

UNDERSTANDING STUDENT LEARNING IN UNDERGRADUATE RESEARCH EXPERIENCES AT THE  
CUTTING EDGE OF BIOTECHNOLOGY AND GENOMICS

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Undergraduate research experiences (UREs) have been at the leading edge of undergraduate science education reform efforts, having the potential to involve students in authentic and cutting edge scientific inquiry. While research has shown that undergraduate research can be effective in recruiting and retaining science students and increasing students' confidence in their abilities to do research, the literature on students' science-learning through participation in undergraduate research is scant. This study described what students learned about the practice of scientific inquiry, the natures of scientific knowledge (NOS) and inquiry (NOSI), and whether students developed epistemologically through participation in summer UREs in cutting edge biotechnology laboratories. This study also explored the types of research projects and intern-mentor transactions in the UREs in order to explain students' gains or lack of gains. 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 inquiry skills (e.g. collecting and summarizing data), but their guided practice included many of the more advanced skills important in developing scientific thinking (e.g. design, evaluating evidence, revising assumptions/hypotheses, and constructing arguments). While few interns made gains in understandings about NOS, many interns made gains in understanding several aspects of NOSI. Gains in NOSI were associated

with greater autonomy in the research and greater independent practice of more advanced inquiry skills. None of the interns made detectable gains in their epistemological thinking. However, students' level of epistemological development showed a significant, positive relationship with their ability to understand aspects of NOS and NOSI. The exploratory investigation found that multifaceted research projects (both observational and hypothesis-driven investigations) and tool development projects provided more opportunities to practice advanced aspects of inquiry in this setting. Interns in mentor-centric transactions, those most highly prescribed, generally achieved lower program inquiry scores than interns in balanced and intern-centric situations. Interns engaged in more indeterminate projects, where methods were less prescribed and outcomes less predictable, generally made greater gains in understandings about NOSI. Gains in understandings about NOS showed no relationship with project or transaction type. In some cases, gains in NOS were linked to critical incidents, for example the discovery of anomalies.

## BIOGRAPHICAL SKETCH

Maya received a Bachelor of Science from Mount Holyoke College in 1993. At Mount Holyoke, Maya studied Biology and Environmental Science, and conducted an independently designed undergraduate research project on biological control of greenhouse pests. The project utterly failed, but it sparked an interest in insect ecology. Maya went on to earn a Master of Science in Entomology at the University of Illinois at Urbana Champaign in 1996. There she studied native communities of Diptera under the guidance of Dr. Michael Irwin. Upon receiving her master's, Maya returned to the east coast, where she taught Biology as an instructor at Ithaca College and then at Georgetown University for several years. At Georgetown Maya also served as an instructor and Science Faculty Chair for the Myer's Institute for College Preparation (MICP) for inner-city youth. Maya's experiences working with excellent students and dedicated faculty of IC and GU, and the students and personnel of the MICP eventually lead her back to school, to pursue a PhD in Education. Maya entered the Department of Education at Cornell University, where she worked under the guidance of Dr. Deborah Trumbull from 2006 through 2011. In her last year as a graduate student, Maya gave birth to a beautiful son and secured a teaching position in the Department of Biology at Ithaca College. She started her new post as Assistant Professor of Biology in Fall 2011.

For Stefan, Ramesh, Ann Marie, and Ram

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## CHAPTER 1

### Introduction/Problem

High quality undergraduate science education in the US is increasingly crucial. In an age when scientific and technological knowledge accumulates and changes at an astonishing rate, the most serious scientific problems of our time are becoming ever more interdisciplinary in nature and global in scope. 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). Hence, numerous calls for undergraduate science education reform have been issued over the past 20 years, and these continue to increase in urgency (e.g. NSB 1986; Boyer Commission, 1998; NRC, 1999 & 2003; Project Kaleidoscope [PKAL], 2006 and references therein).

Resolving the crucial issues of our time (e.g. the environment, biomedicine, technology) can not be accomplished by application of science knowledge alone. It is critical that developing scientists also understand the limits of science knowledge and methods of research. This idea was articulated by the renowned science education reformer Joseph Schwab fifty years ago, yet we continue to struggle with this question: How can we prepare the next generation of scientists to meet the significant challenges of our time, scientists who will not only contribute to the advancement of science knowledge, but also its judicious use? At stake is the ability to address the complex socio-scientific issues of our time.

Reminiscent of the recommendations of Schwab (1960), the most recent synthesis of the undergraduate science reform literature has 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. (Project Kaleidoscope, 2006, pg. 1)

Undergraduate research experiences (UREs) have the potential to address aspects of all four of these recommendations and are therefore at the forefront of current reform efforts (Fortenberry, 2000, Boyer Commission, 2002). A large body of exhortative and descriptive literature promotes UREs for attracting/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 and the Council on Undergraduate Research (<http://www.ncur.org>) jointly endorse this type of experience as a collaborative, investigative pedagogy that integrates teaching and research to provide students with an enriched inquiry-based learning experience. It is believed that 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 blossoming and 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. In Chapter Two I review the empirical literature on the benefits of participating in undergraduate research.

Much research has shown that simple participation in inquiry experiences, even those that approach authentic science practice as in undergraduate research, is not enough to promote desired science-learning outcomes. Students' minds must be engaged, their learning scaffolded, and their practice reflective if they are to develop sophisticated understandings of the research process, the nature of scientific knowledge, and abilities to think critically and scientifically (Minstrel & van Zee, 2000; NRC, 2000, 2005; Zimmerman, 2000). Four major theoretical perspectives frame this research: conceptions of inquiry-based instruction, nature of scientific knowledge (NOS) and nature of scientific inquiry (NOSI); social-constructivist theories of learning; the notion of epistemological development, and sociological studies of science. Chapter Three will explicate these areas.

There is much to learn about the nature of UREs in terms of inquiry instruction, student learning, and enculturation into the world of authentic science practice. It is therefore the purpose of this proposal to empirically investigate these issues. I studied an undergraduate summer research internship at a Research Institute, whose science is at the cutting edge of its field, employing complex research approaches and tools. As a ten-week summer internship, this program served as a form of immersion in science research, and therefore a prime site for an in-depth investigation of students' learning of science and development into scientists as they worked in a controlled setting. My research addressed the questions: What do students actually learn when they participate in a URE, what are the means by which this learning occurs, and what factors limit learning? I will develop these questions more fully in Chapter 4. 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.

## CHAPTER 2

### Existing Research: What do we know about UREs and how they have been studied?

#### Introduction

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” (<http://www.cur.org/about.html>). However, depending on the discipline, a given URE may be described as an inquiry, a creative activity, or scholarship (Kinkead, 2003); it may occur in the classroom, field, laboratory, studio, library, or on-line. 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). UREs are assumed to differ from most classroom inquiries or research term papers in that: 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. They found only nine studies in which claims about hypothesized benefits were well supported. Two major themes emerged from that review. The most prevalent involves preparation for a career in science; students reported understanding of the research process and how scientists think and work, readiness for more advanced research, interest in the discipline, and clarification or confirmation of the decision to pursue a scientific career or graduate school. Another common theme in these studies involves developing a sense of belonging; becoming part of a learning community, bonding with faculty, and building confidence in one’s ability to do research and

persist in a scientific field, particularly for underrepresented students. 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).

### **Learning the Practice and Culture of Science in Undergraduate Research Experiences**

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 (both among the literature reviewed by Seymour et al., 2004 and that which came after) 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 mentors on what they felt were the most important research skills students should acquire during participation in an URE. 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 research experience 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.” Students and mentors reported little gains in those skills students had rated lowest prior their URE: identifying a question, formulating, testing and reformulating hypotheses, and writing a research paper. Kardash concluded that the two sets of 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)

Although the study pointed out perceptions of learning, the study 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<sup>1</sup> 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 viewed scientific knowledge as distinct from data and provable. The only noticeable shift in this aspect of NOS from the early interview to the late interview involved an increased emphasis on the distinction between knowledge and

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<sup>1</sup> 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.

data and on empirical validation of claims. Students' views about the nature of lines of scientific inquiry also appeared to change under the influence of their research experience. Here, Ryder et al. found a marked increase in emphasis on theoretical guidance of scientific questions in students' statements between the early and later interviews. The authors were able to attribute this shift to respondents' informal interactions with graduate students and scientists and experiences with primary literature. Ryder et al. noticed 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 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. In turn, 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. Transcripts were coded for observations about student learning gains and other benefits as described by interviewees (there were no preconceived codes). 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%).

"Thinking and working like a scientist" encompassed students' practical and conceptual understanding of science and research. Most of these observations dealt with applying knowledge and skills through hands-on experiences. For example, students described gaining and using critical thinking and problem-solving skills as they solved research problems, analyzed data, and related theory to practice. However, as with Kardash's findings, students made far less mention of developing research questions and experimental design. Students did report developing greater knowledge and understanding of scientific theories and concepts, particularly as they developed presentations or taught others about their work. Only a small number of interview comments about greater knowledge or understanding (3% of this category) had to do with NOS (open-endedness, the nature of scientific "fact," science as "fallible," how scientific knowledge is built).

The category title, "personal-professional gains," reflects the student's perspective on developing an identity as a scientist. The major type of observation within this category (and the single largest set of gains in this study) had to do with students developing confidence, mostly in terms of conducting or contributing to real research. Students frequently couched their comments about confidence in terms of "feeling like a scientist" as members of the lab took them seriously, and as they presented or defended their research. Other observations in

this category referred to establishing collegial relationships with faculty and other URE participants.

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." This new category reflected the mentor's perspective on students developing attitudes and behaviors necessary for practicing science and coming to appreciate the nature of authentic research and professional science practice. It contained 20% of the faculty observations, compared to 12% of students', and included such elements as: intellectual engagement, responsibility for learning, ownership of the project, patience and perseverance, risk-taking and temperament. As Hunter et al. explained, faculty, (as science professionals) were able to recognize these qualities as important in the process of "becoming a scientist." However, Hunter et al. found that students were not yet able to make the link between these developments and professional science practice. Students viewed most of the developments categorized under "becoming a scientist" in terms of self-development and maturity, rather than in terms of professional development. For students, professional development, i.e. "becoming a scientist," had largely to do with confidence, as described above.

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 the research setting.

### **Epistemological and Critical Thinking and Undergraduate Research Experiences**

Seymour et al.'s (2004) and Hunter et al.'s (2008) description of the ways students benefit from participation in UREs transcend inquiry and science learning. Students gained critical thinking and problem-solving skills as they solved research problems, analyzed data, and related theory to practice. Students also developed attributes and behaviors indicative of intellectual and personal development. These findings relate to other studies focused on critical thinking and epistemological development.

Bauer and Bennett (2008) addressed critical thinking and epistemological development in URE vs. non-URE students in a multifaceted longitudinal study. These researchers administered a variety of instruments to 266 science undergraduates at the University of Delaware each spring for four years (retention rate of 81%). Among the instruments administered in this study were the Reasoning About Current Issues Test, a paper and pencil instrument designed to assess students' epistemological thinking (reflective judgment) in reasoning about ill-structured problems (King, Kitchener & Wood, 1991) and the Watson Glaser Critical Thinking Appraisal (Watson & Glaser, 1980), a measure of aspects of critical thinking about well structured problems (for example, inference, recognition of assumptions, interpretation, etc.). For the analysis, participants were grouped into three categories: no research experience, moderate levels of research, and intensive levels of research (this category includes participants in summer UREs). Bauer and Bennett found that although the total group of students showed a significant increase in critical thinking scores from freshman to senior year

of college, intensive researchers in biology, physics and chemistry showed a stronger increase than non-research students in these majors. Intensive researchers also showed greater gains than non-researchers in reflective judgment scores (ability to reason about ill-structured problems) from freshman to senior year that approached significance. Thus, Bauer and Bennett concluded that intensive research experience as an undergraduate can enhance students' intellectual development and learning in science.

In a paper presented at the 2001 PKAL Summer Institute, Rauckhorst, Czaja and Baxter Magolda (2001) used students' epistemological development to evaluate the summer research program at Miami University of Ohio. These authors administered the Measure of Epistemological Reflection (Baxter Magolda, 1992), a paper-and-pencil instrument, to two groups of undergraduate students matched on class rank: 50 summer URE participants and 41 summer students. URE students participated in research experiences across a variety of disciplines, including, but not limited to, the sciences. Both groups of students were assessed at the beginning and end of their summer experiences. Rauckhorst et al. found that 40% of the summer research students made progress in epistemological thinking, developing from transitional knowing (some knowledge remains absolute, whereas other knowledge may be uncertain) to independent knowing (all knowledge is held to be uncertain). None of the non-research students made this transition. Rauckhorst et al. compared these findings with Baxter Magolda's (1992) longitudinal study of undergraduates' epistemological development. Her findings showed that only 18% of undergraduate students progress to independent knowing by their senior year of college. Thus, these authors felt that their findings provided strong support that UREs can promote intellectual development. Although no descriptions of any of the summer experiences were provided in the paper, the authors found several commonalities among the students showing development: mutual development of a research project and

learning goals, clear communication of expectations, and a mid-term meeting to reassess learning goals and roles.

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), critical thinking (Bauer & Bennett, 2008) and understandings of two aspects of NOS and NOSI (Ryder et al., 1999); develop epistemologically (Rauckhorst et al., 2001; Bauer & Bennett, 2008); 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.

At the undergraduate level, there have been only limited attempts to link any of the aforementioned gains to the depth of engagement with inquiry, or interactions that occur between undergraduate researcher and mentor. We learn very little from the literature reviewed about what students and mentors actually do as they conduct their research that might help to explain gains in or lack of gains, in science learning and epistemological development.

## CHAPTER 3

### Theoretical Frameworks

#### Introduction

Undergraduate research experiences are apprentice-style learning experiences in which students learn domain-specific cognitive and inquiry skills as they engage with authentic aspects of research, interact with a mentor, and participate in the research community. Learning in such a setting can be framed by social constructivist theories of learning, development and scientific practice: learning the nature of scientific inquiry, the nature of scientific knowledge, and epistemological and critical thinking within a community of practice.

