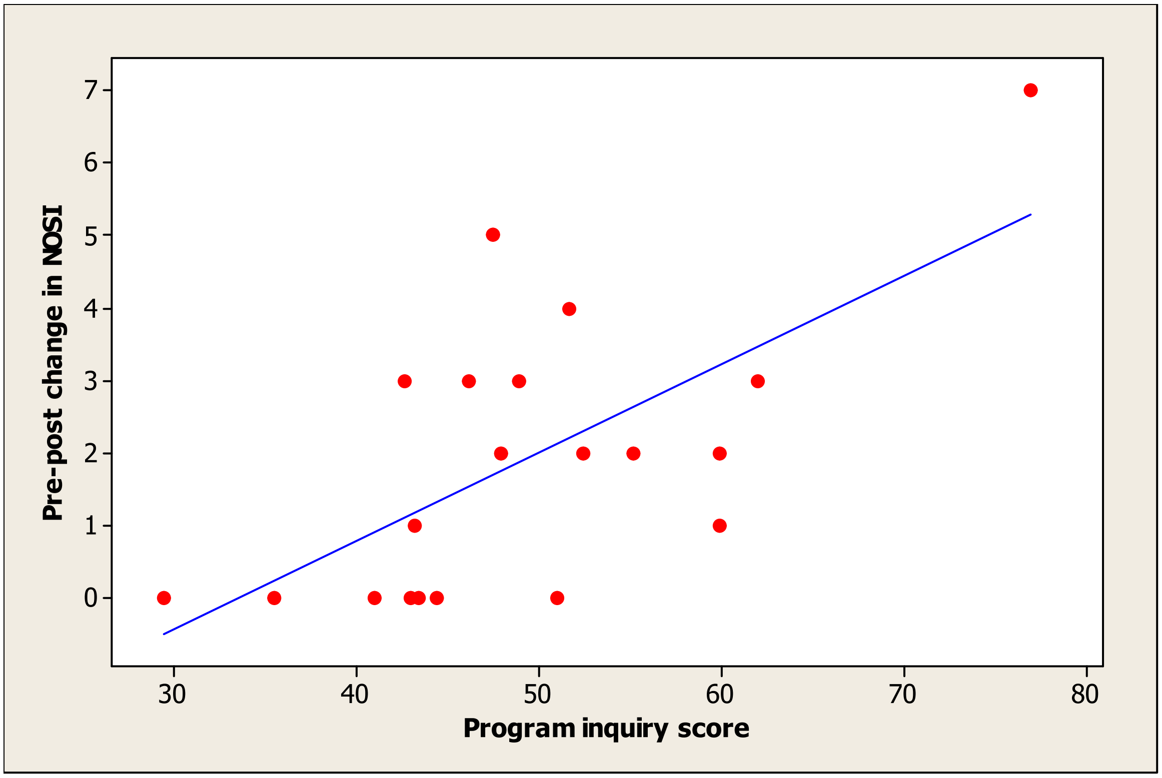

Figure 4: Correlation between Program Inquiry and Change in NOSI Scores (r^2 = 0.424; n=20)

Exploratory Investigation Findings

Research projects. Interns' research projects fell into two broad categories, with some overlap: non-investigations and investigations. To qualify as an investigation, an intern's project had to be framed by a research question and had to attempt to describe or explain a phenomenon. Non-investigations were projects that were not guided by an explicit scientific question or hypothesis; the projects instead focused on developing tools or data to be used in further research. It was also possible to subdivide the larger categories (Table 9).

Non-investigations. Projects that did not an attempt to describe or explain a phenomenon were deemed non-investigations. Non-investigations were of two kinds: genetic screens (four) and tool development projects (two; Table 9). Neither of these types of projects engaged the intern in a research question that went beyond the immediate data set or tool under

Table 9: Research Project Categories and Subcategories.

Project Type		Number
Non-investigation	Genetic screen	4
	Tool development	2
Investigation	Observational	
	• Simple	3
	• Multifaceted	9
	• Hypothesis testing	6

development. The main task did not deviate for the duration of the internship and the intern never experienced the next step in the research: explanation of the phenomenon that generated the data set or application of the tool to test an idea.

Four interns' projects were genetic screening projects, which involved examining large numbers of offspring to determine if these offspring were of the desired genotype or phenotype. Screening is a necessary component of a lot of molecular work and many of the interns did some screening as a component of their larger research plan. However, for four interns, the entire project consisted of screening. For example, Bart's entire project was to extract DNA from plants, use PCR[8] to amplify the gene for a specific trait, and run that material out on a gel through electrophoresis[9] to identify those plants that carried the desired genotype. Data analysis for Bart was to simply identify which plants were heterozygous (showing three bands on the gel) rather than homozygous (showing two bands on the gel). Once the heterozygous plants were identified, the next step would be to collect their seeds to be shipped out for field trials. These next steps were carried out by lab members sometime after the summer internship.

Because non-investigation projects were not framed by a research question or hypothesis, there was no need to do such things as revise one's hypothesis, develop an alternative

[8] Polymerase Chain Reaction (PCR) is a technique that targets a particular sequence of DNA and then copies it over and over. Copy number grows exponentially as the reaction progresses. This is the meaning of "amplify the gene."

[9] Gel electrophoresis is a technique that sorts molecules, like DNA fragments or proteins, according to their size.

explanation of results, or discuss how one frames a question for research. In the kinds of screening done in these projects, the task was merely to sort. There may have been a little trouble-shooting, but only in a mechanical sense requiring little more than trial and error. Data were straight-forward (for example, three bands or two) and required very little manipulation in order to interpret. One needed almost no subject matter knowledge to follow what was going on and do one's daily work. Thus, demands on the mentor's time were low. Once the intern was trained in how to do the screen, there was little further need for a mentor. In this sense, mentoring was more like training and the intern was little more than a lab assistant (see "Mentor-centric Transactions" below).

The two other non-investigation projects involved developing molecular tools for the laboratory's on-going work. For example, the purpose of Wanda's project was to insert DNA of interest into a plasmid[10] in the correct orientation. The plasmid was to be used by a collaborating lab to transform a plant so that it would conduct an alternative form of photosynthesis. Wanda's portion of the project was to create the plasmid that would later be used by the collaborator. It took nearly ten weeks to accomplish this task. Wanda herself described her project as "more of a demonstration than an experiment" during her late interview.

Though tool development projects were not framed by a research question or hypothesis, these projects offered opportunities for practicing aspects of inquiry. For example, trouble-shooting is the major activity of the project. Data should be analyzed in order to evaluate how well the tool was working, and perhaps to suggest what might be modified next in further optimizing the tool. Therefore, scientific reasoning should come into play with subject matter knowledge assisting in this reasoning process. This was not the situation with Wanda because

[10] A plasmid is a small, circular molecule of DNA, typically from a bacterial origin, that can serve as a vector for transferring foreign genetic material into an organism.

her mentor did not or could not make himself available to mentor her.

Investigations. Research projects were considered investigations when they attempted to answer a scientific question, through observational approaches or hypothesis testing.

Observational investigations. The observational investigation was the largest category of research projects in the 2009 cohort (Table 9). These investigations sought to describe a phenomenon, most often a mutant phenotype, through carefully collected observations, rather than through the manipulation of variables. Research questions in this category were of the "what is?" type: What is the scope of naturally occurring variation in this gene? What is the effect of this mutation on the expression of other genes? What is the sequence of this gene? Observational investigations were exploratory, in which the researcher did not know what to expect, or they were based on a set of assumptions, for example, the *kiwi* mutation in tomatoes affects a specific pigment pathway. However, the aim of the research was not to test those assumptions. In the *kiwi* example, the aim of the research was to collect information about which genes in the pigment pathway may be affected by the mutation through comparison with the wild type, not to test the assumption (or hypothesis) that *kiwi* was a flavinoid mutant.

Three of the observational investigations were of simple design, meaning that they focused on a single aspect of the mutant phenotype and the intern's work involved repeating the same procedure over and over. Such work quickly became boring and even frustrating, particularly for interns eager to engage in challenging research. The simple design of the project meant that there were no intermediate steps requiring verification of findings, there was very little trouble-shooting, and data analysis occurred only once, at the end of the program. The vignette featuring Tanis provides a good example of this situation.

The most common form of observational investigation in the Program (nine; Table 9) were characterization projects aimed at describing the variety of phenotypic effects resulting from a mutation in a gene or from the insertion of foreign DNA into a genome. These projects were multifaceted, investigating multiple aspect, and involved greenhouse or field work as well as laboratory work. Such projects involved several smaller investigations, all aimed at addressing the same larger research question, but from different angles. The prevalence of multifaceted characterization projects demonstrates both that this was a very common form of investigation in the graduate and postdoctoral research of the institute, and that such projects represented a good solution to the problem of providing a research experience in a ten-week program. Any number of small investigations could be added or subtracted from the plan as time permitted. Also, as one mentor explained, a characterization project can provide the best of both worlds. Physiology experiments yield visual results – one can actually see the differences in fruit color, plant size, etc. Such things can be measured, converted into a mean, and perhaps even require some statistics. The molecular work teaches the interns new and marketable techniques, how to work with a different form of data (bands on a gel), and gives them a taste of the uncertainty involved in molecular work.

Observational investigations aimed to describe a phenomenon such as the function of a particular gene, metabolic pathway or other cellular process. Taylor's experience (see "Balanced Transactions" below) demonstrated that such a research project can be a rich and gratifying learning experience in scientific inquiry and practice. Though such investigations were framed by a research question ("What is?"), the overall aim was not to test an hypothesis. This in part explains why few interns engaged in developing or modifying an hypothesis – the overall research project was simply not hypothesis driven. However, most observational projects were based on some set of assumptions, and when those assumptions were shown to be questionable, the researcher had to alter his or her thinking and sometimes his or her approach.

Hypothesis testing. Six investigations involved hypothesis testing in some aspect. These projects varied widely from one another. One might expect the hypothesis-testing projects to have a greater potential to teach interns about rejecting ideas and revising one's thinking, and this was the case for at least two of these projects. However, the majority of hypothesis-testing projects were carefully planned by the mentor well before the intern's arrival, in the hope of generating high quality, publishable data. These projects often involved a sophisticated design and advanced techniques, and much of the intern-mentor interactions centered on mastery of the techniques and underlying subject matter. Once the techniques were mastered, the project proceeded in a straightforward manner yielding few surprises. Interpretation and explanation of data was the purview of the mentor as the interns worked to understand the underlying biology.

There was a single case where the intern, Elliot, developed his own hypothesis and designed his own experimental procedure to test it. This was possible because the hypothesis-testing aspect of Elliot's project involved organismal-level (rather than molecular-level) phenomena, meaning that mastery of sophisticated subject matter and advanced molecular techniques were not required.

Mentoring style. Mentoring an undergraduate researcher can be viewed as a transaction. Mentors invest some amount of time in training their intern, especially in the early weeks of the program. In return for this investment, the intern produces or processes data, optimizes a tool, or helps the mentor test/reject ideas. These transactions can be weighted more heavily toward the mentor's needs, well balanced between the needs of both parties, or weighted more heavily toward the intern's needs. Table 10 organizes the 24 research projects in the 2009 cohort according to this continuum of intern-mentor transactions. Plus and minus signs under

"Outcomes" indicate the overall view of the intern (represented first) and mentor during the post-program interview. Interns who expressed negative outcomes (disinterest in further research, negative feelings toward the mentor and/or program, lack of pride or faith in the results of their project, lack of basic understanding of the project's aims and outcomes) were assigned a minus (-) sign. Mentors who expressed negative outcomes (no usable product or data) were also assigned a minus sign. Table 10 also illustrates that there were novice interns and first-time program-mentors in each of the three categories.

Mentor-centric transactions. Mentor-centric transactions occurred when the mentor's need for the data was the focus of the internship, rather than the intern's learning. Three of the non-investigations and all three of the simple-observational investigations fell within this category. Each of these six projects had negative outcomes for the intern; three also resulted in negative outcomes for the mentor. These three projects involved interns with no prior research experience. Six of the eight mentors were new to the program. Most (5/8) of the mentors involved in these projects viewed the intern as an assistant who could complete a simple task for the mentor, rather than as an apprentice with interests in learning how to do science independently one day. Dick, a new post-doctoral researcher who was assigned to the role of mentor by his PI, expressed an extremely mentor-centric view of undergraduate research that clearly missed the mark of "independent, mentored research:"

MRP: Tell me what an ideal ten-week summer project would look like.

Dick: I think the ideal would probably be if I had some massive pile of tedious work to do. You know, like tons of DNA extractions. And I would take time to teach her more than that so she would get more out of it, but that would really benefit me because that would be something that I would

> personally have to do, that someone with less training could do just as well. (Dick, Interview)

Two intern-mentor transactions within this category were quite different from the others, and resulted in positive outcomes for both parties (Table 10). The two mentors, Franck (a postdoctoral researcher) and Qiao (a PI), had been involved in the program for several years, and both made a point of selecting an intern with a strong research background in order to insure that their own time investment would be suitably rewarded. Both of these mentors assigned demanding projects for their intern, and both interns met the challenge. Though the *transaction* was mentor-centric, the *outcome* was balanced for these two cases. The two interns each felt pride in their work and its outcomes, and were also likely to be listed as an author on the eventual publications. For example, Helen was an example of an intern with a strong research background situated within a mentor-centric research experience. Though she did not expand her practice of advanced inquiry skills or her understanding of NOS or NOSI, she finished the program with positive feelings about her mentor, the program, her project and its results.

Balanced transactions. Balanced transactions were the most common form of intern-mentor transaction in the Program. In balanced transactions, the needs of both intern and mentor were adequately met and the outcomes were positive for both parties (with only one exception where the final product required more time to achieve than ten weeks). Most (7/12) balanced transactions were multi-faceted observational investigations, most (8/12) involved interns with prior research experiences, and half (6/6) involved returning mentors in the program. Balanced transactions occurred in two ways: the intern's learning and engagement with research were important considerations for the mentor, and/or the intern's learning and engagement with research were easily achieved.

Many of the interns within this category had prior research experiences that helped them acclimate to the molecular laboratory setting and its common procedures, such as pipetting, conducting PCR, and gel electrophoresis. Mentors in balanced transactions found these qualities to be helpful but not mandatory, feeling that such things were easily taught. Harry, an experienced mentor (Jake was his fourth intern from a limited research background) had a simple formula for describing an "ideal" intern:

> Harry: So, there are three main things: hard worker, capable, and interested in what you're doing. If they're missing one, the other two can make up for it. Two out of three is best.
>
> MRP: Of those three, is one more critical than the others?
>
> Harry: The only one that's not completely important is being interested, though it definitely makes things better. The other two are equally important. You can really get ahead with a good intern. But you can still break even with a bad one. (Harry, Interview)

For Harry, and many of the other mentors in the balanced category, the intern-mentor transaction was viewed as a relationship of give and take, though it was incumbent upon the mentor to recognize and work through (or around) the intern's deficiencies. Such a relationship of give and take, though it was incumbent upon the mentor to recognize and work through (or around) the intern's deficiencies. Such a relationship was made far easier when the intern was, as Harry described above, some combination of hard working, intellectually capable, and interested in the work.

The case of the Taylor is an example of a well-prepared intern situated in a balanced transaction. As far as Faith, her mentor, was concerned, Taylor had no deficiencies of any consequence. Faith, had specific goals for her own summer work, and purposefully selected an experienced intern to help her. At the same time, Faith was concerned with providing Taylor new learning experiences and pushing her to think more independently. Thus, Faith's view of the role of the intern was that of an apprentice learning to become a scientist. Mentors that shared this view with Faith expressed a desire to provide new learning experiences for their intern that afforded the intern some room to test their abilities and make mistakes.

Intern-centric transactions. Intern centric transactions occurred when the intern's learning became the focus of the internship, rather than the mentor's need for usable data. Only four intern-mentor pairs fell into this category. Three involved students from minority groups underrepresented in science. These three students were also from small institutions with limited research opportunities for undergraduates, and two were research novices. All four intern-centric transactions resulted in positive outcomes for the intern, though two resulted in negative outcomes for the mentor.

Intern-centric transactions developed in two ways. For three cases, the intern's background knowledge and laboratory experience were so limited that the mentor's original assumptions about what was do-able in ten weeks had to change in order to support the intern towards a positive outcome. As with mentors in the balanced-transactions described above, these mentors viewed the intern as an apprentice, but they also recognized the intern as an individual with unique and sometimes pressing needs. Nancy's attitude toward mentoring is a good example of this small group:

Table 10: Intern-Mentor Transactions. Research projects and types of outcomes are described in the text. Interns with no prior experience and new mentors in the Program are in bold. (NI=non-investigation, SOI=simple-observational investigation, MOI=multifaceted-observational investigation, HT=hypothesis test)

Mentor-centric			**Balanced**			**Intern-centric**		
Intern/mentor pair	Project Type	Out-comes[*]	Intern/Mentor Pair	Project Type	Out-comes	Intern/Mentor Pair	Project Type	Outcomes
Wanda/**Jinsong**	NI	-/-	**Bart**/**Tim**	NI	+/+	**Shanell** (URM)/Nancy	NI	+/-
Vicky/**Ajay**	NI	-/+	Todd/**Guy**	NI	+/-	**Angela** (URM)/Young	MOI	+/+
Heather/**Priya**	NI	-/-	**Lisa**/**Midori**	MOI	+/+	Elliot/**Mandy**	MOI-HT	+/+
Eddie/**Marisol**	SOI	-/+	Quinn/**Bernard**	MOI	+/+	Monique(URM)/ Christiaan	HT	+/-
Tanis(URM)[†]/**Arthur**	SOI	-/-	Taylor/Faith	MOI	+/+			
Claire/**Dick**	SOI	-/+	Hans/**Pierre**	MOI	+/+			
Ricky/Qiao	MOI	+/+	Elyssa(URM)/Selena	MOI	+/+			
Helen/Franck	HT	+/+	Gene/Xiang	MOI	+/+			
			Minnie/Grant	MOI	+/+			
			Betty/**Gabriella**	HT	+/+			
			Abraham/**Lijuan**	HT	+/+			
			Jake/Harry	HT	+/+			

[*](-) for the intern indicates that negative outcomes outweighed the positive outcomes: limited understanding of the research project's aims or outcomes, negative feelings toward the program and/or mentor, disinclination to pursue further research experiences. (-) for the mentor indicates the research project did not produce usable results.