#### **Inquiry, Nature of Science and Nature of Scientific Inquiry**

##### **Understanding Inquiry in Science Education**

The American Association for the Advancement of Science established scientific literacy as a central goal in science education in their reform publication, *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.” Both the nature of scientific inquiry (NOSI) and the nature of scientific knowledge (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; as they do so, 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).

A focus solely on *abilities* associated with doing inquiry may fail to acknowledge how important it is for learners to understand scientists’ rationales for doing these various activities (Bybee, 2000). Such a focus also undervalues the cognitive skills necessary for inquiry.

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.

### **Understanding Authentic Scientific Inquiry**

Scientists engage in a wide variety of activities to address different kinds of questions and problems using reasoning and logic. The diversity of activities and problems means that it is difficult to prescribe a single method to scientific work. Yet many students and educators understand the process of scientific investigation as The Scientific Method (TSM), a six-step formula for scientific success: “observe, develop a question, develop an hypothesis, conduct an experiment, analyze data, state conclusions, generate new questions” (Windschitl, Thompson &

Braaten, 2008). Indeed, many introductory courses and textbooks for undergraduate science still teach TSM. This limited view of inquiry over-emphasizes the role of experimentation and hypothesis falsification and de-emphasizes the flexible and open nature of authentic scientific inquiry. It is important for students to learn that in reality, scientists use a variety of rigorous methods to construct knowledge about the natural world, including experimentation, but also description, exploration, modeling, studying records of the past; and that scientists use both inductive and deductive reasoning to solve both empirical and conceptual problems (Finley & Pocoví, 2000). The process, also, is less linear than TSM presents, and much more iterative.

Many science education researchers promote a model-based view of inquiry to challenge TSM. In science, models are explanations of phenomena, representations produced through analogic reasoning that simplify the natural world such that it can be mentally manipulated (Gilbert, Boulter & Rutherford, 1998). The modeling process begins with creating a theoretical structure, a tentative mental or material model of the phenomenon. Theory, as the lens through which the world is viewed, guides the selection and use of evidence to formulate explanations. The model “stands between” the theory and the data, influencing cross-talk between them (Duschl, 2005). Viewing inquiry in this way is to view it as a dialectic between theory and evidence in the formulation of explanations, rather than a linear process that progresses in an orderly way from data to theory.

Viewing scientific inquiry as building, testing and revising models also emphasizes the critical roles of scientific reasoning, reflection and argumentation in the process of knowledge construction in authentic scientific research. Chin and Malhotra (2002) adopt this view in their description of the types of reasoning involved in authentic scientific inquiry tasks. For example, scientific inquiry involves synthesizing the research of others to develop one’s own theoretical framing of research questions and scientists must employ strategies for interpreting and

coordinating disparate, sometimes conflicting results and for choosing between viable theories as they develop their understanding of the underlying explanatory mechanisms. Scientists must also make informed decisions in selecting from among multiple variables, controls, measurements and procedures that will influence the generalizability and validity of their results. The task of explaining results requires that scientists recognize perceptual bias, search for flaws in their thinking and methods and make inferences in the transformation of data into evidence. Scientists must be able to integrate their explanations for phenomena with their developing theoretical model, making revisions when necessary and coordinate their developing model with those proposed by other scientists to demonstrate its validity.

Sociological studies of scientists at work also represent the doing of science as an iterative and often messy process, more like “tinkering and reckoning” (Golinksi, 1990) or “resistance and accommodation” (Pickering, 1995; see also Collins, 1992; Delamont, Atkinson & Parry, 2000; Nersessian, Kurz-Milcke, Newstetter & Davies, 2003). Furthermore, these scholars maintain that the outcomes of scientific investigations are far more open-ended than finite. The research of Latour and Woolgar (1979), Lynch (1985), and Collins (1992), have demonstrated how outcomes of scientific investigations are resolved not only by reference to data, but also through rhetorical and other social practices among scientists and their critics.

When we look at the practice of science considering the above factors, it is clear that consideration of the advanced cognitive skills that are clearly necessary for authentic inquiry, such as coordinating multiple theoretical perspectives, evaluating competing claims and theories, reflecting on the influences of one’s own biases and reasoning, are completely absent in TSM. Windschitl *et al.* (2008) make this point in arguing that teaching scientific investigation as TSM obviates the need for students to actually think as they conduct their investigations. For students of science to develop these cognitive skills, they need opportunities to practice them.

It is therefore crucial that students learn about how science inquiries are done as they practice a more accurate representation of authentic scientific inquiry. In this way students can develop more than simple understandings of scientific steps, but also reasoning and reflective skills important in building understandings about NOSI and NOS.

### **The Natures of Scientific Inquiry and Scientific Knowledge in Science Education**

Because NOSI and NOS are closely related, overlapping and often confused, it is important to distinguish clearly between the two. Abd-El-Khalick, Bell and Lederman (1998), Lederman, Abd-El-Khalick, Bell and Schwartz (2002), and Schwartz (2004) have conceptualized working definitions of both of these constructs in order to clarify their meaning and implications for science education and research. Scientific *inquiry* refers to the processes whereby scientific knowledge is produced, and includes scientific reasoning (Chin and Malhotra, 2002) and critical thinking skills (Kuhn, 1999) as much as process skills (abilities to do inquiry, NRC, 1996). The *nature* of scientific inquiry resembles the nature of model-building within a community of practitioners and is addressed in the “important understandings *about* scientific inquiry” sections of the reform literature. Schwartz (2004) has synthesized a framework that highlights the general aspects of NOSI most relevant to science education and around which there is consensus in the literature (building on *Science for All Americans, The Standards*, science education research and sociological studies of science):

The general aspects of nature of scientific inquiry include: a) multiple methods of scientific investigations, b) multiple purposes of scientific investigations, c) the form and role of argumentation in the development and acceptance of new knowledge, d) recognition and handling of anomalous data, e) sources, roles of, and distinctions between data and evidence, and f) community of practice. (p. 10)

Nature of science refers to science as a way of knowing and the system of values and beliefs within which scientific knowledge is constructed and validated (Lederman & Niess, 1997; Abd-El-Khalick *et al.*, 1998). Therefore NOS reflects the social epistemology of science and is

grounded in sociology, philosophy and history of science, and is reflected in the “History of Science” section of *The Standards*. Although Abd-El-Khalick *et al.* note that there is no consensus on a specific NOS<sup>1</sup>, there seems to be consensus around these seven aspects of NOS most relevant to science education:

Scientific knowledge is tentative (subject to change); empirically based (based on and/or derived from observations of the natural world); subjective (theory-laden); partly the product of human inference, imagination and creativity (involves the invention of explanation); and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between scientific theories and laws. (p. 418)

The discussion of authentic scientific inquiry above helps to demonstrate how facets of NOSI and NOS interact and overlap. For example, understandings about the myth of TSM are important to both. Another example is that scientific knowledge is inherently tentative because it is based on empirical evidence (Schwartz & Lederman, 2008) as interpreted through the model used at the time. Evidence, then, represents the product of both analysis and interpretation, each of which are influenced by the underlying theoretical model, current perspectives of the scientific community, and the scientist’s personal history, preferences and values. For the same reason, scientific knowledge should be considered theory laden and subjective. Scientific knowledge should also be viewed as socially and culturally embedded, in part because of the rhetorical practices involved in establishing a knowledge claim within the scientific community and in part because the laboratory and its tools are social constructs nested within overlapping socially constructed worlds (Knorr-Cetina, 1983). The larger social world of science is itself nested within a broader community in which economic, political and historical forces have influence.

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<sup>1</sup> It is for this reason that the word “the” is traditionally omitted before “NOS.”

Clearly, in order to fully grasp the facets of NOSI and NOS at the level where their interactions and implications can be understood and applied, learners must employ sophisticated cognitive skills. Therefore, at the undergraduate level, it is not only important for students to learn about these aspects of the scientific endeavor through experiences that model authentic inquiry, it is also important that these experiences be structured in ways that develop the critical thinking and epistemological thinking necessary to reflect upon, process and apply these understandings.

### **Social Constructivist Perspective on Learning**

The recommendations for viewing inquiry as a social practice, and the practice of inquiry as a context for developing both skills and understandings about the scientific endeavor draw from social constructivist theories of how people learn. A social constructivist perspective on learning places the learner, with her own internal, cognitive processes, within a learning community where both knowledge and learning are socially mediated. Thus, social constructivist theory has its roots in both the constructivist learning theory of Jean Piaget, and the cultural-historical theoretical perspective of Lev Vygotsky.

As described by Beilin (1992) and Fosnot and Perry (2005), neoPiagetian theory focuses on the learner's accommodative processes – those reflective and integrative cognitive processes that occur as the learner attempts to assimilate new information, especially when confronted with information or situations that are incongruent with her prior experiences and current thought structures. In this view, development drives learning; learning is dialectic between the individual's extant cognitive structures and her environment. Though the learner is the active creator of her knowledge through her own constructive processes, the environmental surround of the child is of equal importance and extends beyond objects to include social interactions, constructs and cultural influences.

The theoretical focus on the social dimensions of cognitive development has its roots in the writings of Lev Vygotsky. Vygotsky believed that children acquire psychological tools that, once internalized, can become the learner's inner cognitive tools for organizing higher cognitive functions. Psychological tools are human constructs, symbolic schemes with a specific socio-historical context, for example language, signs, symbols and text. Learners acquire and internalize these tools through processes mediated by other symbolic systems (such as structured learning activities) or humans (older peers or teachers) (Kozulin, 2003). In the appropriation and subsequent application of these now cognitive tools, the learner develops higher order thinking skills and processes. Thus in this view, learning drives development.

One of Vygotsky's most productive ideas was the zone of proximal development, which can be thought of as a zone into which the learner has the potential to develop, though not yet on her own. The learner can be prompted to penetrate and encouraged to cross the zone by guidance from a more knowledgeable collaborator. The zone of proximal development can also be thought of as a psychological "space" where the learner's preconceptions about the world, her independent and spontaneously formed knowledge, can be drawn out and built up to meet the more formal and systematic "adult" knowledge of the culture (Chaiklin, 2003). Within the zone of proximal development, then, the learner interacts with more-knowledgeable others, older peers and adults, to reformulate her spontaneous knowledge and co-construct the meanings of "scientific" knowledge and the contours of socio-cultural tools. In this way her knowledge, cognitive skills and processes are elaborated in ways that align with the conventions of her community; "Socially constituted cognitive activity is individual thinking that has embedded within it the contributions of the social world" (Gauvain, 2001, p. 41).

Rogoff described the social interactions within the zone of proximal development as an enculturation process, an "apprenticeship in thinking" where "both guidance and participation

in culturally valued activities are essential” to learning and cognitive development (Rogoff, 1990). Similarly, Brown, Collins and Duguid (1989) use the term cognitive apprenticeship to emphasize both the learning of cognitive skills and the enculturating experiences through which they are learned. Thinking of learning as a cognitive apprenticeship emphasizes the active role of the learner as she participates in learning activities, as well as the active role of her guide in structuring learning activities. In an apprenticeship, a newcomer to a community of practice learns the concepts, skills and procedures of the community through guided participation in domain specific activities. At first the work of the novice is peripheral and scaffolded by more knowledgeable and skilled members of the community. As the novice gains in proficiency, she progresses from peripheral participation toward fuller participation and greater independence (Lave & Wenger, 1991). Using this apprenticeship metaphor for learning allows us to focus on three integrated planes of socio-cultural interaction: the community of practice, the novice-mentor dyad and the individual’s development through practice (Rogoff, 1990). All three of these planes of interaction are evident in the URE as a science apprenticeship.

If the purpose of undergraduate research is to provide students a scientific inquiry experience in an authentic research setting, then the URE serves as the context for the learner to practice and internalize the cognitive and practical skills involved in scientific research. Within this context, the learner’s activities are mentored by an expert already initiated in the practices of the scientific community. Therefore, a URE can be a cognitive apprenticeship if the student’s participation is considered legitimate work by members of the community in which it is practiced, and if the work is scaffolded by the mentor in ways that promote both cognitive and practical skills. Such an experience would permit students opportunities to actively engage in authentic, mentored inquiry activities in which they learn *to do* inquiry skills such as experimental design and implementation of procedures as well as reasoning, critical thinking

and other scientific problem solving skills, and *about* the socio-cultural aspects of specific laboratory and more general scientific practices.

### **Epistemological Development in the College Years**

The social-constructivist theoretical framework holds that it is the dialectic between cognitive and social processes that drive cognitive development. A related line of theorizing examines how learners develop understanding of how knowledge claims are made, supported, and evaluated. Research examining the epistemological development of college students finds that learners experience significant shifts in their conceptions of the nature of knowledge and learning during college. Learner's personal theories about the nature of knowledge and knowing evolve in relation to higher cognitive skills like problem solving strategies, metacognition and critical thinking, which themselves evolve over time and through practice (Kuhn, Amsel & O'Laughlin, 1988). Therefore, a student's epistemological development is likely to influence her understanding of NOSI and NOS as social practice and social epistemology.

The earliest work on personal epistemological development was conducted by Perry in the 1950's and was grounded in Piagetian theory. This pioneering study resulted in a scheme of development during the college years involving nine epistemological positions. These fall into four general phases along a continuum ranging from a dualistic view of the world as containing either good/bad or right/wrong information, to a more pluralistic view of the world where an individual must make his own commitments in matters of truth and values. Perry's scheme serves as the foundation for many of the stage models that came after, particularly Baxter Magolda's (1992) Epistemological Reflection Model, discussed below. Perry believed that college students transition from one stage to the next as they are confronted by new ideas, alternative views and ways of thinking through their interactions with peers, professors, and the nature of their academic work. He used the metaphor of opposing forces in describing his

subjects' attempts to balance internal drives to progress, with the need to conserve what is safe and stable within the self. Perry stressed the need for both detachment from the self and metacognitive work in making progress. Discovering how to "think about thinking" and having the courage to take responsibility "from outside to inside" the self were two critical points of passage for his subjects (Perry, 1968).