[†]URM – Intern belongs to a minority group underrepresented in US science

MRP: I think that if Shanell had another mentor, that mentor would have spent a lot of time being frustrated. That's not to say you weren't -

Nancy: Yeah, but how many other mentors are in their forties and have children at home? And realize that their children will be in an internship one day? And how many of them have thought about developmental steps in a college student? Ok, first thing, "The book is right." Second thing, "I'm right." Third thing, "Well I don't know." Fourth thing, "Let's go find out." Would any of them look at her and say, "Oh my god, she's still at number 1!?"

MRP: One of the PIs was a mentor. So she's probably in her forties, and she does have two kids at home…

Nancy: Yeah, but are they average kids or exceptional kids? This is one of the reasons I thought we should probably take Shanell.

In these transactions, the give and take relationship was weighted more heavily toward the intern, because the intern's needs were considerable, but also because the mentor had (or made) the time and flexibility to devote to the intern's learning and engagement. The vignette featuring Angela below is a good example.

In the fourth case, that of Elliot, the intern's knowledge and experience were not limiting factors. Rather, this transaction was intern-centric because the mentor's primary concern was the intern's learning and engagement with research.

Interactions. Figure 5 sorts program inquiry scores, and Figure 6 sorts NOS and NOSI scores, according to project type and intern-mentor transactions. Figure 5 demonstrates that interns with the greatest program inquiry scores were situated in balanced or intern-centric transactions. Among these, hypothesis testing research projects frequently resulted in the highest program inquiry scores. Even non-investigations resulted in relatively high program inquiry scores when the transactions were balanced or intern-centric, compared to similar research projects that were mentor-centric. Figure 6 demonstrates most of the interns who made gains in understandings about NOSI were involved in hypothesis testing or non-investigations (tool development), and most were situated in balanced or intern-centric transactions. A pattern for gains in NOS is more difficult to discern. Students in all three transaction types, and most project types (though not simple-observational investigations), made some gains in understandings about NOS.

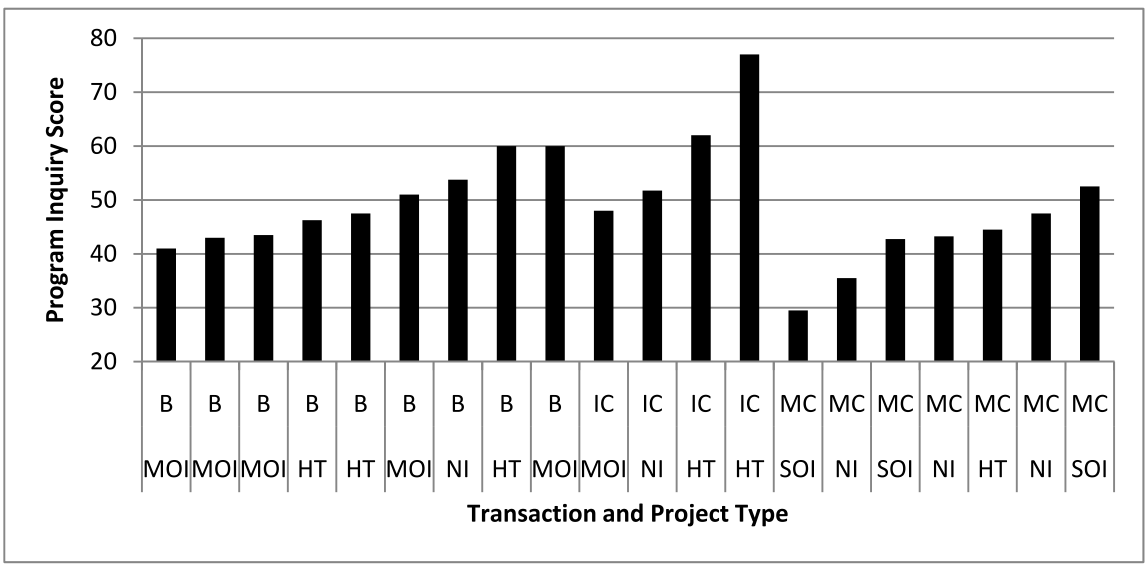

Figure 5: Program Inquiry Scores among Intern-mentor Transactions and Project Types (n=20). Intern-mentor transactions: B=balanced, IC=intern-centric, MC=mentor-centric. Project type: NI=non-investigation, SOI=simple-observational investigation, MOI = multifaceted-observational investigation, HT=hypothesis test.

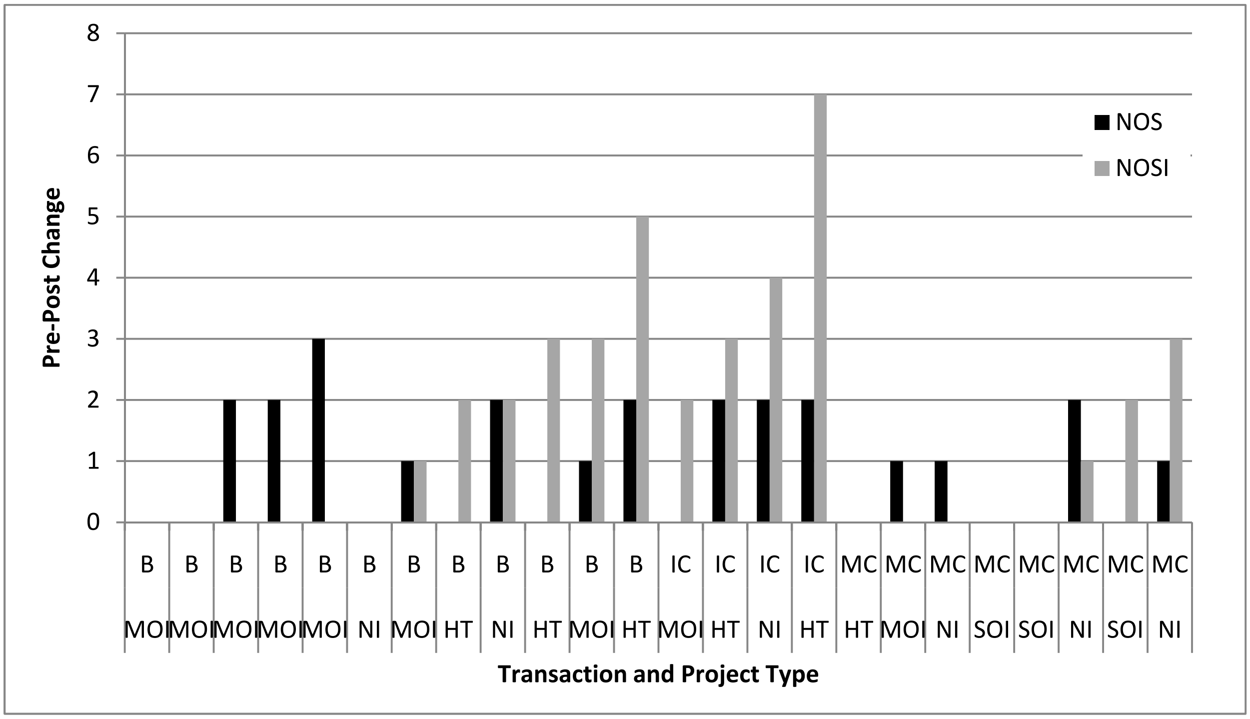

Figure 6: Pre-post Change in Interns' NOS and NOSI Scores (n=24) among Intern-mentor Transactions and Project Types. Intern-mentor transactions: B=balanced, IC=intern-centric, MC=mentor-centric. Project type: NI=non-investigation, SOI=simple-observational investigation, MOI=multifaceted-observational investigation, HT=hypothesis test.

Selected vignettes. Two illustrative vignettes are provided in this section. These vignettes were chosen to contrast the very different experiences of two students from similar backgrounds: Tanis and Angela. These two young women were from minority groups underrepresented in science, attended very small, two-year institutions, and had just completed their first-year of higher education (Table 1).

Tanis and Arthur. Arthur, the mentor in this transaction, was in his final year of graduate study when assigned to the task of mentoring by his PI. In his interview Arthur claimed to take a "cynical" perspective on mentoring, selecting a "low risk" project that did not take him far from his own research, but that also was not critical to the completion of his thesis. The research project was a simple-observational investigation of the assortment of compounds produced by the plant's cuticle and employed gas chromatography to analyze the extracts. The intern's (Tanis's) role was to follow a protocol to produce the plant extracts, load these into the machine, and then push a button. The machine identified and measured the compounds and dumped the data into an associated computer. Arthur had additional plans for the project, but he found Tanis's very limited background knowledge to be an insurmountable challenge.

Though new to the program, Arthur had mentored an undergraduate during the academic year, and he had been a research intern himself as an undergraduate. These experiences led him to have certain expectations for his intern:

> I don't know how else to answer this except to say – my experience, when I first worked in the lab as an undergrad, it was very overwhelming and it was – I had completed my third year in college. So I had much more course background and I was still overwhelmed. And I think that to really get something out of the experience, I think ideally an undergrad in this sort of program ought to be a little older, or further along in school – more course background. Which was a little bit frustrating for me.
>
> …
>
> I think some sort of lab course experience, biology or chemistry, um just in terms of being comfortable with their hands and um sort of basic concepts of, of like, "What is a milliliter? How do you make a solution? What is molarity? How do you make a dilution of a solution? What are units and how do you convert between different units?" Which I always thought people learned to some degree in high school but I guess that's not, that's not necessarily the case. (Arthur,

Interview)

Tanis, a Native American student, was a rising sophomore in community college with but a single semester each of introductory biology and chemistry already completed. She did not meet Arthur's expectations, and he spent many hours explaining and diagramming the basics of organic chemistry, plant development and plant anatomy with her. Tanis took notes and read introductory textbooks, but felt overwhelmed by the complexity and amount of new information. Arthur became frustrated when he felt that his attempts to teach Tanis about what she was doing were unsuccessful:

> She was like, very good at following the protocol in the lab. But it was very frustrating that she was following it like a recipe, not understanding the meaning behind steps. I really tried to stress that. In fact I've always felt like that was an important part of teaching somebody to do something, to help them understand why they're doing X. Why they're doing Y. So that when things start to go wrong, they can trace it back and understand why it didn't work. And I tried that a lot, but I don't think she, based on like the trouble-shooting stuff we did when things did go wrong, I don't think she grasped the importance of the, "Why?" when things were going wrong. But she was very good at, once you showed her how to do something, she was good at attention to detail. So that was something she did good, I guess. (Arthur, Interview)

Arthur did not feel that he had time to continue to work intensely with Tanis, nor did he feel that he had the expertise to develop a project that was better suited to her background. Tanis developed the habit of sleeping late and left lab early because there was little work for her to do. Tanis learned how to do a specific protocol, eventually with complete independence, and she learned some subject matter relevant to her project (the plant cuticle, organic molecules such as waxes and alcohols, fruit development and plant growth). However, at the end of the program, she did not understand what she had done, why she had done it, or what her data meant. For example:

MRP: And what was the overall reason for investigating cutin and the cuticle?

Tanis: Uh, cutin? I don't know.

MRP: Why does Arthur care?

Tanis: Oh. Probably because he wants to find out a gene, to help out, um like um, [*haltingly*] like how a gene could like be used for um like agriculture for like making like drought tolerance?

MRP: Do you have a sense for what he will use the data for in the future?

Tanis: No. He hasn't been here this past week. He won't be here for my presentation. A lot of people from my lab are gone for conferences this week.

MRP: Do you know what the next step will be for, once you have this information, what the next step will be in the research plan?

Tanis: No. No I Don't. (Tanis, Late Interview)

This simple-observational investigation fell within the mentor-centric category of transactions because Arthur was unable to make the shift from the intern he had been expecting, to the intern he had been assigned. Tanis's had no prior research experience and very little background knowledge. She employed and absolutist way of knowing that focused on receiving information, rather than understanding, application, or independent thinking. She was paired with a mentor unprepared to cope with a student who could not perform these cognitive tasks.

Had Arthur been assigned an intern that happened to meet his expectations, this intern-mentor transaction would likely have been more balanced. As it was, the transaction required too much effort for Arthur to balance his need for the data, which was of limited value, with Tanis's need for support, which was considerable. Tanis's autonomy and program inquiry scores were among the lowest in the cohort, and she made no gains in understandings about NOS or NOSI.

Angela and Young. The case of Angela, and her mentor, Young, is an exceptional example of an intern-centric transaction where the intern's needs were considerable, that resulted in positive outcomes for both intern and mentor. Young, a postdoctoral researcher from Korea and an experienced mentor of both graduate and undergraduate students, explained his views and approach to mentoring in this way:

MRP: What does the ideal intern look like for you?

Young: (*little chuckle*) Well that is nothing ideal intern. It depends on the connection between the supervisor and student. It depends on the student…This is most important… So you may expect this supervisor is very good - in terms of scientific career, is very good. But sometimes they failed to make up with student in the end. So this I believe is case by case, person by person.

…

MRP: Do you have a personal philosophy of being a mentor?

Young: It shouldn't be a one way direction. It should be a both way direction. And I should have time for the individual approach. Otherwise I can't be mentoring. It means I have to organize my time schedule for her and me. Individual approach is very important for me, and that two way. I always think I can learn something from the student. That is most important. Then I can be very involved and motivated. Otherwise I don't have motivation.

MRP: Did you learn something from Angela?

Young: I learned something from her actually. Yes, how I can teach student. How I can approach student individually and teach something. How I can speak even.

…

MRP: Can you describe the ideal research project?

Young: Well, in case of Angela, you should have a very straight forward project. But you can learn something from this, basic things. In terms of scientific, some knowledge and mechanisms behind of this experiment, not just the answer. They have to learn the way I was thinking, how this project was developed. What they can learn in this ten weeks. I don't think the mentor has to create very fantastic project or big project for student, but I think a small project make very clear for student is most important. I spend two weeks with Angela just for discussion. Discussion and discussion and discussion. She get an idea what she going to do for the ten weeks. And I thought I should not start because she cannot understand this project. So, after, she really understood very clearly, although she had no experience before this period. (Young, Interview)

Young's intern, Angela, was a rising sophomore in community college, and had completed a single semester of introductory biology (without laboratory) prior to the program.

She understood very little about molecular biology, scientific writing or primary literature. In addition, Angela's first language was Spanish. During her summer internship, she and Young worked closely together to write her research proposal and final presentation; read, with a little bit of understanding, some primary literature; and complete a set of molecular techniques, that by the end of ten weeks, Angela felt capable of conducting at the bench on her own.

Angela's project was a multifaceted-observational investigation involving microscopy, RNA extractions, reverse transcriptase PCR, gel electrophoresis, searching an on-line gene database, and seedling physiology experiments. Angela struggled to understand the details of her project, which focused on two transcription factors in a complicated signal transduction pathway also involving precursor molecules, photosynthetic pigments, second messenger molecules (singlet oxygen) and cell death. She felt very overwhelmed by all of these terms and concepts at the beginning of the program. The following exchange demonstrates her grasp of some of these concepts by the end of the program, illustrating a very general understanding bounded by the specifics of her project:

MRP: Can you tell me what transcription factors are?

Angela: Ok. Those are proteins that (*pause*). Umm those are the proteins that are involved in the (*pause*) umm making of umm DNA I think. But I'm not sure.

MRP: That's Ok. I don't know what a "singlet oxygen responsive gene" is (*reading from Angela's written proposal*).

Angela: Ok. A singlet oxygen is a single reactive oxygen species. And a reactive oxygen species is very reactive. Um. Very reactive. Um, hold on.

MRP: Take your time. Don't feel rushed.

Angela: They are vey reactive, reactive oxygen species and singlet oxygen is this one that also is very toxic to the cell and they, the genes that are responsive to singlet oxygen are the genes that activate after the release of singlet oxygen.

MRP: Ok. And what's the point of reacting after the singlet oxygen?

Angela: So they're, those genes are like suppressed or asleep if singlet oxygen is not released. So singlet oxygen is released so they like wake up. And that's when the cell death happens.

…

MRP: Do you think you have a better understanding of what genes and proteins are?

Angela: I - yes?

MRP: Could you explain that to me?

Angela: Well that's always, like I don't have the definition of genotype in my head but like last time (*referring to her early interview*) I had trouble answering you what a gene was, and I think I still do [have trouble]. But I think I have a little more knowledge of it.

MRP: What's changed?

Angela: The, the fact that I know that different genes are for different umm things in the plant's physiology, and the umm proteins that help activate some other things and yeah.

MRP: And you learned both of those ideas from this internship?

Angela: Mmhm (*nodding*).

MRP: Have you learned about the relationship between genes and proteins?

Angela: Umm? Well the fact that a transcription factor is a protein and that protein can activate some responsive genes - that might have something to do with it.

Angela achieved some independence in her day-to-day work at the bench by the final weeks of the program, but her confidence in her own work and judgments, and her deference to Young's authority were her greatest barriers. Angela was absolutist in her thinking across all of the MER domains. Young described her as very shy and passive, and gently pushed her to take a more active role as he noticed her becoming more comfortable in the lab setting and in her work. Around the fifth week of the program, Young began to ask Angela to design the next step of the project on her own. When she had done, he would review her design and discuss whether or not it made sense. Though this approach took a lot of time and effort, Young felt it was very important for Angela to also develop her thinking skills. He felt greatly rewarded when Angela put the final slide of her presentation together on her own:

> Not only me, our PI and our colleagues were really impressed. She really tried to create her own hypothetical models in the last slide and she presented this in the presentation. Yeah. She did herself actually and then she asked me whether this was correct or not. (Young, Interview)

Angela's results (presented in earlier slides) indicated that a) TF46 came earlier in the signaling pathway than TF53, b) TF46 was responsible for activating TF53, and c) TF53 promoted cell death after a stress response. She reasoned, that TF53 activity would be absent in the *tf46* mutant (since there was no TF46 protein to activate it) as well as the *tf53* mutant, and that therefore both of these strains should have recovered and survived the stress response. However, since only the *tf53* mutant recovered, Angela *hypothesized* an *alternative explanation* for the activity of TF46 that seemed to fit her data.