Perry's work, which focused on undergraduate men, was expanded by that of Belenky, Clinchy, Goldberger and Tarule (1986), which focused on college-age women. The latter work discovered that learners can take two different orientations, or stances, toward knowing in the post-dualistic stages of epistemological development. Connected knowers take an interpersonal or cooperative approach to knowledge and knowing, whereas separate knowers take a more impersonal or independent approach. Belenky *et al.* did not assert that women prefer one orientation and men another – members of both gender may lean more heavily toward one orientation than the other, and the direction of their leaning may depend on context. In the final stage of their model, the two orientations merge in a form of "dialectical thinking."

Baxter Magolda's work in the 1980's integrated and expanded on that of Perry (1968) and Belenky *et al.* (1986). Baxter Magolda studied both college-age men and women and attended specifically to their beliefs about knowledge, learning, instruction and evaluation in college classrooms. Her Epistemological Reflection Model describes a developmental sequence very similar to Perry's, where students progress from believing in the *absolute* certainty of knowledge and absolute authority of experts, through a *transitional* phase where some knowledge remains absolute (notably scientific knowledge) and other knowledge may be uncertain, to an *independent* phase where all knowledge is held to be uncertain, leading finally to *contextual* knowing where knowledge claims must be supported by evidence and what one believes depends on the context. By studying both young men and women, Baxter Magolda

uncovered two gender related (though not gender specific) orientations at each of the four stages. Absolutists took either a receiving orientation toward knowledge (more common to women) or a pattern oriented towards mastering knowledge (more common to men). In later stages, more women took an interpersonal or interindividual approach similar to Belenky *et al.*'s connected knowing; whereas more men took an impersonal or individual approach, similar to Belenky *et al.*'s separate knowing.

Another important aspect Baxter Magolda's work is that she followed her subjects beyond graduation from college (neither Perry nor Belenky *et al.* felt they had enough subjects at the most advanced stage of their models for full characterization). Baxter Magolda found contextual knowing in many of her post-college subjects. And, as Belenky *et al.* described in their latest stage, Baxter Magolda's contextual knowers came to integrate the two gender-related patterns, drawing on each as deemed necessary to address the challenges of adult life. Contextual knowers have come to realize that they need to take responsibility in deciding what to believe and pass through two phases before developing an internally generated belief system. Early contextual knowers rely on external formulas to make decisions. Later contextual knowers begin to search for internal authority. This search ultimately leads to establishing an internal foundation for belief by the late 20's and early 30's (Baxter Magolda, 2002). This final phase in Baxter Magolda's model also reflects elements of Perry's final stage:

Developing this internal belief system also required a shift in the intrapersonal and interpersonal dimensions of development (Baxter Magolda, 1999). To adopt and act on internally derived beliefs, participants needed a coherent sense of self that could be influenced but not overwhelmed by others' perceptions and approval. (Baxter Magolda, 2002; p. 99)

Baxter Magolda attributed this final shift to the nature of post-college life. Advanced education, managing the responsibilities and challenges of the professional world, and complex relationships all challenge the self in ways that are structurally different from the typical

challenges raised in the setting of undergraduate education with its emphasis on socialization. The dissonances brought about by the complex challenges of post-graduate life require an internal system for self evaluation (Kegan, 1994). Baxter Magolda and Kegan both view this shift to an internally generated belief system as the foundation for self-authorship:

This new whole is an ideology, an internal identity, a *self-authorship* that can coordinate, integrate, act upon, or invent values, beliefs, convictions, generalizations, ideals, abstractions, interpersonal loyalties, and intrapersonal states. It is no longer *authored* by them, it *authors them* and thereby achieves a personal authority. (Kegan, 1994; p. 185)

### **Relation of Epistemological Thinking and Critical Thinking**

Metacognition plays a central role in the aforementioned models of epistemological development and is the key to advanced epistemological and critical thinking (Kuhn, 1999). The epistemological stage model of King and Kitchener (1991), the Reflective Judgment Model, explores this link very clearly. This model emphasized how the forms of justification that people employ change as they develop in their cognitive processing abilities. It describes the same developmental sequence discussed above, but carves it into seven different stages that group into three clusters: pre-reflective, quasi-reflective and reflective judgment. To uncover subjects' epistemic thinking, King and Kitchener used ill structured problems, "problems about which 'reasonable people reasonably disagree'" (King & Kitchener, 2002) - problems analogous to those that Baxter Magolda's subjects encountered for the first time in ways that mattered (in other words solution of these problems were of consequence to their daily lives) in their post-college years.

The first level of cognitive processing, pre-reflective thinking, involves basic processes such as memorizing and computing – basic cognition. Pre-reflective thinkers (absolutists) treat all problems as well-structured, well defined and solvable because they know with certainty and what they know is certain; they question neither knowledge claims made by others nor their

own meaning making. The second level of cognitive processing, quasi-reflective thinking, involves the ability to monitor the basic cognitive processes, i.e. metacognition. Quasi-reflective thinkers (Perry's transitionalists and Baxter Magolda's independent knowers) accept that knowledge is uncertain, but believe that the uncertainty arises from having incomplete information or faulty methods for collecting evidence:

Although they use evidence, they do not understand how evidence entails a conclusion (especially in light of the acknowledged uncertainty) and thus tend to view judgments as highly idiosyncratic. (King & Kitchener, 2002, p. 40)

The third level of cognitive processing is the ability to be metacognitive about the limits, certainty and criteria of knowing, skills that "allow individuals to monitor the epistemic nature of problems, such as whether they are solvable and the truth value of different solutions" (King & Kitchener, 2002, p. 38). Reflective thinkers (contextualists) are comfortable with the uncertainty of knowledge claims and their justification. They believe that they are responsible for constructing judgments and evaluating knowledge claims and justifications within contexts and situations. Having the ability to be metacognitive about one's epistemic thinking (epistemic cognition) is the culmination of the Reflective Judgment Model and it is similar to the notion of self-authorship.

Metacognitive processing also plays a central role in Kuhn's (1999) thinking about epistemological development. Her model of epistemological development focuses on the coordination of the subjective and objective dimensions of knowing and relates their coordination to critical thinking. As we have seen in the summaries of the various models described above, epistemological development progresses from a state where the objective dimension of knowing dominates (*absolutist* epistemology: assertions are either copies of reality or factual representations of reality), through a state where the subjective dimension dominates (*multiplist* epistemology: assertions are opinions), to a final state where the two are

coordinated and balanced and assertions are considered judgments to be evaluated based on criteria and evidence (*evaluativist* epistemology).

As Kuhn explains (1999), in the *absolutist* epistemological state, knowledge is viewed in objective terms, is located in the external world and is knowable with certainty. Evaluation for the absolutist involves either direct observation or consultation with an authority. Thus, evaluation of assertions against some standard of truth requires simple critical thinking skills. These elementary skills can serve as the foundation for more advanced skills later in development, though demands upon these skills at this stage are minimal. Most people, particularly college students, progress to a *multiplist* epistemological level as they discover the subjective nature of knowledge. Here beliefs are opinions and, as Perry put it (1968), “everyone has the right to their own opinion.” Though reality is considered directly knowable at this stage, knowledge is constructed by people and therefore uncertain. Thus, the most compelling basis for evaluating a judgment is its persuasive power. This mind-set renders critical thinking moot! Consider that Kuhn’s research suggests that many people remain at this level of epistemological understanding for life.

Some people do press onward to the *evaluativist* epistemological level. The evaluativist, in integrating and coordinating the objective and subjective dimensions of knowing, reconciles differences of opinion with the understanding that some opinions are more valid than others. Judgments of validity are made by evaluating assertions against criteria of argument and evidence.

[Evaluativists] see the weighing of alternative claims in a process of reasoned debate as the path to informed opinion, and they understand that arguments can be evaluated and compared based on their merit. (1999; p. 22)

In other words, evaluativists think critically. In Kuhn’s argument, epistemological thinking *is* a form of metacognition because it reflects upon what one knows and how one

knows it to be true, and sophistication of both forms of cognition make critical thinking possible. Her view is different from conventional wisdom in that it is developmental. Critical thinking, rather than being a set of mental competencies to teach and learn, develops throughout the lifespan as metacognitive abilities emerge, strengthen and evolve.

The work summarized above indicates that college students make some progress along the same general trajectory, but the highest level of development in epistemological thinking tends not to emerge during college but in later years, if at all. Therefore it seems that on average, college students can be expected to transition through phases of cognitively coping with the uncertain nature of knowledge and the “fall” of expert authorities. Only some of them can be expected to enter into a phase where they grasp the situated and contextual nature of knowledge and become savvy in using domain-specific rules or evidence to judge knowledge claims.

### **Epistemological Development, Inquiry and NOS**

In *Creating Contexts for Learning and Self-Authorship* (1999) Baxter Magolda made an explicit link between learning through inquiry and developing epistemologically. She has identified three principles common to education experiences that foster students’ epistemological development: “validating students as knowers, situating learning in students’ own experiences, and defining learning as mutually constructed meaning” (p. 64, 1999). In her view, as a social constructivist approach to teaching, inquiry can address each of these principles. Through inquiry, students can gain personal experience with the social construction of knowledge claims as they co-construct new knowledge with mentors and peers. The understandings that students hold for this new knowledge are situated in the experience of crafting it.

Higher levels of epistemological thinking permit one to balance multiple perspectives

judiciously, to decide for one's self what to believe based on criteria of reasoned argument, and therefore to think critically. Inquiry can provide the context for exercising, strengthening and perhaps elaborating these cognitive abilities. As these abilities develop, students become better able to engage in independent inquiries that can lead to meaningful outcomes, including fundamental understandings about NOSI and NOS.

NOSI and NOS are complex and multifaceted constructs that reflect socially constructed practices and social epistemology. It may not be possible for a student whose personal epistemology views knowledge as a photocopy of a certain and knowable external reality, to comprehend scientific knowledge as tentative and subjective because it is based on empirical evidence, which is itself a product of both an individual's creative interpretive processes and a socially negotiated theoretical framework. Such students may easily grasp that scientific knowledge is based on evidence and that it is tentative because sometimes people, especially students, are wrong, without being able to distinguish between or coordinate theory and evidence, observation and inference. The key to developing and holding correct understandings about NOSI and NOS lies in the interacting influences of inquiry practice, metcognition and epistemological thinking. A student who can make her own evaluative judgments (because her life/educational experiences have made it necessary and important for her to do so) about conflicting or equally reasonable competing claims, is in a much better position to apprehend the contextual, tentative, constructed nature of scientific knowledge and the flexible nature of scientific inquiry.

### **Sociology of Science: Science Studies**

The sociological study of science explores the social construction of scientific knowledge, practices and tools. The social constructivist epistemological stance views scientific inquiry as an indeterminate, constantly changing practice, rather than a system for describing

the natural world as it really exists (Knorr Cetina, 1983). Sociological studies of scientists at work have provided a number of useful analytic tools that can be applied to the study of learning through laboratory practice; the notions of black boxes, tacit knowledge and the mangle of practice are key among these.

Latour and Woolgar (1979) emphasized the importance of literary inscriptions in scientific practice in their ethnographic study of scientists at work. Literary inscriptions are documents of all kinds (from data traces to standard curves to primary literature) used by scientists to persuade colleagues to accept some claim, ultimately to become taken for granted fact. The processes leading to the construction and general acceptance of a scientific fact are together a process of reification through which the whole package may eventually become a material, taken for-granted object in another laboratory. Latour and Woolgar concluded that scientists are primarily occupied with this activity of creating black boxes,

of rendering items of knowledge distinct from the circumstances of their creation...Once an item of apparatus or a set of gestures is established in the laboratory, it becomes very difficult to effect the retransformation into a sociological object. (1979, p. 259)

The expensive and time consuming processes involved in the creation of black boxes, of widely accepted practices, causes them to be expensive and time consuming to re-open. It is precisely this nature of “black boxification” that solidifies the knowledge claim as an uncontested fact.

Much of what the novice encounters in a modern research laboratory is a black box: theories, inscription devices and other instruments, standardized procedures and lab animals. An important question in training novices is when to open the black box in order to foster understanding of its make-up, and when to keep the black box closed in order to facilitate work progress. Neresessian *et al.*'s (2003) study of biomedical engineering students at work in the laboratory described how learning can occur when a novice forms a “cognitive partnership” with a laboratory device. To the novice, the device can at first be merely a black box to be mastered.

Gradually, however, a student may begin to question the assumptions inherent in the black box, tinker with its construction, and test ideas, the device becomes a cognitive tool to be used in answering scientific questions.

Another powerful idea that developed from studies of scientists at work was the importance of tacit knowledge in solving complex scientific problems. The role of tacit knowledge in scientific work was first developed by Polanyi (1958). Polanyi, a trained chemist, viewed research as an artful process that could not be fully articulated by rules. He felt that research skills are craft skills and can only be learned through imitation and experience and require a close association with a master. In studying the information transactions between scientists working in different labs to construct their own particular apparatus, a TEA laser, Collins found that tacit knowledge was crucial in a scientist's ability to produce this complex piece of equipment (1992). Published accounts of the laser's design were not sufficient. Personal contact with others who had successfully constructed their own TEA laser was required for a person to develop his own TEA laser. Collins (2001) has since identified five categories of tacit knowledge in the practice of science: 1) knowledge that is concealed for various reasons; 2) knowledge that is mismatched in terms of what variables and questions are salient to different parties; 3) ostensive knowledge that can be better conveyed through demonstration than text or figures; 4) knowledge whose importance is unrecognized by the experimenter; and 5) knowledge that one is unaware that one has and uses.

Developing tacit knowledge in learning and executing research skills is a common theme across the small body of literature dealing with undergraduate and graduate students' enculturation into science practice. For example, Delamont, Atkinson and Parry (2000) strongly implicated tacit knowledge in graduate students' abilities to overcome uncertainty and in their identity development. Though some forms of tacit knowledge cannot be taught, or even

articulated, and hence must be “grasped and intuited” rather than “taught and caught” (Delamont & Atkinson, 2001, p. 100), others can be shared directly between old-timers and novices. Roth and Bowen (2001) described the importance of direct transmission of tacit knowledge for novice field ecologists who spend little time in the company of others from whom they can “grasp and intuit” wilderness survival skills, for example.