Angela's research experience fell into the intern-centric category because her mentor's goal from the outset was to teach. He selected Angela form the intern pool because of the

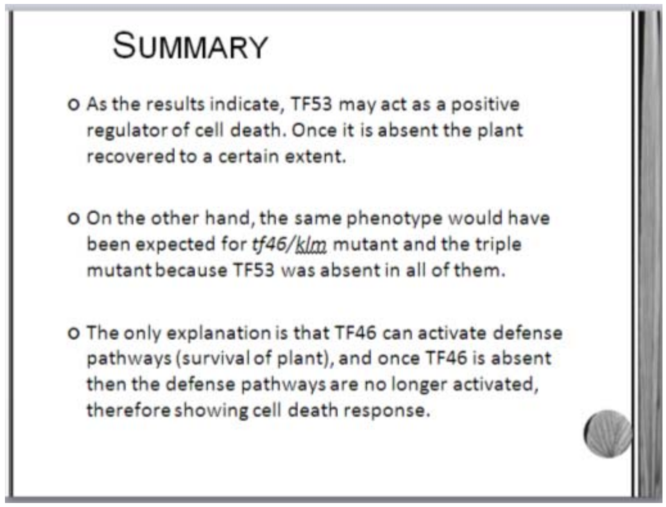

Figure 7: Final Slide of Angela's Student Symposium Presentation

honest way she represented herself in her application materials; he therefore had realistic expectations as to her background knowledge and skill level. Young also placed a priority on teaching his intern about the thinking that underlies scientific inquiry. The final slide from her presentation (Figure 7) demonstrates her deep intellectual engagement with a project whose subject matter and techniques were far beyond the scope of her prior educational experiences. It also demonstrates that a high level of reasoning can be achieved through skillful and patient mentoring, even without complete mastery of the subject matter. Angela's autonomy score was among the highest in the cohort, and her program inquiry score was in the middle of the range. Though she did not make any gains in understandings about NOS (Figure 2), she did make modest gains in understanding aspects of NOSI (anomalies and multiple purposes, Figure 3).

Discussion

Since the publication of the Boyer Commission's Report (1998), undergraduate research programs have enjoyed strong support from institutions and major funders such as the NSF and the HHMI. Yet there is but a small body of empirical work supporting UREs as experiences in which students learn abilities and understandings about inquiry and the scientific enterprise. Evidence suggests that undergraduate researchers make small gains in laboratory research skills (Kardash, 2000) and understandings aspects of NOSI and NOS (Ryder *et al.,* 1999), and begin the enculturation process into the social world of science practice (Seymour *et al*., 2004; Hunter *et al.,* 2008). Yet little of this research attempts to explain the mechanisms or interactions that facilitate or constrain science learning through participation in research. The purpose of this research project was to explore and explain what undergraduate students learned through participation in authentic and cutting edge scientific laboratory research. Specifically, what inquiry skills did interns practice, and what understandings about NOS and NOSI did they develop during their participation in research practice? I also sought to identify aspects of the research experience that might help to explain gains, or failure to make gains, in the practice of inquiry skills or in understandings about NOS and NOSI.

Experience with Inquiry and Research Skills

Analysis of interns' pre-program surveys helped to discern two sets of inquiry/research skills: those so common, or easily mastered, that even research novices had practiced them independently to some degree, and those less commonly practiced or more difficult to master. This second set of skills, similar to Kardash's (2000) "higher order skills," was more frequent in the group of students with prior research experience, many of whom were upper-class students with advanced coursework. Higher order inquiry skills, such as posing a scientific question, developing and modifying hypotheses, and considering alternative explanations are more characteristic of authentic scientific inquiry (including cognitive tasks epistemology), than of the simple inquiry most often practiced in educational settings (Chinn and Malhotra, 2002).

Interns' independent practice of inquiry in the Program, including those students with a history of research, resembled the pre-program independent practice of research novices. Thus, intern's *independent* research work offered very few opportunities to develop skills beyond those typical of undergraduate science coursework. Similarly, Kardash (2000) found that students felt their basic skills had been enhanced through participation in research, but not the higher order skills such as posing scientific questions or designing experiments. Seymour et al (2004) also noted very few instances of students reporting gains in these more advanced inquiry skills. My results suggest that the findings of these authors may be due to limited opportunities for interns to independently practice these advanced skills. However, it is important to note that most interns' *guided* work as participants in the Program *did* offer opportunities to experience (either through practice or observation) nearly the complete set of inquiry skills more than "once or twice." Thus, participation in this URE can offer opportunities to experience, and therefore opportunities to learn about or to do, the more advanced aspects of authentic inquiry.

It is likely that successful practice of advanced inquiry skills would require significant mentoring in an advanced biotechnology research laboratory. It may be that the advanced and technical nature of the research conducted in this setting was too demanding to allow interns to grapple with the more advanced aspects of inquiry on their own. The research projects of most interns, both novice and experienced researchers, were heavily prescribed and partial inquiries (NRC, 2000). The experience of only one intern approached "full and open" inquiry (Brown et al., 2006). I found no correlative relationship between semesters of prior research or pre-program inquiry scores and program inquiry scores. Together these findings suggest that most mentors either did not take interns' prior research and inquiry experience into consideration, or, if they did, felt that interns' prior experiences were not significant enough to permit them greater autonomy in conducting their research. This is important because Russell (2005a) found that students who reported greater autonomy and greater satisfaction with mentoring developed greater confidence in their research skills, and suggests an area for improvement in developing UREs as more effective learning experiences for interns.

Understandings about NOS and NOSI

This group of interns made very few gains in their understandings of aspects of NOS through participation in undergraduate research. Interns' understandings of nearly all aspects of NOS were naïve or emerging before and after the Program. These results are consistent with those of others investigating college students' views of NOS (Smith & Wenk, 2006; Abd-El-Khalick, 2004). I also found no correlation between NOS or change in NOS and practical experiences with inquiry. These findings are similar to those of Ryder et al.'s (1999) investigation of developing understandings about NOS through participation in undergraduate research. Few interns' research experiences involved explicit, or even implicit, messages about aspects of NOS (Schwartz & Crawford, 2004). However, for two students, some gains in understanding aspects of NOS occurred because of a critical event involving surprising, anomalous data. Because the interns participated in the mental work of explaining the anomalies, they were able to come to new understandings of the role of theory, the tentative NOS (Hans), and the role of creativity (Taylor) in forming scientific knowledge. My findings suggest that for most students, the context of a summer research internship involving cutting edge laboratory techniques and tools, does not generally promote deeper understandings of NOS. However, such a research experience *can* promote some advancement in NOS understandings, particularly when outcomes are surprising and the intern can participate more actively in the process of reasoning through a logical explanation.

Interns made greater gains in understandings about aspects of NOSI, especially understandings about anomalies, the community of practice, justification of claims, and multiple purposes of scientific work. Though I did not find any relationship between interns' prior or program practice of inquiry and their understandings of NOSI, I did find a strong, significant correlation between their program inquiry scores and change in NOSI. These findings suggest that some aspects of NOSI are easier to grasp through research practice in a laboratory community than aspects of NOS. At the same time, the finding that interns with lower pre-program scores made greater gains than interns with higher pre-program scores suggests that there may be factors that limit the level of understanding that can be developed through participation in a summer research internship in this setting.

Research Projects

Research projects took on a variety of different forms in this URE, ranging from non-investigations where the intern simply measured seedlings for ten weeks, to highly sophisticated, cutting edge biotechnology experiments. Project type had some influence on the kinds of inquiry skills interns experienced and the understandings about NOS and NOSI that interns developed. For example, non-investigations did not address a question or test an hypothesis, and most provided limited or superficial engagement with inquiry, particularly the more advanced inquiry skills. Simple-observational investigations did address a research question. Yet interns' experiences with inquiry in these situations were more limited than those in non-investigations. The vignette featuring Tanis illustrate how such research experiences can result in limited gains in practice, knowledge and understanding, and lead to negative outcomes for the intern (for example, limited understanding of the subject matter or research plan, lack of pride or faith in one's results, disinterest in pursuing further research, negative feelings about the mentor or program).

Multifaceted-observational investigations and hypothesis tests were the most prevalent form of research project (approximately 63%), and both tended to result in positive outcomes for interns and mentors. Multifaceted-observational investigations aimed to describe a phenomenon rather than test an hypothesis. However, these projects involved several smaller investigations, each with a specific question, set of assumptions, techniques to trouble-shoot, and data set to analyze. Such projects provided opportunities for interns to experience more aspects of inquiry with greater frequency. Most multifaceted-observational and hypothesis-testing investigations were designed by the mentor in order to help the intern navigate the advanced subject matter requirements, complete a project in only ten weeks, and produce concrete, analyzable data. Thus, even in hypothesis testing projects, there was little need to revise hypotheses, seek alternative explanations, or defend an argument. One reason for a high level of prescription in some projects was the great importance of high-quality data to the mentor. Another reason was the mentor's philosophy or attitude about the intern-mentor relationship.