Of most relevance to this research, Fujimura applied the ideas of the black boxes and tacit knowledge to the standardized packages common to modern molecular laboratories. A standardized package is a bundle of theory, technology and methods that is highly transferable between lines of research, laboratories and scientific fields (Fujimura, 1988). Standardization is a simplification process that essentially black-boxes a technique’s history of development and reduces the tacit knowledge requirements and inherent uncertainty in its use (Star, 1983). For example, standardization of recombinant DNA technology has resulted in the production of pre-fabricated kits of materials, recipe-like protocols, and instruments for automating many processes, transforming what was once cutting edge science into routine laboratory practices. These innovations made recombinant DNA technology highly transferable between laboratories and subdisciplines by reducing tacit knowledge requirements, but also discretionary decision-making and trial-and-error work. This reduced the amount of training, need for specialized skills, and costs. Fujimura found that the standardized package of recombinant DNA technology was especially advantageous for students and beginning researchers as a pathway into the “hot” and productive new fields in which to build their scientific careers.

The discussions above highlight the importance of working with and learning from material objects in science practice (though not all black boxes are material and not all tacit knowledge has to do with material objects). Material agency is central to Pickering’s conceptualization of science practice as cultural work. Pickering (1995) defined scientific culture

as “the ‘made things’ of science...skills and social relations, machines and instruments, as well as scientific facts and theories” and scientific practice as “the work of cultural extension and transformation in time” (1995, pp. 3-4). Pickering argued that material agency inevitably and unpredictably emerges as humans engage with materials in their practice:

...problems always arise and have to be solved in the development of, say, new machines. And such solutions – if they are found at all – take the form, at a minimum, of a kind of delicate material positioning or *tuning*, where I use ‘tuning’ in the sense of tuning a radio set or car engine, with the caveat that the character of the ‘signal’ is not known in advance in scientific research. (1993, p. 374)

Pickering described this “tuning” as a dance between human and material agencies,

*a dialectic of resistance and accommodation*, where resistance denotes the failure to achieve an intended capture of agency in practice, and accommodation an active human strategy of response to resistance, which can include revisions to goals and intentions as well as to the material form of the machine in question and to the human frame of gestures and social relations that surround it. (author’s emphasis, 1995, p. 22)

It is this dialectic of resistance and accommodation that characterizes science practice for Pickering. It is a cycle of human passivity while the machine (for example) performs (or fails to), followed by human agency in making adjustments to the machine or in altering goals. Both material and human agency are emergent in this process; for example, goals are re-oriented in response to material resistance. Pickering used the metaphor of the mangle, a device into which one places wet laundry in order to squeeze the water out of it.

The “mangle of practice” is Pickering’s metaphor for cultural change in science: the emergent nature of human and material agencies in real-time science practice. It is also a description of a process of mental modeling, similar to that practiced by Nersessian *et al.*’s biomedical engineering students who put ideas into a device on the bench top to see if those ideas work. It describes a learning process, a cognitive partnership, in which tacit knowledge,

reasoning skills and scientific knowledge are produced through interactions with objects in the laboratory.

## CHAPTER 4

### Research Design, Method, and Data Analysis

#### Introduction

My aims in undertaking this research were two-fold: to describe what students learn, and to explain some factors that appear to contribute to learning, through participation in mentored, laboratory research. The aspects of student learning upon which I focused were: practicing scientific inquiry, developing understandings about NOS and NOSI, and developing epistemologically. In considering how students were learning through research, I looked for: relationships among these elements of interns' learning, interactions between intern and mentor in the laboratory, and relationships between interns' prior inquiry experiences and their experiences in this URE.

#### Research Questions

The specific questions guiding the collection and analysis of data in this research project fall into two categories: descriptive questions addressing student learning gains, and explanatory questions addressing the means by which this learning occurred, or reasons why learning may have failed to occur.

##### Descriptive questions about 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?
3. What gains, if any, did interns make in their epistemological thinking?

Explanatory questions about how interns develop understandings:

4. In what ways, if any, did these aspects of interns' learning (questions 1-3 above) interact?
  - a. Did practical experience relate to understandings about NOS, and NOSI, or epistemological development?
  - b. Did epistemological thinking relate to developing understandings about NOS and NOSI?
5. 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 Research Experience for Undergraduates in the field of plant biotechnology and genomics. The Summer Internship Program (hereafter referred to as the Program) is now in its seventh year and is administered by a highly regarded Research Institute located on the campus of a Research University with very high research activity (RU/VH)<sup>1</sup>. The research conducted at the Institute is at the forefront of its field, employing sophisticated research tools and cutting edge techniques in a highly collaborative and international environment. The goals of the Program, according to its website, are 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."

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<sup>1</sup> Carnegie Classification

I chose this site for two reasons. As part of a program evaluation, I not only had access to the site, but also had the opportunity to pilot and revise data-gathering instruments and procedures during two summers prior to the actual research study (2007-2008). Secondly, 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. As lab members they could observe the current problems in the field, how these break down into testable questions, and how research tools are matched to research questions. Interactions with lab mates provided opportunities for implicit and explicit messages about the realities of scientific research and the nature of graduate training. 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). Furthermore, each laboratory setting was unique, and the specific nature of the research project and relationship between intern and mentor was left to the discretion of the laboratory, most frequently the mentor. This resulted in a wide variety of UREs within the Program, offering a breadth of cases in which to investigate my research questions.

In addition to the laboratory work, interns engaged in a variety of academic activities: they attended lab meetings; wrote a research proposal; attended weekly seminars involving on-going research at the institute; attended workshops on ethics, graduate and career opportunities; and presented their research in a student symposium open to the campus community. Interns also participated in a variety of social events and lived communally on

campus. There were ample opportunities for formal and informal discussions with peers, graduate students and scientists about fields of study, graduate school, careers and the scientific life-style. Thus, the Program provided a diversity of opportunities for learning inside and outside the laboratory and a rich context in which to investigate student learning.

### **Laboratory Organization**

Laboratories involved in the Program belonged to the Research Institute or its affiliated departments within the University and had similar organizational structures. Each was headed by an established scientist, a Primary Investigator (PI). As the laboratory's head, the PI determined the laboratory's research goals and helped lab members develop their own research agendas that aligned with the overarching work of the laboratory. The PI supervised the postdoctoral researchers and research assistants<sup>2</sup>, and was the academic and research advisor for the graduate-student members of the lab. Postdoctoral researchers and research assistants also played a role in supervising and mentoring graduate and undergraduate students in the laboratory. Undergraduate lab-members were either interns conducting mentored research or lab workers hired to conduct the routine support work of the lab, for example cleaning glassware, disposing of laboratory waste, maintaining stock solutions. The number of laboratory personnel varied between labs, depending on the number of active grants, how long the lab had been established, and fluctuations in the graduate student population. PI's whose labs were newly established, tended to have fewer postdoctoral researchers and graduate students, and tended to conduct their own research at the bench. More established PIs tended to have more lab personnel and did little, if any, bench-work, focusing more on supervisory and administrative duties.

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<sup>2</sup> Research assistants at the Institute are research personnel who are not graduate students and have not obtained their PhD.

## Participants

### Interns

The program supported 15 – 20 interns each summer, selected from a pool averaging 300 applicants. As an NSF Research Experience for Undergraduates, 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 4.1). 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 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

**Table 4.1: Interns Participating in the Summer Internship Program 2009.** Bold text indicates interns who participated in field observations.

PSEUDONYM	YEAR (rising)	SEMESTERS* PRIOR RESEARCH	URM <sup>†</sup>	MAJOR	HOME INSTITUTION CARNEGIE CLASSIFICATION <sup>‡</sup> (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
<b>Heather**</b>	<b>So.</b>	<b>0</b>		<b>Plant Sci</b>	<b>Research University (VH)</b>
<b>Wanda**</b>	<b>So.</b>	<b>0</b>		<b>Biology</b>	<b>Research University (VH)</b>
Todd	So.	3		Biochem	Doctoral/Research University
Betty	Jr.	0		Genetics	Research University (H)
Claire	Jr.	1.5		Biology	Baccalaureate College
<b>Elliot</b>	<b>Jr.</b>	<b>3</b>		<b>Biology</b>	<b>Baccalaureate College</b>
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
<b>Shanell</b>	<b>Sr.</b>	<b>0</b>	<b>X</b>	<b>Biology</b>	<b>Master's University (smaller)</b>
<b>Vicky</b>	<b>Sr.</b>	<b>1</b>		<b>Biology</b>	<b>Research University (H)</b>
<b>Jake<sup>§</sup></b>	<b>Sr.</b>	<b>1.5</b>		<b>Biology</b>	<b>Associate's (large rural)</b>
Gene	Sr.	2		Biochem	Baccalaureate College
Hans	Sr.	2		Biology	Baccalaureate College
Helen	Sr.	4		Biochem	Research University (VH)
<b>Monique</b>	<b>Sr.</b>	<b>6</b>	<b>X</b>	<b>Biology</b>	<b>Master's University</b>
<b>Quinn</b>	<b>Sr.</b>	<b>5</b>		<b>Biology</b>	<b>Research University (H)</b>
Ricky	Sr.	7		Biology	Research University (H)
Eddie**	Postbacc	1		Biology	Master's College
Minnie**	5 <sup>th</sup> yr. Sr.	4		Pre-Vet	Master's University
<b>Taylor**</b>	<b>5<sup>th</sup> yr. Sr.</b>	<b>4</b>		<b>Biochem</b>	<b>Master's University</b>

\* Summer research experiences were counted as one semester.

<sup>†</sup> Students from minority groups underrepresented in US science.

<sup>‡</sup> Carnegie Classification (<http://classifications.carnegiefoundation.org/descriptions/>)

<sup>§</sup> 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 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 4.2).

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.

My pilot work revealed the importance of the mentor's role in determining the intern's experience. 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

**Table 4.2: 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 Program XX = 1 <sup>st</sup> time mentor)	NON-US CITIZEN
<b>Bernard</b>	<b>RA</b>	<b>XX</b>	
Lijuan	Grad	XX	Asian
Arthur	Grad	X	
<b>Mandy</b>	<b>Grad</b>	<b>X</b>	
Tim	Grad	X	
Selena	Grad		Latin American
<b>Harry</b>	<b>Grad</b>		
Midori	Post Doc	XX	Asian
<b>Priya</b>	<b>Post Doc</b>	<b>X</b>	<b>S Asian</b>
Jinsong	Post Doc	X	Asian
Dick	Post Doc	X	
<b>Ajay</b>	<b>Post Doc</b>	<b>X</b>	<b>S Asian</b>
Xiang	Post Doc	X	Asian
Pierre	Post Doc	X	N American
Guy	Post Doc	X	
<b>Young</b>	<b>Post Doc</b>		<b>Asian</b>
<b>Nancy</b>	<b>Post Doc</b>		
Franck	Post Doc		European
<b>Christiaan</b>	<b>Post Doc</b>		<b>European</b>
Marisol	Post Doc		Latin American
Grant	Post Doc		Austral Asian
<b>Faith</b>	<b>Post Doc</b>		
Gabriella	PI	X	E European
Qiao	PI		Asian

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.

The diversity of interns, the diversity of mentors, and the indeterminate nature of the research projects caused each intern's experience to be a unique case of learning through mentored practice.

### **Design and Data Sources**

The scope of my research called for multiple modes of inquiry involving both quantitative and qualitative data (Creswell, 2009). Multiple modes of inquiry allowed me to address both descriptive and explanatory questions, and to triangulate interns' and mentors' self-reports. 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 and illustrative cases (Stake, 1995; Yin, 2003). Table 4.3 summarizes the schedule for data collection, the data sources, and the relationship between data sources and research questions.

#### **Pre-post Assessment of Interns**

The pre-post design allowed me to identify any gains in interns' 1) practice of inquiry skills, 2) understandings of NOS and NOSI, and 3) personal epistemology. In the following subsections I describe how each of these three areas was addressed. Interns completed a written questionnaire during the week prior to the program, and then participated in a follow-

up, semi-structured interview. These early interviews took place during the first two weeks of the program. In my pilot studies, providing the questionnaire to interns prior to the interview helped stimulate the intern's thinking in preparation for the interview, and was especially useful for the NOS and NOSI questions, some of which were perceived by participants as abstract, unfamiliar, and difficult to answer. In designing the questionnaire and interview protocols, I endeavored to balance length with quality of data, having found that a longer interview generated fuller participation than a longer questionnaire. The 2009 pre-program questionnaire incorporated a Likert survey on practical experiences with aspects of inquiry and questions about NOS/NOSI and personal epistemology (Appendix A). During the follow-up interview, interns were asked to clarify and elaborate upon their responses to the written questionnaire and answer additional questions about NOS/NOSI and the intern's 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 about NOS/NOSI and epistemology, 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 and mentor (Appendix C).

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.

**Experiences with aspects of inquiry.** I developed a Likert survey to obtain information about interns' prior- and program-experiences with specific inquiry and laboratory research skills. I began with the survey of 14 research skills developed by Kardash (2000) from interviews

with faculty mentors about skills they valued in undergraduate research. I modified several of the items to more explicitly reflect the lists of “important abilities to do inquiry” and “the five essential features of inquiry” outlined by the NRC (2000). My survey consisted of 14 items and was piloted with the 2008 cohort. Participants were asked to rate the frequency with which they had practiced each survey item on a scale from zero (never) to four (very often). After completing the survey, interns were asked to comment on their understanding of survey items and the reasoning behind their ratings. This retrospective think-aloud process (Sudman, Bradburn & Schwartz, 1995) helped clarify the meaning of items for the interns, and the reasoning behind interns’ ratings. In 2009 I used the survey in combination with the retrospective think-aloud process to capture the intern’s perspective of his or her own inquiry practice.

I included additional questions in the 2009 survey about the intern’s day-to-day independence and autonomy (See Appendix A). Autonomy was a measure of the intern’s feelings of independence in their project’s design, and in decision making that might influence the development or outcomes of the project. Autonomy helped to estimate the degree to which the intern’s project was prescribed by the mentor.

In the pre-assessment, interns were asked to indicate the frequency with which they had practiced each skill independently as undergraduate science students prior to the program. In the post-assessment, interns were instructed to focus explicitly on their experiences in the summer URE, first to describe how frequently they had practiced each skill independently, and a second time to describe how frequently they had practiced each skill under the guidance of their mentor. During the post-assessment, interns were asked to give examples from their summer research experience where appropriate. The survey helped me to examine and compare

**Table 4.3: 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	<b>Application Materials</b>	●—●												5
	<b>Pre-Program Questionnaire</b> ● Likert Survey of Inquiry Skills ● Views of Nature of Science /Scientific Inquiry ● Measure of Epistemological Reflection	●—●												1-3
	<b>Early Interviews</b> ● Follow-up to questionnaire ● Intern's background and expectations ● Perceptions of the research setting		●—●											1-5
	<b>Research Proposals</b>			●										1 and 5
	<b>Longitudinal Observations</b>				●—●									1-5
	<b>Late Interviews</b> ● 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
	<b>Research Presentations</b>												●	1 and 5
MENTORS	<b>Post-Program Interviews</b> ● Likert Survey of Inquiry Skills (Intern's Practice) ● Mentor's background and expectations ● Perceptions of intern and the research experience											●—●		1 and 5

students' prior exposure to elements of inquiry, and their exposure to these elements in this URE project. Autonomy helped to estimate the degree to which the intern's project was prescribed by the mentor.

In the pre-assessment, interns were asked to indicate the frequency with which they had practiced each skill independently as undergraduate science students prior to the program. In the post-assessment, interns were instructed to focus explicitly on their experiences in the summer URE, first to describe how frequently they had practiced each skill independently, and a second time to describe how frequently they had practiced each skill under the guidance of their mentor. During the post-assessment, interns were asked to give examples from their summer research experience where appropriate. The survey helped me to examine and compare students' prior exposure to elements of inquiry, and their exposure to these elements in this URE.

**Understandings about NOS and NOSI.** Lederman *et al.* (2002) developed an instrument to assess views of NOS (Views of Nature of Science questionnaire or VNOS) which has been used by many different researchers across a wide variety of settings and age-education levels. In particular, the VNOS form C has been used with undergraduates (Abd-El-Khalick, 2004). Similarly, Schwartz (2004) developed an instrument to assess scientists' views of NOSI (Views of Scientific Inquiry questionnaire or VOSI-Sci). In their recent work, Schwartz & Lederman (2008) have conducted research in which they have combined the VOSI-Sci and the VNOS-C to more fully describe participants' conceptions of inquiry and scientific knowledge. VNOS-C and VOSI-Sci overlap in several areas. I collaborated with a colleague versed in the use of the VNOS-C 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).

I included three questions from the combined VNOS/VOSI in the written pre-questionnaire to ease students into this part of the interview. During the early interview, interns were asked to clarify and elaborate on their written answers before being asked to verbally comment on the remaining VNOS/VOSI questions. During the late interview, interns were asked to review their earlier responses to the VNOS/VOSI questions and describe ways in which their understandings or views may or may not have been altered through participation in the summer research experience.

**Epistemological thinking.** The pre-program questionnaire and early interview also include questions in the area of personal epistemology. I obtained permission to use Baxter Magolda's (1992) Measure of Epistemological Reflection (MER) from the author. The MER is a written instrument that addresses students' views on knowledge and learning in six domains: decision making, role of the student, role of the instructor, role of peers, certainty of knowledge, and purpose of evaluation. The focus on students' experiences with knowledge and learning in undergraduate classrooms makes this an attractive framework for investigating learning in an undergraduate research setting. All six of the MER questions were included in the pre-questionnaire. During the early interview interns were asked to clarify and elaborate on their responses to these questions to ensure that I understood their thinking on each question. During the late interview, interns were asked review their earlier responses to the MER questions and describe ways in which their views may or may not have been altered through participation in the summer research experience.

### **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 (see Appendix C).

**Application materials.** Interns' application materials included personal statements, letters of recommendation, and transcripts. These materials helped me to triangulate self-reports about prior research and coursework.

**Research proposals and presentations.** 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 understand all of these things. In my pilot studies I learned that these products are heavily groomed by the mentor, particularly the final, public presentation. Thus, though they are evidence of at least guided practice in scientific communication, they cannot stand alone as evidence of intern learning. However, 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 D) 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. Mentor's perceptions of the intern's experiences included completing the Likert survey through a think-aloud process during the interview. As in the intern's post-assessment, mentors completed the survey twice, first to describe the intern's independent work, and then to describe the intern's guided work. 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 as they worked 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 4.1 and 4.2 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 4.3).

In conducting my observations, I took the role of an outsider ethnographer visiting the laboratory to learn about its ways of doing work and its culture (Latour & Woolgar, 1979). I shadowed the intern, recording as much of his or her activities, conversations and interactions as was possible. I focused my attention on the intern's individual learning and interactions within the intern-mentor dyad, employing a pair of overlapping frameworks. The intern-centered framework attended to instances of learning: declarative knowledge about the subject

matter, NOS and NOSI; procedural knowledge of inquiry and research skills, problem solving and reasoning; and the means by which one learns - self-reflection, application of knowledge, interactions with physical objects and people. The mentor-centered framework attended to instances of teaching: teaching that (declarative knowledge) and teaching how (procedural knowledge and the means by which one learns). When possible, I recorded descriptions of the physical space and the atmosphere that the intern worked in. I also conversed with the participants during the observations in order to learn about what they were doing and build rapport. On three occasions, the intern invited me to participate in her work, which I did, balancing note-taking with the bench-work. After each observation I made notes about my impressions of the setting, activities, and any interesting happenings, interactions or remarks.

Field observations provided rich data on the practices and interactions of both the intern and mentor. These data were crucial in triangulating findings from interviews and questionnaires. Field observations also permitted me to observe change over time in the nature of the intern's project, practice and interactions with objects and actors.

## **Data Analysis**

### **Pre-post Assessment of Interns**

**Experiences with aspects of inquiry.** Interns' experiences with aspects of inquiry were investigated via the Likert survey of inquiry and research skills. The Likert survey used an ordinal scale and included fourteen items reflecting inquiry and other laboratory research skills and 3 items addressing independence and autonomy. As Clason and Dormody (1994) pointed out, educational researchers choose a variety of statistical methods to analyze Likert-style data, including both parametric and non-parametric approaches. The ordinal scale and small sample size (N=24) meant nonparametric statistical approaches were most appropriate for comparing individual items (Göb, McCollin & Ramalhoto, 2007). However, the summed survey score is a

continuous variable, meaning that parametric statistics were most appropriate for comparisons between interns' summed independent and guided scores and between interns' and mentors' surveys. Each of these treatments of the data is described below.

**Individual Likert items.** To address the research questions about the practice of specific inquiry and research skills (questions 1.a. and 1.b.) I computed a median rating and interquartile range<sup>3</sup> (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.

**Engagement with inquiry: program inquiry scores.** Each of the survey's first 14 items represented a different research skill or ability to do scientific inquiry. Participants rated each item twice, once for independent practice, and once for guided practice. 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). The grand sum incorporated both independent and guided practice. Twenty mentors also completed the survey. In my pilot studies, I found that interns tended to overrepresent their independent practice compared to mentors, and mentors tended to overrepresent guided practice compared to interns. I therefore combined these two perspectives 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. Since four mentors did not complete the survey, the dataset of program inquiry scores has an n of 20. A normality test confirmed normal distribution for

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<sup>3</sup> Median and interquartile range are nonparametric analogs to the mean (an estimate of location) and standard deviation (a measure of variability).

these data.

**Autonomy scores.** Two additional items on the Likert survey 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 NOSI and in epistemological development. Two simple linear regressions tested for a relationship between research experience and inquiry:

- Does quantity of prior research predict pre-program independent inquiry?
- Does pre-program independent inquiry predict program inquiry?

One set of multiple linear regressions tested for relationships between pre-program attributes:

- Are quantity of prior research, pre-program inquiry, or epistemological development predictors of pre-program understandings of NOS?
- Are quantity of prior research, pre-program inquiry, or MER predictors of pre-program understandings of NOSI?

Another set of multiple linear regressions tested for relationships among program outcomes

- Are program inquiry or epistemological development predictors of post-program understandings of NOS?
- Are program inquiry or epistemological development predictors of post-program understandings of NOSI?

Calculation of numerical scores for understandings of NOS and NOSI and for epistemological development 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 began by reading all of the material to develop a general sense of the range of participants' responses. 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. We then began to classify participants' responses for each aspect into three bins: "naïve," "intermediate," and "more informed." As we discussed our process and progress, we agreed that the intermediate category needed refinement. Though Lederman et al. (2002) used three bins, 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. To test and further refine the rubric, we exchanged transcripts, independently scored them, and then compared the results. Wherever it was difficult to achieve consensus, we conducted a horizontal analysis: the particular question under discussion was compared across all participants, re-scored and discussed until we were satisfied with our consistency. Final consensus resulted in a final refinement of the rubric and final scoring of transcripts (naïve = 0, emerging = 1, informed = 2, and more informed = 3; Appendix E). I then tallied each intern's scores on aspects of NOS and NOSI to provide summary scores for that intern. These scores were used to describe the range of understanding of aspects of NOS and NOSI held by interns,

to identify any changes in understandings, and to look for correlative relationships with engagement with inquiry and epistemology as described above. I also tallied the group's scores on each aspect of NOS and NOSI to see if some aspects were more enhanced through participation in the internship than others.

**Epistemological thinking.** Written responses to the MER and the transcripts from this portion of the interviews were analyzed to discern each intern's epistemological level. I followed the constructivist interpretation approach outlined in Baxter Magolda (2001), which begins by reading all of the material for a given subject to provide an overall context for interpreting the subject's responses in the different domains. I then used Table 2.1 in Baxter Magolda (1992, see Appendix F) as a rubric to interpret the response in each domain as either absolute, transitional, independent, or contextual knowing (assigning a score of 0, 1, 2, or 3 respectively). Following the constructivist interpretation approach, I analyzed an individual's response for a particular domain in light of the responses she offered in the other five domains. However, I did not strive to assign an intern's domain responses uniformly to a particular way of knowing. For example, if an intern expressed absolutist views about the role of peers and the nature of knowledge, but transitional views about the role of the learner, instructor, and evaluation, I classified her epistemological level as between absolutist and transitional and gave her an overall score of 3. I then selected a random sample (n=10) of the transcripts and shared these with a colleague versed in the theory and use of the MER. She independently scored the transcripts using the same approach and rubric. We then met to discuss discrepancies in scoring until we came to consensus. There were no instances where it was difficult to achieve consensus.

MER scores were used to characterize the range of epistemological development of this group of interns, to identify any changes in epistemological thinking, and to look for correlative

relationships with engagement with inquiry and understandings about NOS and NOSI as described above.

### **Exploratory Investigation**

In order to understand what factors might have contributed to or inhibited intern's experiences with inquiry, understandings of NOS and NOSI, and epistemological thinking, I engaged in an interpretive analysis of the qualitative data. 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.

Transcripts from field notes made during longitudinal observations of nine intern-mentor pairs yielded qualitative data addressing intern's experiences with inquiry as they conducted their research. I used ATLAS.ti (2010) to code and sort the data. I used 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. For example, the code "problem solving" emerged from the initial code "troubleshooting" to distinguish between overcoming a general challenge (problem solving) and figuring out what went wrong in an investigation and trying to fix it (trouble-shooting). After two passes through the data, 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. The final list of codes used in this analysis can be found in Appendix G.

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.

I selected two interns' whose experiences were particularly interesting to develop two contrasting, illustrative cases. The cases helped to demonstrate the complexities of interactions that occurred between the intern, his or her mentor, and the summer research experience.

## **CHAPTER 5**

### **Pre- and Post-Assessment Findings**

#### **Introduction**

This chapter reports the findings from the pre-post assessment of: interns' practice of inquiry and research skills, their understandings of NOS and NOSI, and their epistemological development. Findings address pre-post change that occurred during participation in the summer URE, and relationships that might exist between these different areas of interns' learning.

#### **Experience with Inquiry and Research Skills**

Interns completed a Likert survey of inquiry and research skills prior to, and at the end of the Program. Survey results indicated what skills interns practiced during their prior undergraduate science education, and what skills interns practiced as participants in the Program. The survey helped me to examine and compare students' prior exposure to elements of inquiry, and their exposure to these elements in this URE.