Intern-Mentor Transactions

The nature of the intern-mentor relationship was an important factor in determining positive or negative outcomes for the intern. Most mentor-centric transactions resulted in negative outcomes for interns, lower inquiry scores, and fewer gains in NOS and NOSI, particularly when the mentor was new to the Program. However, having a novice mentor did not guarantee negative outcomes or a mentor-centric transaction. It seems that mentor attitude was the more important factor determining transaction type. Mentor-centric mentors viewed the intern as an assistant or lab hand, rather than a scientist-in-training. Instruction, where it occurred, explicitly focused on mastering techniques. Cognitive skills, such as reasoning and evaluating, were rendered moot either by the simplicity or the heavily prescribed nature of the research project. Many novice mentors, and most experienced mentors approached the internship as an apprenticeship (balanced and intern-centric transactions), where the intern was viewed more as a scientist-in-training. All balanced and intern-centric transactions (even those that were non-investigations) resulted in positive outcomes for the intern (deeper understanding of subject matter and the research plan, pride in one's work and its results, interest in pursuing further research, positive feelings about the mentor and program). Further, balanced and intern-centric transactions tended to result in greater inquiry scores and greater gains in NOS and NOSI. These transactions more closely resembled a cognitive apprenticeship (Brown et al., 1989; Rogoff, 1990) particularly when the intern participated in higher order inquiry skills on his or her own, or in partnership with the mentor.

Only four of the 24 intern-mentor transactions were intern-centric. These transactions had positive outcomes for the intern, though not necessarily the mentor. Intern-centric transactions arose when the mentor had an apprenticeship view of the intern and was able to cope with the intern's needs for considerable support. These mentors met the student at their developmental level, and with skill and patience pushed their interns into the zone of proximal development in ways that most closely resembled conscious, constructive-developmental pedagogy (Baxter-Magolda, 1999). In three of the four intern-centric transactions, the intern was among those least prepared for a research experience and required the greatest support: underrepresented students from small institutions with limited research opportunities. It is noteworthy that the NSF encourages the undergraduate research programs it supports to recruit young students, students from two-year institutions, students from primarily undergraduate institutions, and underrepresented minority students. It is reasonable to expect that students from these backgrounds, particularly students with several of these factors in their backgrounds, might require significant support in an advanced and competitive research setting. This is especially true for students with no prior research experiences, as was the case with Angela (who was situated in intern-centric transactions) where she received significant support from their mentor and experienced many positive outcomes. Unfortunately, this was not the case with Tanis, a young minority student from a two-year institution, who was situated in a mentor-centric transaction.

Implications

The findings from this research have a number of important implications for improving the URE as a science learning experience that would better prepare undergraduate students for graduate education such that they are retained in STEM career pathways.

My findings suggest that undergraduate researchers need more opportunities to practice advanced inquiry skills independently and with guidance, in order to ultimately use these skills as independent researchers. In other words, mentors must consciously take the URE from practical apprenticeship to cognitive apprenticeship, where the learner is also trained in the ways of scientific thinking. For this to be the case, interns need opportunities to struggle with the more challenging cognitive tasks of scientific inquiry within their zone of proximal development (Rogoff, 1990, Chaiklin, 2003).

This Program, and others like it, need to reevaluate what is meant by "independent mentored research." The advanced and technical nature of the research conducted in this context was too demanding and high stakes to allow most interns to grapple with the more advanced aspects of inquiry on their own, and made it necessary for mentors to plan the interns' projects. "Independent, mentored research" did not mean that interns conducted their own, independently designed research projects with the guidance of a mentor. In this Program, "independent, mentored research" meant that interns were mentored such that they could achieve day-to-day independence executing cutting edge techniques in service of their mentor's research goals.

This distinction speaks to a need to better balance the intern as a learner with the mentor's needs for high-quality data. One way that this can be achieved is through mentor training. Mentors can be made aware of the merits of different forms of research project they can offer to interns. Hypothesis testing, multifaceted observational investigations and tool-development non-investigations are more likely to provide interns with greater opportunities to practice inquiry at a level that could promote deeper understandings about NOS and especially NOSI. Mentors can also be encouraged to offer interns some choice in research question and, where possible, greater involvement in the development of the project and evaluation of its outcomes. Even a small and non-technical self-designed investigation has the potential to improve learning outcomes for the intern.

Finally, mentors need to recognize the different forms of intern-mentor transactions and how these map onto a cognitive apprenticeship. Mentor-centric transactions are likely to result in positive outcomes for only the most experienced and skilled interns, and even then are not likely to lead to greater practice of advanced inquiry or deeper understandings of NOS or NOSI. These situations may lead very skilled interns to develop advanced technical skills, high-quality data, and perhaps co-authorship of a scientific publication. But they do little to prepare the intern for independently coping with the messy and indeterminate nature of authentic scientific inquiry as graduate students. Balanced intern-mentor transactions were the ideal for most interns and mentors in this Program. However, most of these interns had prior research experience and upper-level science coursework. As URE programs expand to welcome a greater diversity of students, particularly younger students with no prior research or upper-level coursework, and students from smaller and two-year institutions, they must attend to the increased needs of these interns for support. My findings suggest that care should be taken to pair interns with the greatest need for support with mentors who take an intern-centric approach to mentoring undergraduate researchers.

Appendix A

Intern Pre-Program Questionnaire: Learning Styles and Views of Inquiry

Questions 1-6 are about your learning style and learning preferences. These questions are actually a lot shorter than they look at first glance! Please write a short paragraph for each, answering ALL of the components with as much detail as you can. Try to give examples to illustrate your point.

1a. Think about the last time you had to make *a major decision* about your education in which you had *a number of alternatives* (e.g. which college to attend, college major, career choice etc.) What was the nature of the decision?
  b. What alternatives were available to you?
  c. How did you feel about these alternatives?
  d. How did you go about choosing from the alternatives?
  e. What things were the most important considerations in your choice? Please give details.

2a. Do you learn best in classes which focus on factual information or classes which focus on ideas and concepts?
  b. Why do you learn best in the type of class you chose above?
  c. What do you see as the advantages of the choice you made above?
  d. What do you see as the disadvantages of the choice you made above?
  e. If you could give advice to anyone on how best to succeed in college coursework, what kind of advice would you give them? Talk about what *you* believe is the key to doing well in college courses.

3a. During the course of your studies, you have probably had instructors with different teaching methods. As you think back to instructors you have had, describe the method of instruction which has the most beneficial effect on you.
  b. What made that teaching method beneficial? Please be specific and use examples.
  c. Were there aspects of that teaching method which were not beneficial? If so, please talk about some of the aspects and why they were not beneficial.
  d. What are the most important things you learned from the instructor's method of teaching?
  e. Please describe the type of relationship with an instructor that would help you to learn best and explain why.

4a. Do you prefer classes in which the students do a lot of talking, or where students don't talk very much?
  b. Why do you prefer the degree of student involvement/participation that you chose above?
  c. What do you see as the advantages of your preference above?
  d. What do you see as the disadvantage of your preference?
  e. What type of interaction would you like to see among members of a class in order to enhance your own learning?

5a. Some people think that hard work and effort will result in high grades in school. Others think that hard work and effort are not a basis for high grades. Which of these statements is most like your own opinion?
  b. Ideally, what do you think should be used as a basis for evaluating your work in college courses?
  c. Who should be involved in the evaluation you described above?

d. Please explain why you think the response you suggested above is the best way to evaluation students' work in college courses.

6a. Sometimes different instructors give different explanations for historical events or scientific phenomena. When two instructors explain the same thing differently, can one be more correct than the other?

b. When two explanations are given for the same situation, how would you go about deciding which explanation to believe? Please give details and examples.
c. Can one ever be sure of which explanation to believe? If so, how?
d. If one cannot be sure of which explanation to believe, why not?

Questions 7 – 10 address your views on the nature of scientific inquiry. There are no right or wrong answers to these questions – they are about your views or beliefs.

7. A person interested in animals looked at hundreds of different types of animals who each either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.

a. Do you consider this person's investigation to be an experiment? Please explain why or why not.
b. Do you consider this person's investigation to be scientific? Please explain why or why not.

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction.

a. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?
b. Is it possible for two different scientists to do the same procedures and come to different conclusions? Explain.

9. Is there a role for creativity and/or imagination in scientific investigation? Please explain.

10. What qualities/characteristics/attitudes are important for success in a scientific profession? Please explain why you believe these attributes are important.

11. Please read the directions below carefully. Provide your answer to each of the following using the scale provided below.

You can use **bold** or highlighting from the menu bar above to highlight your answer.

(*Consider each question independently, these are not cumulative. If you feel like you need to explain or qualify your selections, please do so by typing right beneath that question within the table.)*

In your past experiences as a science student, how <u>often</u> have you been able to do each of the following INDEPENDENTLY? **Independently = On your own** (or with a partner or group) – the key is that **the work was self-directed** and not teacher-directed.	**0** = Never **1** = Once or twice **2** = Sometimes **3** = Often **4** = Very often.
1) pose your own scientific questions to test	0 1 2 3 4
2) select/design the methods for a scientific investigation	0 1 2 3 4
3) determine what evidence to collect in a scientific investigation	0 1 2 3 4
4) decide how to summarize collected evidence (in a graph, figure or table, or statistically)	0 1 2 3 4
5) formulate an explanation for the evidence (data analysis/interpretation)	0 1 2 3 4
6) form connections between your explanations and existing scientific knowledge	0 1 2 3 4
7) use primary literature (scientific journals)	0 1 2 3 4
8) develop a reasonable and logical argument to communicate your explanation	0 1 2 3 4
9) defend your argument (respond to oral or written questions/criticism/critique)	0 1 2 3 4
10) formulate alternative explanations based on data/evidence	0 1 2 3 4
11) modify a hypothesis based on new evidence or ambiguous data	0 1 2 3 4
12) figure out what went wrong in an investigation and attempt to fix it (troubleshoot)	0 1 2 3 4
13) relate results of an investigation to the “bigger picture” in your field	0 1 2 3 4
14) orally present the results of a scientific investigation	0 1 2 3 4

Appendix B

Interview Protocol: Intern, Early-program

1. Describe these prior research experiences – what did you do for each?
    - What kind of labs did you do in these courses?

2. Matches survey Q2: Probe about description
    - Why did you want to do undergraduate research?
    - Why plant biotechnology/genomics?

3. Describe the research project you're mentor has put you on.
    - What is your research question? What are you looking at?
    - How will you go about doing this project?
    - What have you done on this project so far?
    - What interactions have you and your mentor had so far? Describe what these are like.
    - How does your mentor go about teaching you how to do things?
    - What kind of things has your mentor explained?

4. Probe survey question 3

5. How do you think scientists make a genetically engineered plant?
    - What is a gene?
    - How is a protein made?
    - You make this process sound so easy! What are some of the technical difficulties?
    - What are some of the ethical issues?
    - What do you know about a genome? What can you do with it? What can't you do with it?

6. I have a short series of questions about scientific inquiry – look at the printout and read along with me. You will recognize some of these from the survey you filled out: (modified from VNOS-C [Lederman et al., 2002] and VOSI, Schwartz et al. [2008]). Parts in bold will be printed for the students to read along. Parts that are in normal formatting will be used to probe.)

I) A person interested in animals looked at hundreds of different types of animals who each either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals. (VOSI.5)

a) Do you consider this person's investigation to be an experiment? Please explain why or why not. (VOSI.5)

- What is an experiment? What makes an investigation an experiment? (from VOSI.3 &VNOS$_C$.2)
- What are the criteria for a *good* experiment?
- What is a controlled experiment? What is the point of the control?
- Do you have to be doing experiments in order to be doing science? (modified from VNOS$_C$.2)

b) Referring back to the paragraph above, do you consider this person's investigation to be scientific?

Please explain why or why not. (VOSI.5)

- What makes an investigation scientific? (modified from $VNOS_C$.1)
- What is science? What makes science different from non-science? What are your criteria for differentiating between science (like chemistry, physics, biology, geology) and non science (religion, philosophy)? (modified from $VNOS_C$.1)

c) What have you learned about the scientific method? (modified from VOSI.6)

- Is this how all science gets done?
- Do all scientists use the scientific method?
- What about different fields of science?
- Did your summer project follow the scientific method? (for post)

II) What are theories in science? How do scientists use theories?

- What is an hypothesis?
- After scientists have developed a scientific theory, does the theory ever change? ($VNOS_C$.6.)
- How are facts and theories related? Explain.

III) What does the word “data” mean in science? (VOSI.4A)

- Is “data” the same or different from “evidence”? Explain. (VOSI.4B)

IV) How certain is the scientific knowledge found in text books? ($VNOS_C$.7.modified)

- What do scientists need in order to be certain about their findings? (modified from VOSI.7)
- When scientists report their results to other scientists, what kind of information do you think they need to include in order to convince others that their conclusions are valid? Be as specific as possible. Try to give an example. (VOSI.7)

V) Is there a role for creativity and/or imagination in scientific investigation? (modified from $VNOS_C$.8).

- If yes, explain that role and provide an example.
- If yes, then at which stages of the investigations do you believe that scientists use their imagination and creativity: planning and design; data collection; after data collection? Please explain why scientists use imagination and creativity (from $VNOS_C$.8)
- If not, explain why and provide an example (modified from $VNOS_C$.8)

VI) It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, tow enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions? ($VNOS_C$.9)

- Is it possible for two different scientists to do the same procedures and come to different conclusions? (modified from VOSI.8)

VII). A. How do scientists decide what to study in their investigations? (VOSI.10)

B. How do scientists decide how to conduct their investigations? (VOSI.10)

- Describe all the factors that you think influence the work of scientists. (VOSI.10)
- Do society and culture (so politics, philosophy, cultural norms) influence scientific practice?

Scientific knowledge? (modified from $VNOS_C$.10).

7. Now I have a short series of questions that get at how you think and learn best. You will recognize some of these from the survey you've already filled out. (From MER, Baxter Magolda, 1999).

MER1) Think about the last time you had to make *a major decision* about your education in which you had *a number of alternatives* (e.g. which college to attend, college major, career choice etc.) What was the nature of the decision?

- What alternatives were available to you?
- How did you feel about these alternatives?
- How did you go about choosing from the alternatives?
- What things were the most important considerations in your choice? Please give details.

MER2) Do you learn best in classes which focus on factual information or classes which focus on ideas and concepts?

- Why do you learn best in the type of class you chose above?
- What do you see as the advantages of the choice you made above?
- What do you see as the disadvantages of the choice you made above?
- If you could give advice to anyone on how best to succeed in college coursework, what kind of advice would you give them? Talk about what *you* believe is the key to doing well in college courses.

MER3) During the course of your studies, you have probably had instructors with different teaching methods. As you think back to instructors you have had, describe the method of instruction which has the most beneficial effect on you.

- What made that teaching method beneficial? Please be specific and use examples.
- Were there aspects of that teaching method which were not beneficial? If so, please talk about some of the aspects and why they were not beneficial.
- What are the most important things you learned from the instructor's method of teaching?
- Please describe the type of relationship with an instructor that would help you to learn best and explain why.

MER4) Do you prefer classes in which the students do a lot of talking, or where students don't talk very much?

- Why do you prefer the degree of student involvement/participation that you chose above?
- What do you see as the advantages of your preference above?
- What do you see as the disadvantage of your preference?
- What type of interaction would you like to see among members of a class in order to enhance your own learning?

MER5) Some people think that hard work and effort will result in high grades in school. Others think that hard work and effort are not a basis for high grades. Which of these statements is most like your own opinion?

- Ideally, what do you think should be used as a basis for evaluating your work in college courses?
- Who should be involved in the evaluation you described above?
- Please explain why you think the response you suggested above is the best way to evaluation students' work in college courses.

MER6) Sometimes different instructors give different explanations for historical events or scientific phenomena.

- When two instructors explain the same thing differently, can one be more correct than the other?
- When two explanations are given for the same situation, how would you go about deciding which explanation to believe? Please give details and examples.
- Can one ever be sure of which explanation to believe? If so, how?
- If one cannot be sure of which explanation to believe, why not?

Appendix C

Interview Protocol: Mentor, Post-program

1. Why did you become a mentor this summer?

2. Did you have any expectations as a mentor?
   - What do you think are the goals of the program?
   - How would you screen the applicants?
   - What would the ideal intern look like?

3. Have you been a mentor of undergraduates before?
   - What was it like?
   - How would you say it affected your own productivity in the lab?
   - Describe the ideal research project

4. Describe your intern's research project.
   - How did she go about doing this project?
   - How did it develop over the course of the summer?
   - What is the next step?
   - What will happen with her findings?
   - What techniques did she learn to use really well?

1. What is similar/different between this kind of research experience and entering grad school?
   - What do you wish you had learned before becoming a grad student?
   - What do you think interns need to gain from a program like this in order to be successful in grad school?

6. Describe your intern – what skills did she/he bring to this experience? In what ways did you observe your intern growing into the role of scientist as a participant in this program? Provide specific examples of how your intern progressed.
   - How well prepared was this student for her experience?
   - What do you think she's learned from this experience?
   - What do you think she learned – about the subject; about research; about herself as a student?
   - What do you think interns need to gain from a program like this in order to be successful in graduate school?
   - What do you wish you had learned before becoming a grad student?

7. Did you do research in undergrad? Did you learn anything about mentoring from that experience?
   - How did you learn to mentor?
   - How would you describe your PI as a mentor?

8. Describe your approach to mentoring. How did you develop this approach?
   - So what makes an ideal mentor?
   - What was y our biggest challenge?
   - In what ways could the program have better supported you as a mentor? Would reading the application be helpful?

9. What have you learned from this mentoring experience…
    - about yourself
    - about how to be a good mentor
    - did you benefit from this in any way?
    - Would you do it again?