#### **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 5.1). 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

**Table 5.1: 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).

Pre-program Survey Item	Novices (n=9)		Experienced (n=15)	
	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

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 5.2): 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 5.2). 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

**Table 5.2: 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).

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

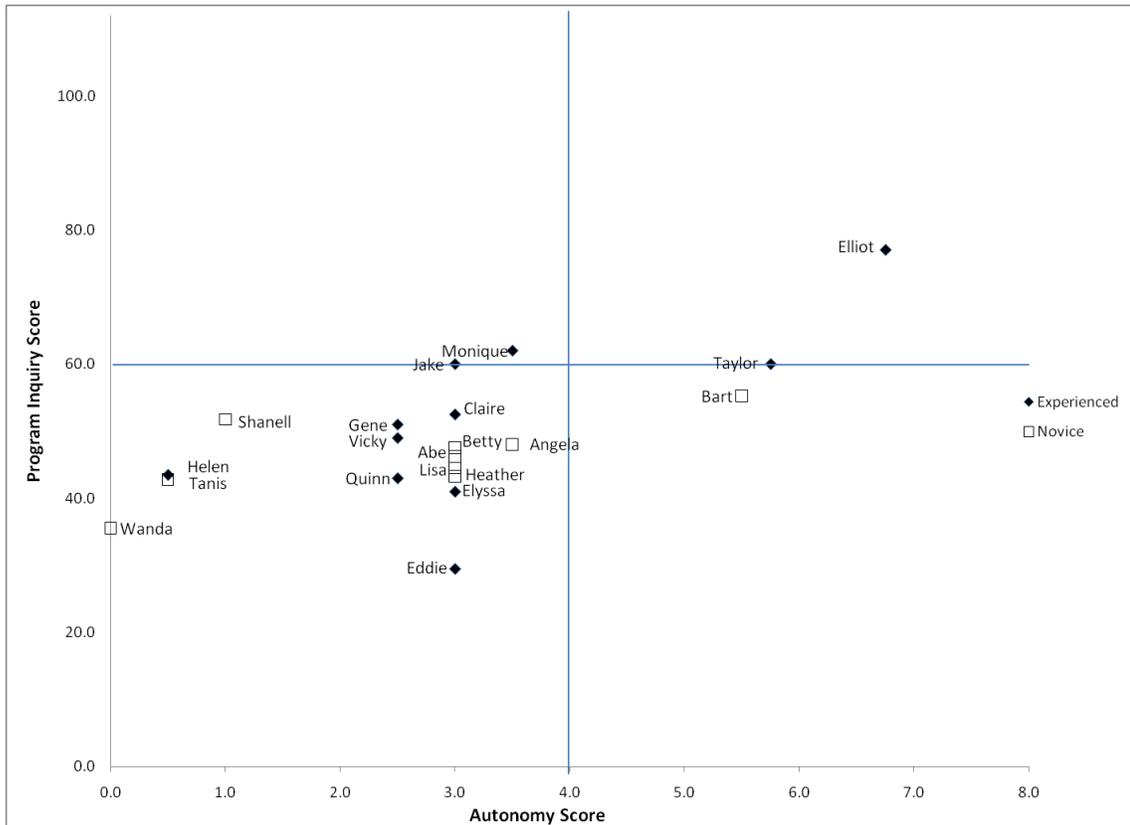
skills at a median of 2 or above than they did for their independent practice (Table 5.2). Additional skills practiced with guidance included: select/design methods, determine what data to collect, relate results to the “bigger picture” and develop an argument. The results from the mentors’ surveys also 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.

### **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 Chapter 4. Program scores varied widely, ranging from 29.5 to 77 out of a possible 112 (mean =  $49.1 \pm 10.4$ ,  $n = 20^1$ ). These program scores were used to investigate relationships between intern’s 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 in Chapter 4. These scores varied from zero to seven out of a possible 8 (mean =  $3.25 \pm 1.9$ ,  $n = 20$ ). Program inquiry and autonomy helped to describe the variability in interns’ UREs (Figure 5.1). 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. One of these UREs, that of Elliot, whose experience is described in Chapter 7, was more self-directed, and closer to full inquiry than any of the others.

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<sup>1</sup> 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.



**Figure 5.1: 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 5.3). 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

**Table 5.3: 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)

Aspects of NOS	% informed/robust	
	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

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)

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. For example,

An experiment is something where you can create a hypothesis and where you have anticipated results. Meaning that you both could explain reasons why your hypothesis could be right or could be wrong, whether you expect that to happen. And that there's some kind of data, whether that be quantitative or qualitative that you can measure

...

Experiments usually involve a control - samples or trials that show that zero modification of this control will not have the same result as something else that you're trying to manipulate or change by exposing it to something else. It shows that what you're doing - you're essentially doing something. Whatever you're measuring in the other samples is a result of what you changed rather than something that happens anyway. (Gene, Early Interview)

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<sup>2</sup> that are known for this grain species - and I mean there are

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<sup>2</sup> Quantitative trait loci (QTLs) – areas of the genome that determine quantitative variation in phenotype. In this case, the desired phenotype is improved grain yield.

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 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.

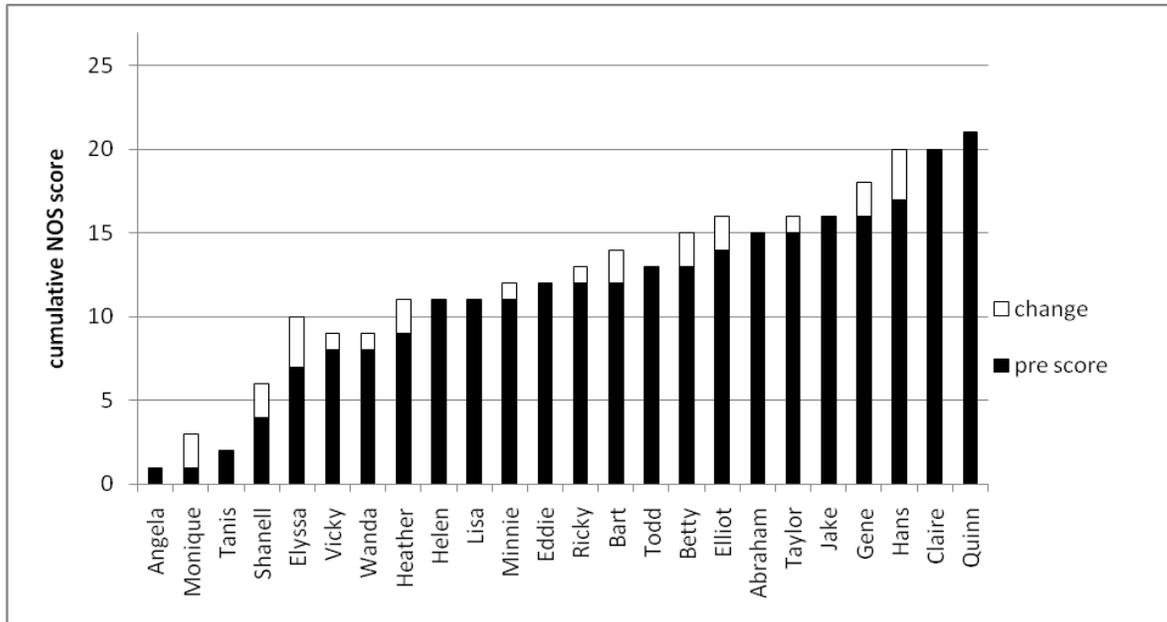
MRP: Do you see room for creativity in other aspects of science than that one you just described, like do you see room for creativity in the data collecting or data analysis phases?

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 5.2 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.

As with NOS, most interns' conceptions of many aspects of NOSI were naïve or emerging prior to the Program (Table 5.3). 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



**Figure 5.2. Interns’ Pre- and Post-program NOS Scores.** Mean pre-program NOS score =  $11.2 \pm 5.5$ ; mean post-program NOS score =  $12.3 \pm 5.4$  (maximum possible score = 27).

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 5.3). 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 5<sup>th</sup> 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<sup>3</sup> 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 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 is 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:

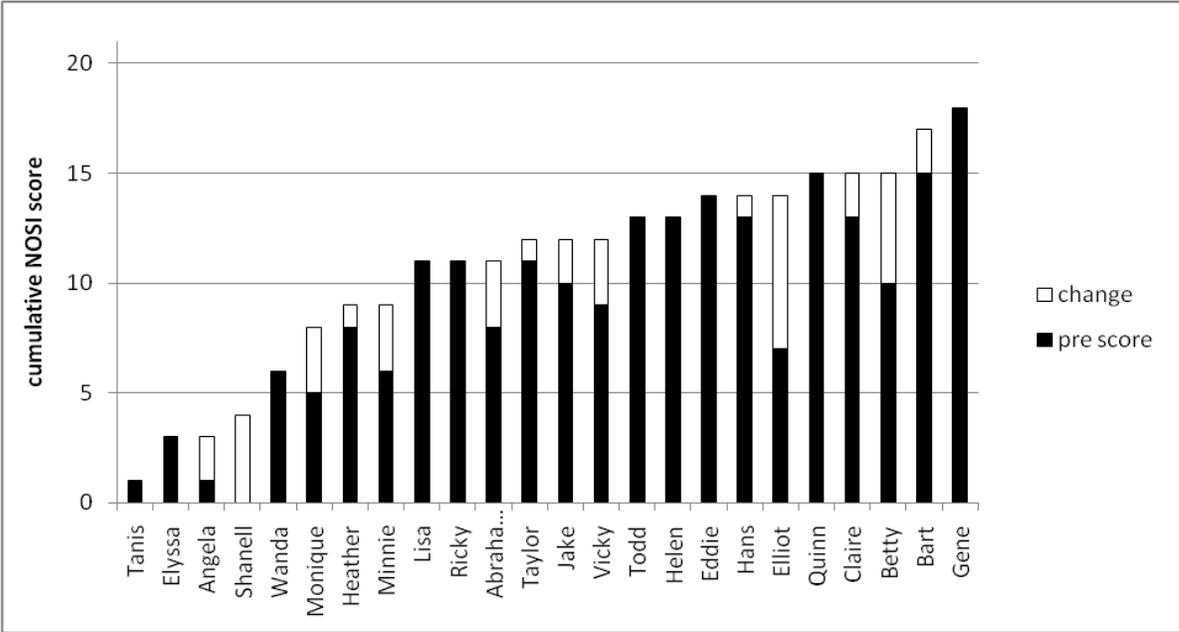
One has these theoretical classes on science and you have discussions about what is science, what is theory a lot of times. But I've never had something first hand come at me where I thought something was established, where I'd wish that it had been clearer to me what we really do know and what we don't 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 neat. (Hans, Late Interview)

Figure 5.3 demonstrates a wide range of 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 5.2 and 5.3). 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 5.3 suggest that interns with a more

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<sup>3</sup> Shade avoidance syndrome (SAS) is a suite of morphological changes that occur in some plants in response to limited light conditions.

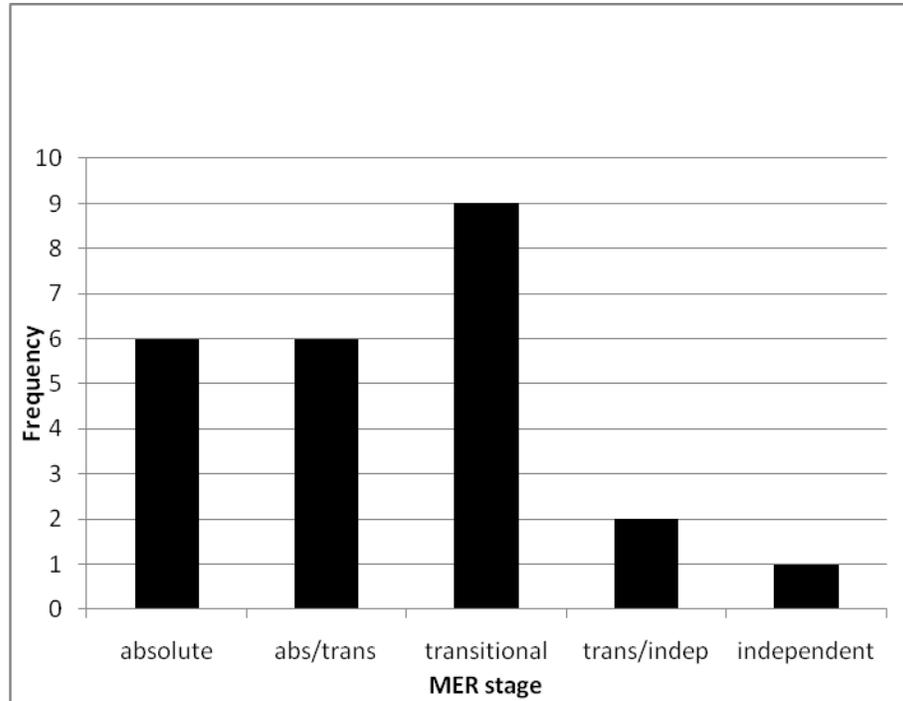
limited understanding of aspects of NOSI at the beginning of the program were more likely to make pre-post gains in this area. However, no such pattern emerges for pre-post gains in understanding aspects of NOS.



**Figure 5.3. Interns’ Pre- and Post-program NOSI Scores.** The mean pre-program NOSI score was  $9.2 \pm 4.8$ ; mean post-program NOSI score was  $10.8 \pm 4.6$  (maximum possible score = 21).

**Epistemological Development**

Very little change in personal epistemologies was observed in this cohort of interns pre- to post-program. Hans’s experience, described above, caused a shift in his views of the nature of knowledge from absolutist to transitional. Also, Monique’s views on the role of the learner shifted from absolutist to transitional. Each of these interns’ post MER score was greater by 1 point than their pre, however, neither of these shifts resulted in the intern moving into a new stage of epistemological development. Because so little pre-post change in MER score occurred, post MER scores were used throughout the analysis.



**Figure 5.4: Stages of Epistemological Development among Interns in the 2009 Cohort (n=24).**

The majority of interns in this sample were at or near the transitional stage both prior to and after participating in the Program (Figure 5.4). Most held a mixture of absolutist and transitional views across the different domains of the model. One area where absolutist views were most prevalent was in the role of peers. Most interns (15/24) viewed peers as having too limited an understanding of subject matter to engage in worthwhile exchange of ideas or serve as a source of knowledge, particularly in science courses. A few interns believed that in upper-level courses, this was not necessarily the case. However, only a handful of interns in the 2009 cohort had experienced a discussion-based course in science where their assumptions about peers could be tested. For these students, most discussion in science classrooms occurred between the student and the professor, if at all. In every other domain, the majority of interns expressed transitional views: the role of the learner was to understand material (17/24), the

role of the instructor was to use techniques aimed at fostering understanding and application (14/24), and the role of evaluation (16/24) was to test that understanding. The transitional view that some knowledge was certain and some knowledge was uncertain, was also the most common (15/24). Most interns believed that scientific facts, especially the foundational concepts that have stood the test of time, were certain. However, aspects of literature, history and philosophy were uncertain because these were based on people's opinions. For example, Minnie, a philosophy minor and 5<sup>th</sup> year senior, described her view of the difference between philosophy and science:

I don't know. Philosophy is just kind of the way people think. I'm a philosophy minor but I think it's all crap. It's not real. It's not there. I like it because I like to see the way other people think... Science is real. It's something you can observe. You can actually conclude something. In philosophy you're never going to conclude something. It's not real. You can conclude something in science because you can do experiments. In science it's real. You can show it and you can back it up with experiments. (Minnie, Late Interview)

Six interns held mostly absolutist views. For these students, the role of the learner was to obtain knowledge, the role of the instructor was to deliver that knowledge appropriately, the role of peers was to share knowledge, and the role of evaluation was to demonstrate one's knowledge. These interns also believed in the certainty of knowledge and the infallibility of authorities like professors and textbooks. These interns preferred facts over concepts (which they often equated with opinion or theory) because facts are proven and correct. For example,

Shanell: I like learning that stuff, facts, you know. You can be like, "This is fact and I can prove it." You know, we can prove this, instead of concepts.

MRP: And what is it that appeals to you about that?

Shanell: Because the concept can change and I may be saying something that somebody else has the more updated, and I'm like, "Oh, I don't know that."

MRP: And that gets back to our discussion on whether facts can change or not.

Shanell: Yeah. And it will confuse me because one teacher may say this and then another professor may say that and I'm like (*shrugs as if to say, "what do I do?"*)

MRP: What do you do in those situations?

Shanell: A lot of times I'll question them on it. Like if one professor says this, I'll ask the other professor about it and they'll say what they have to say and then I'll ask the other one and they'll say, you know. And if I'm still confused, I'll – a lot of times I still stay confused (*laughs*). (Shanell, Early Interview)

When two authorities differed in their views, Shanell, a rising senior, was more comfortable remaining confused, not because she felt that everyone had a right to their own views, but because she was uncomfortable with the idea that some authorities might be wrong.

Two interns held a mixture of transitional and independent views about the nature of learning and knowledge, and a third held mostly independent views. For independent knowers, the role of the learner was to think independently and develop his or her own perspective, the role of the instructor to promote independent thinking, and the role of evaluation to reward independent thinking. Here is how Claire, a rising junior, described the teaching method she found most beneficial to her way of learning:

The teaching method that is most beneficial is the one that leaves students to do a certain amount of discovery on their own. A couple of professors in my experience have used a similar pattern of teaching in which they present material more complex than a student can grasp immediately. The expectation is that the student will ask questions during class, puzzle over the gaps of understanding and problems that inevitably come up, go to office hours to discuss the material, etc. Other characteristics of such professors often include a heavy reliance on experimental data during lectures and a great degree of comfort with the limits of their own knowledge or the current limits of the field in question. This is in contrast to a few professors in my experience who present information categorically, drily, seemingly restricting the realm of exploration and the limits of knowledge to their PowerPoint bullets of information. Such instruction is depressing and suffocating. These professors don't seem as ready as the other type to engage in intellectual dialogue with students, which in my opinion, is an essential demonstration of how learning actually happens. The other type of instructor is willing to tackle problems presented by students with the students. (Claire, Pre-program MER Survey)

Independent knowers view knowledge as open to interpretation. Jake, a non-traditional student who predominantly used independent ways of knowing provided the following example:

Dr. J. gave a presentation a few weeks ago on GMOs. His was pretty much fact based, "Here's what it is." You can kind of tell from his tone that he wasn't against it, he was for it. I have one professor who is so against it, and I'm not saying he is right or wrong, but I do think people have a tendency to find the information that reinforces what they already believe. So when two professors give conflicting ideas, I think it's because it's intrinsically what they believe or whatever, based on their own value system and whatnot. Does that mean one's right and one's wrong? Sometimes. I think they both can also be true. I think that that information needs to be presented in such a way that it doesn't detract from the student forming their own opinion on it.

...

... lets put it this way. We have either of two options. Either they both give good explanations but there aren't enough facts to support very definitively one or the other, and if they have a valid argument, I think it's fine. However, if one of them is just being a quack, giving an argument that is not supported by the facts, or is not as strong as the other one, then you have to base your conclusions based on, well I guess the grade you want in the class or who you believe to be right. Sometimes people draw different conclusions for whatever reasons. (Jake, Late Interview)

While Jake recognized the value of weighing facts and evidence in deciding whose ideas to believe, he felt that these too were open to interpretation. Ultimately, students should be allowed to decide for themselves what/whom to believe. Jake also recognized that complex issues, such as the use and development of genetically modified organisms, may have multiple truths.

### **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, and with their epistemological development. I sought to discern whether deeper engagement with inquiry resulted in gains in understandings about aspects of NOS and NOSI, or higher levels of

epistemological thinking. I also sought to discern whether epistemological development helped to explain gains in understanding about NOS and NOSI.

**Prior Research, Pre-program Independent Inquiry and Program Inquiry**

Interns’ prior research experience ranged from 0 to 7 semesters (see Table 4.1). Pre-program independent inquiry scores ranged from 1 to 45 out of a possible score of 56 (mean =  $29.9 \pm 10.6$ , 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 5.4).

**Table 5.4: Correlation for Prior Research, Prior Independent Inquiry and Program Inquiry Scores.**

<b>Dependent variable</b>	<b>Independent variable</b>	<b>r<sup>2</sup></b>	<b>df</b>	<b>P</b>
Pre-program independent inquiry	semesters prior research	0.13	23	0.083
Program inquiry	pre-program independent inquiry	0.10	19	0.174

**Pre-program Relationships**

To test if interns’ MER scores were influenced by their practical inquiry experience prior to the program, I compared MER scores with prior research and pre-program independent inquiry scores (Table 5.5). There was a significant, positive relationship between MER and pre-program independent inquiry and no relationship with semesters of prior research. Pre-program inquiry scores explained 28.6% of the variability in MER scores (Figure 5.5).

To test if interns’ epistemological thinking or prior inquiry experiences influenced their pre-program understandings of NOS and NOSI, I compared prior research, pre-program independent inquiry, and MER with pre-program NOS and NOSI scores (Table 5.5). Amount of prior research and prior independent inquiry scores did not correlate with pre-program NOS or NOSI scores. However there was a significant positive relationship between MER and pre-

program NOS and NOSI scores. MER explained 50% of the variability in pre-program NOS scores and 36.5% of the variability in pre-program NOSI scores (Figure 5.6).

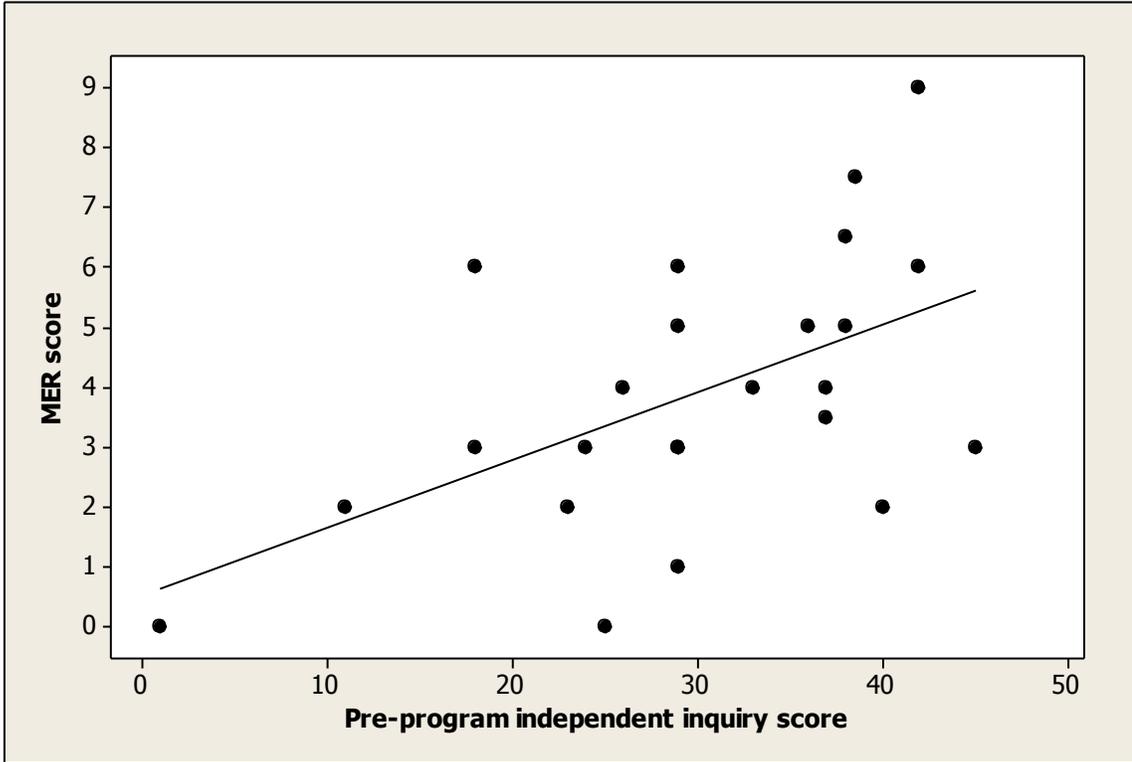


Figure 5.5: Correlation between MER and Pre-program Independent Inquiry ( $r^2 = .286$ ).

Table 5.5: Correlation for Pre-program Attributes (n=24). Results from multiple linear regression analysis. Independent variables in bold text indicate a significant relationship with the dependent variable.

Dependent variable	Independent variable	F	P
MER	semesters prior research	0.435	0.517
	<b>pre-program independent inquiry</b>	<b>6.22</b>	<b>0.021</b>
pre NOS	semesters prior research	0.149	0.703
	pre-program independent inquiry	0.023	0.879
	<b>MER</b>	<b>15.9</b>	<b>0.000</b>
pre NOSI	semesters prior research	0.028	0.867
	pre-program independent inquiry	0.333	0.569
	<b>MER</b>	<b>6.71</b>	<b>0.017</b>

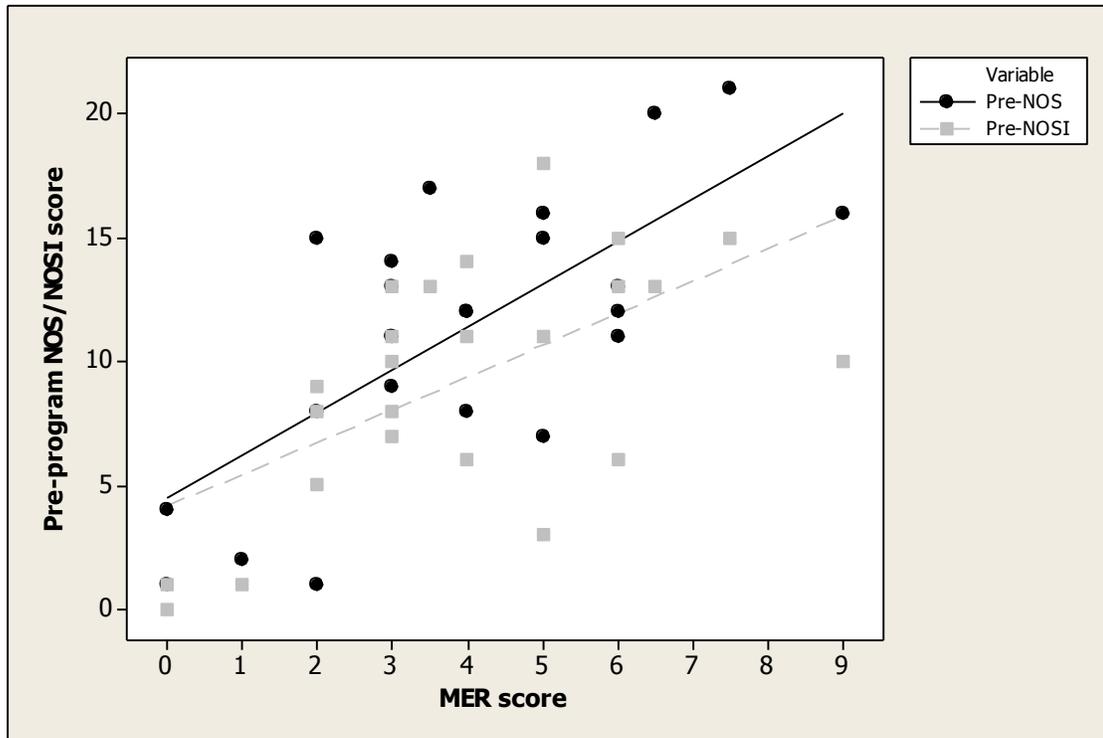


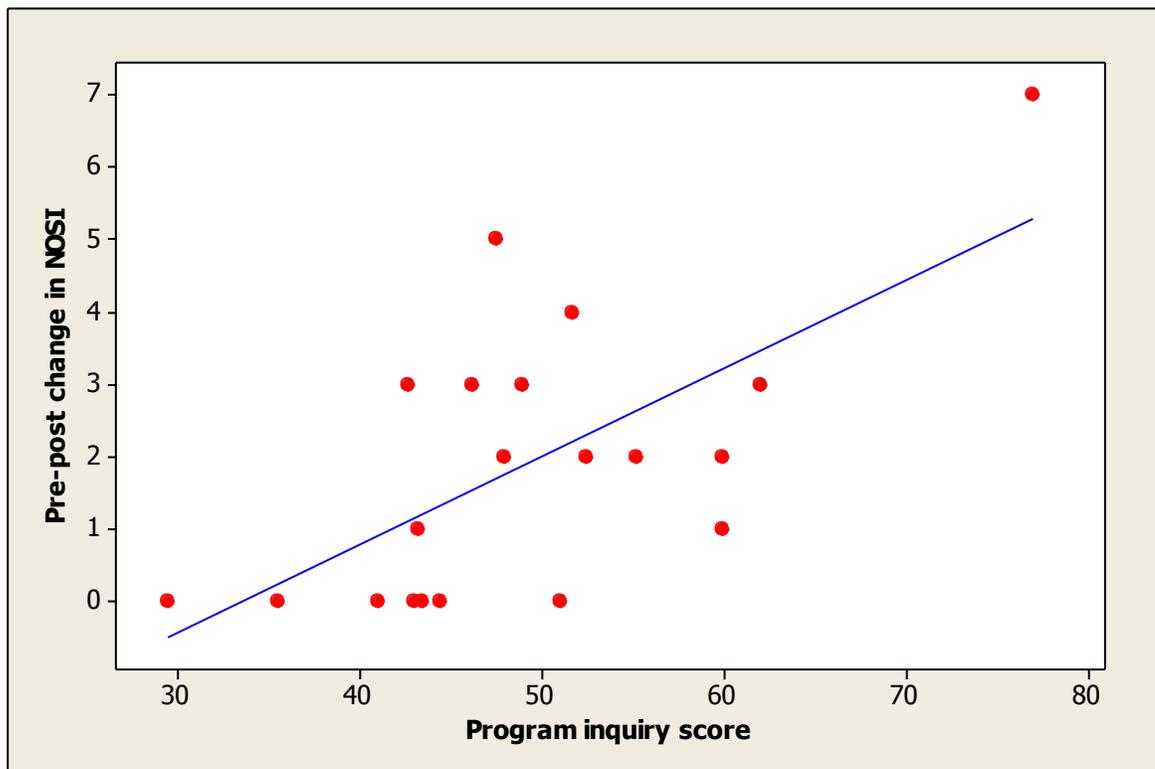
Figure 5.6: Correlation between MER and Pre-program NOS ( $r^2 = 0.506$ ) and NOSI ( $r^2 = 0.365$ ) Scores ( $n=24$ ).