10. Inquiry Aspects: Please rate your intern on each of the following aspects of inquiry. First, for the intern's independent or self-directed work. Then again for the work she did under your guidance. Provide your answers to each of the following on a scale from 0 to 4 where:

0 = Never
1 = Once or twice
2 = Sometimes (less than once a week)
3 = Often (more than once a week)
4 = Very often (nearly every day)

As an Intern in the program, to what extent (how often) DID you do each of the following:	**a) self-directed**	**b) mentor-guided**
1. pose your own scientific questions to test	0 1 2 3 4	0 1 2 3 4
2. select/design the methods for a scientific investigation	0 1 2 3 4	0 1 2 3 4
3. determine what evidence to collect in a scientific investigation	0 1 2 3 4	0 1 2 3 4
4. decide how to summarize collected evidence (in a graph, figure or table, or statistically)	0 1 2 3 4	0 1 2 3 4
5. formulate an explanation for the evidence (data analysis/interpretation)	0 1 2 3 4	0 1 2 3 4
6. form connections between your explanations and existing scientific knowledge	0 1 2 3 4	0 1 2 3 4
7. use primary literature (scientific journals)	0 1 2 3 4	0 1 2 3 4
8. develop a reasonable and logical argument to communicate your explanation	0 1 2 3 4	0 1 2 3 4
9. defend your argument (respond to oral or written questions/criticism/critique)	0 1 2 3 4	0 1 2 3 4
10. formulate alternative explanations based on data/evidence	0 1 2 3 4	0 1 2 3 4
11. modify a hypothesis based on new evidence or ambiguous data	0 1 2 3 4	0 1 2 3 4
12. figure out what went wrong in an investigation and attempt to fix it (troubleshoot)	0 1 2 3 4	0 1 2 3 4
13. relate results of an investigation to the "bigger picture" in your field	0 1 2 3 4	0 1 2 3 4
14. orally present the results of a scientific investigation	0 1 2 3 4	0 1 2 3 4

Appendix D

Scoring Rubric for Understandings about NOS and NOSI

Aspect	Response Category and Associated Score 0 Uninformed/Naive	1 Emerging	2 More Informed	3 Robust Understanding
Empirical NOS	Science is anything having to do with biology, chemistry or physics, studying the natural world, and/or science is following a method. Science is a collection of facts, proven through experimentation, objective, absolute.	Subject matter and method inferred. Science has mostly to do with collecting data and analyzing it to make claims. But still hangs on to the idea that science is special because of its objectivity and reliance on facts.	Subject matter and method inferred. Science has mostly to do with collecting data and analyzing it to make claims. Has let go of the idea that science is special because of it is more objectivity and factual than other fields.	Science has mostly to do with collecting data and analyzing it to make claims. Has let go of the idea that science is special because it is more reliant on objectivity and facts than other fields and understands that subjectivity plays a role.
Experiments	Does not know what an experiment is or has serious misconceptions (for example, “anything is an experiment” or “dropping a ball and watching it fall” is an experiment). A way to answer a question.	An experiment is a test of an hypothesis or an experiment is a way to collect data. No example or faulty example provided, includes misconceptions.	A way to test an hypothesis and gather data, may mention the use of variables and controls. No major misconceptions (e.g. good understanding of controls)	An experiment is a controlled way to test an hypothesis against data/evidence. It involves manipulating the objects/variable of interest while keeping all other factors the same. Few/no misconceptions. Good understanding of controls.
Validity of Observational science	Science must involve experiments OR maybe, maybe not (with no explanation)	Sometimes science involves experiments, but should also note other ways of doing science, for example through observational or descriptive studies (but offers no example of such or explanation). Includes misconceptions.	Sometimes/often there are other ways of doing science, for example, observational or descriptive studies. Offers an example or an explanation.	The methods used in a scientific investigation depend on the question asked (for example, “some questions/hypotheses cannot be tested directly.”) AND/OR the practice of science is a form of mental modeling.
Scientific Theory	Demonstrates major misconceptions about what a theory is: e.g. theories are theories because they have not been proven “theories develop into laws (once they are proven correct)” or “ a theory is just a hunch.”, it’s a big idea, a guess.	Theories are based on evidence, they are something we believe to be true.	Theories are based on evidence. They describe or explain.	Explanatory framework, based on evidence (observed patterns), can generalize and predict (basically similar to 2, but goes beyond). No Theory-law misconceptions. (T-L misconceptions sets this back to a 2 rather than a 3)

Theory Change	Demonstrates major misconceptions about how theories are used. e.g. Answer is an absolute: theories have to change, theories never change.	Theories can/do change because of new information, data, discoveries or technology. However, makes no connection between data and evidence.	Theories can change when new evidence weighs in against it (repeated testing). Answer must convey the importance of weighing evidence beyond that gained from new technologies and includes no major misconceptions.	Theory change requires the weighing of evidence, but theories are unlikely or difficult to change. Answer also includes no major misconceptions.
Theory Laden NOS (Subjective NOS)	Does not know how to respond to question, responds that the events in question happened too long ago for us to really know, or were too violent/chaotic to be understandable. These theories are just opinions. OR the data are inconclusive, there is not enough data.	Indicates that different people have different interpretations of events or different perspectives, but provides no further explanation (other than different backgrounds or personal biases). May include misconceptions.	Indicates that different people have different interpretations of events or data, or different perspectives of such. Also provides a reasonable example or further explains (Scientists use subjectivity and creativity to form conclusions). Includes no major misconceptions.	Scientists weigh evidence/judge arguments AND employ subjectivity/creativity. May also offer a social-constructivist explanation involving acceptance of the scientific community.
Creative NOS	Science is objective, there is no creativity in what scientists do. OR science is subjective.	Indicates that creativity is important in some combination of the following: developing questions, experimental design, collecting and/or displaying data.	Indicates that creativity is important in interpretation, analysis and or explanation but offers no explanation for example other than in terms of trouble-shooting.	Indicates that creativity is important in all stages of scientific investigation and provides explanations or an example pertaining to interpretation, explanation, or the construction of an argument. AND/OR takes the social/constructivist perspective of scientific knowledge: scientific knowledge is socially constructed and culturally embedded (e.g. “human component”).

Tentative NOS	Does not know how to respond to question OR responds that facts are immutable, absolutely true. Scientific knowledge is certain, at least for our time (no explanation). Newer scientific knowledge is less certain but will become so with more testing. AND/OR Scientific knowledge changes because new information is added to it (accumulates, builds).	Scientific knowledge is reliable/durable, but also tentative because it is changeable with new evidence.	Scientific knowledge is reliable/durable but also tentative because it is changeable with new evidence (or new ways of thinking) AND because interpretation plays a role in forming conclusions/explanations.	Scientific knowledge is reliable/durable but also tentative because it is changeable with new evidence (or new ways of thinking) AND because interpretation plays a role in forming conclusions/explanations. No Theory-law misconception (theories, once proven, become laws). ALSO includes some or part of the following: new knowledge is vetted by the scientific community; scientific knowledge is also tentative because one cannot prove or test all cases.
The Scientific Method	I do not know, scientific method must be used, or *good* science must follow the scientific method.	Indicates that the scientific method is more flexible or fluid than commonly believed/taught: not all of the steps are always necessary, specific order of steps is not important.	Indicates that there are multiple methods of science (beyond the understanding as in 1). For example, not all science is experimental, or some scientific investigations are observational or descriptive.	Indicates that there are multiple methods of scientific investigation (as in 2) both within scientific discipline and across different scientific disciplines. AND/OR the methods of an investigation depend on the question(s) posed. OR describes science practice as mental modeling.
Socially and culturally embedded NOS	No outside influences on science other than personal attributes (for example, personal religious beliefs)	People belong to a society and their personal beliefs can be influenced by that society/culture	Social norms limit what gets funded AND/OR socio-political issues guide funding (little or no explanation or example [beyond stem-cells])	Social norms limit what gets funded AND socio-political issues guide funding – provides a good concrete example
Role of Questions in NOSI	Science investigates science subject matter or science investigations start with observations.	Scientific investigation employs a method to answer questions	Science builds on what is already known to answer questions about the unknown. For example: "You formulate your knowledge based on previous things found and then you form a hypothesis or speculate."	Science involves answering questions about the unknown and comparing the answer to existing scientific knowledge. For example: "Science involves collecting data, drawing connections from the data to make evidence, and using that evidence to explain things in light of what is already known."

Multiple purposes of SI	Interest/curiosity and practicality	New questions/directions arise from within the research process – includes anomalies, reading the literature	Broader intrascientific factors: circumstances or situation, especially in the training environment (includes most funding examples, though not all). OR extrascientific factors: what society deems important, political influences on where funding is shifted, humanitarian/health reasons.	BOTH intrascientific AND extrascientific factors
Role of justification in NOSI	Involves repeatability and lots of supporting evidence	More sophisticated than just repeatability and lots of evidence – for example, multiple forms of evidence, organization of evidence, use of logic, use of literature	Conveys the idea of constructing an argument (beyond just using the word "argument") and considering/recognizing alternative explanations.	Logically consistent argument, recognizing alternative explanations and negotiating consensus with the scientific community.
Role of Anomalous Data in NOSI	Anomalous data arise from human error (i.e. sampling, contamination, unaccounted for factors)	Data are actually difficult to reproduce (data are inherently "murky")	Anomalies can lead to new directions in research, new discoveries. OR Anomalies can lead to theory change or peripheral theory change	Anomalies can lead to new directions in research, new discoveries AND anomalies can lead to theory change or peripheral theory change
Data vs. Evidence	Data are collected information. Evidence is different – evidence is something left behind (like trace evidence). AND/OR data and evidence are the same thing – there is no difference between how these two terms are used in science	Data and evidence are the same thing but the words are used differently in science (cannot explain). Data and evidence are different degrees of the same thing (cannot explain)	Data are amassed to produce evidence that supports or refutes a claim.	Data are interpreted to provide evidence that supports or refutes a claim
Role of Communities of Practice in NOSI	Little or no awareness of the scientific community's influence on what scientists do.	Awareness of usefulness of literature – background knowledge, building on methods (but not scrutinizing or criticizing methods)	Practices and standards for developing scientific knowledge. May mention peer review here, but does not explain it.	Practices and standards for accepting scientific knowledge – importance of critical peer review in acceptance of scientific claims.

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