### Post-program Relationships

To test if inquiry experience or epistemological thinking influenced interns' post-program understanding of NOS and NOSI, I compared program inquiry scores and MER with post-program NOS and NOSI scores, and pre-post change in NOS and NOSI scores (Table 5.6). Program inquiry did not correlate with post NOS or change in NOS scores. As with pre-program NOS and NOSI, there was a strong, positive correlation between MER and post-program NOS and NOSI. 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 5.7).

**Table 5.6: Correlation Between Program Inquiry, MER 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
post NOS	program inquiry score	0.498	0.489
	<b>MER</b>	<b>23.1</b>	<b>0.000</b>
change in NOS	program inquiry score	1.97	0.179
	MER	0.380	0.546
post NOSI	program inquiry score	0.874	0.363
	<b>MER</b>	<b>7.71</b>	<b>0.013</b>
change in NOSI	<b>program inquiry score</b>	<b>20.6</b>	<b>0.000</b>
	<b>MER</b>	<b>8.17</b>	<b>0.011</b>



**Figure 5.7: Correlation between Program Inquiry and Change in NOSI Scores ( $r^2 = 0.424$ ;  $n=20$ )**

## Discussion

### 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.

### **Epistemological Development**

Baxter Magolda (1992) found that most college students were transitional in their epistemological thinking. The majority of interns in the 2009 cohort were also transitional in

their epistemological thinking, and made no gains in their epistemological thinking pre- to post-program. The lack of gains in personal epistemology are at odds with Rauckhorst et al. (2001), who found that many students moved from transitional to independent ways of knowing after participation in a summer URE. My results suggest that, as with understandings of NOS, it may be more difficult to induce a shift in epistemological thinking through participation in a short-duration research internship.

I found a strong, positive and significant relationship between interns' scores for personal epistemology and their understandings about NOS and NOSI. I also found a strong, positive and significant relationship between epistemological development and pre-post change in NOSI (there was very little pre-post change in understandings about NOS). These findings suggest that a student's abilities to grasp tenets of NOS and NOSI are tied to their epistemological development. Further, practical experience with inquiry and personal epistemology together contribute to students' developing understandings about NOSI. It may be that personal epistemology bounds what one is able to understand about NOS and NOSI, and practical experiences influences what one can gain within those boundaries. These findings have important implications for our understanding of how students develop more advanced views about NOS and NOSI, particularly younger students who rely on absolute ways of knowing.

In the next chapter, I further explore interns' research and mentoring experiences to illuminate the ways in which these experiences may have (or may not have) influenced interns' gains in inquiry practice and understandings about NOS and NOSI.

## CHAPTER 6

### Exploratory Investigation Findings

#### Introduction

This chapter describes findings from the exploratory investigation of interns' research experiences. I used multiple, qualitative data sources to construct a descriptive vignette for each intern's research experience. Vignettes helped me to categorize interns' research projects and the interactions (or transactions) between intern and mentor. I describe the categories of research project and mentoring, and their relationships to interns' gains in inquiry practice and understandings about NOS and NOSI. I then use selected vignettes to illustrate the main categories and the ways in which participants experienced them. All participants' names are pseudonyms. Certain details about the research projects have also been altered in order to protect the identity of the individuals involved. These are mostly changes in the names of genes, proteins, or species, and should not affect the reader's understanding of the structure of the research project or the experiences of the participants.

#### 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 6.1).

#### Non-Investigations

Projects that did not attempt to describe or explain a phenomenon were deemed non-investigations. Non-investigations were of two kinds: genetic screens (four) and tool

**Table 6.1: Research Project Categories and Subcategories.**

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

development projects (two; Table 6.1). Neither of these types of projects engaged the intern in a research question that went beyond the immediate data set or tool under 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<sup>1</sup> to amplify the gene for a specific trait, and run that material out on a gel through electrophoresis<sup>2</sup> to identify those plants that carried the desired genotype. Data analysis for Bart was to simply identify which plants were heterozygous (showing 3 bands on the gel) rather than homozygous (showing 2 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

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<sup>1</sup> 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."

<sup>2</sup> Gel electrophoresis is a technique that sorts molecules, like DNA fragments or proteins, according to their size.

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 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" and the vignette featuring Vicky in the sections that follow).

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<sup>3</sup> 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.

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<sup>3</sup> 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.

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 her mentor did not or could not make himself available to mentor her. However, Betty's experience (see the vignette featuring Betty in the sections that follow) demonstrates that one can in fact learn a lot about molecular techniques, inquiry skills, NOS, NOSI and subject matter through tool development, because her project was clearly part of an investigation.

### **Investigations**

**Observational Investigations.** Research projects were considered investigations when they attempted to answer a scientific question, through observational approaches or hypothesis testing. The observational investigation was the largest category of research projects in the 2009 cohort (Table 6.1). 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 6.1) 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" and the vignette featuring Taylor in the sections 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 (See Chapter 7), 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 6.2 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 6.2 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 6.2). 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. The vignette featuring Helen and her mentor, Franck in the section below, provides 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 3, 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

**Table 6.2: 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	Outcomes *	Intern/Mentor Pair	Project Type	Outcomes	Intern/Mentor Pair	Project Type	Outcomes
<b>Wanda/Jinsong</b>	NI	-/-	<b>Bart/Tim</b>	NI	+/+	<b>Shanell (URM)/Nancy</b>	NI	+/-
Vicky/Ajay	NI	-/+	Todd/Guy	NI	+/-	<b>Angela (URM)/Young</b>	MOI	+/+
<b>Heather/Priya</b>	NI	-/-	<b>Lisa/Midori</b>	MOI	+/+	<b>Elliot/Mandy</b>	MOI-HT	+/+
Eddie/Marisol	SOI	-/+	Quinn/Bernard	MOI	+/+	Monique(URM)/Christiaan	HT	+/-
<b>Tanis(URM)<sup>†</sup>/Arthur</b>	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	+/+			
			<b>Betty/Gabriella</b>	HT	+/+			
			<b>Abraham/Lijuan</b>	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.

<sup>†</sup>URM – Intern belongs to a minority group underrepresented in US science

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, whose characterization project is described in a vignette below, 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:

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.

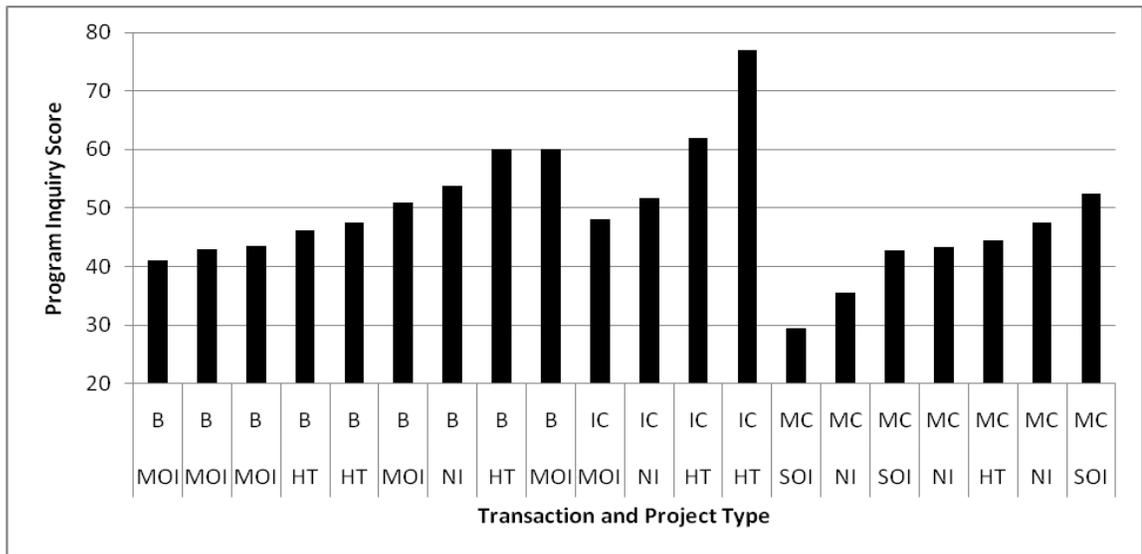
In these transactions, the give and take relationship was weighted more heavily toward the intern, because the intern's needs were considerable, but also because the mentor had (or made) the time and flexibility to devote to the intern's learning and engagement. The vignette featuring Angela below is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

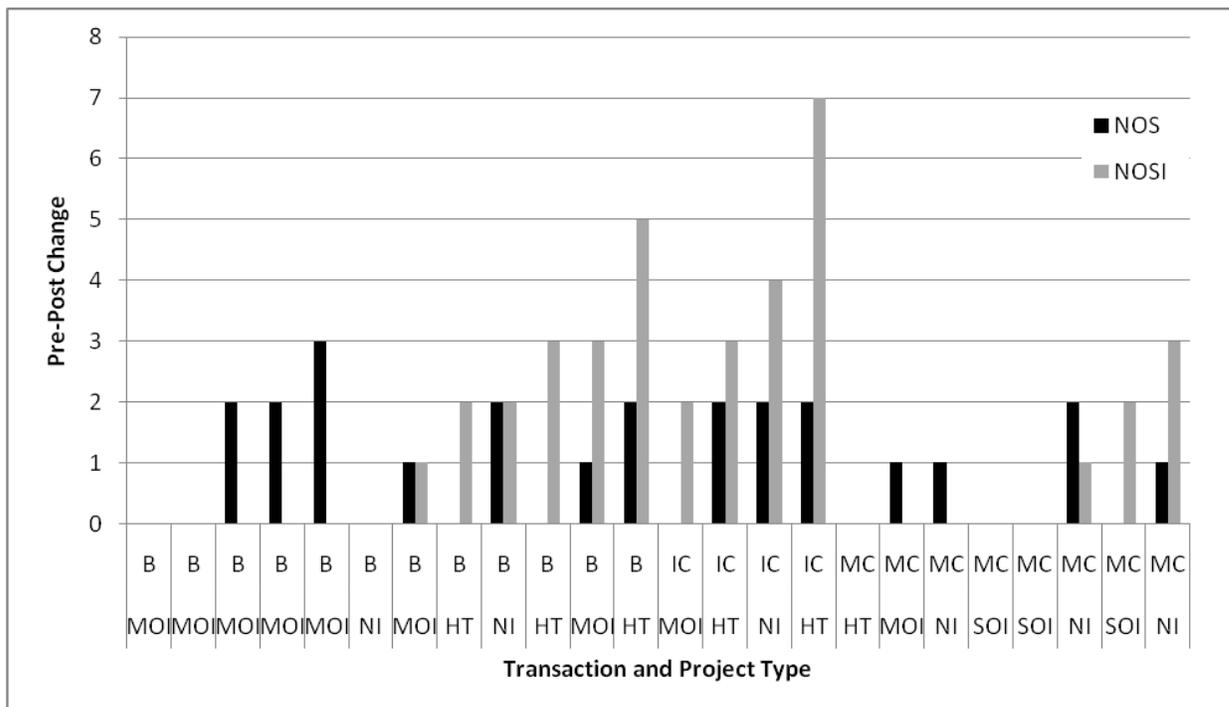
### **Interactions**

Figure 6.1 sorts program inquiry scores, and Figure 6.2 sorts NOS and NOSI scores, according to project type and intern-mentor transactions. Figure 6.1 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 6.2 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 6.1: 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 6.2: 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.

### Vignettes

Six illustrative vignettes are provided in this section. Each is an example of a different combination of project and transaction type, helping to illustrate some of the ways in which project type and transaction interacted and influenced outcomes for intern and mentor. The first three vignettes describe three different project types within mentor-centric transactions, the fourth and fifth vignettes describe two different project types within balanced transactions, and the sixth vignette describes one of the intern-centric transactions. Two other intern-centric transactions have been developed more fully into cases in Chapter 7.

### **Vicky and Ajay: A Lost Opportunity**

Vicky was a rising senior with one summer research experience already completed. She was hoping that another such experience might help her make the impending decision about graduate school and a future career in science. However, her summer experience demonstrates a lost opportunity to become engaged in scientific research. Vicky's screening project was unique among the others in the Program as it involved no molecular techniques. She spent several hours every day for the first seven weeks of the program plating seeds. She worked alone in a small room off the main laboratory, carefully pipeting tiny seeds into neat rows on agar plates. Vicky prepared approximately 35 such plates each day. Other regular tasks included pouring the agar plates, sterilizing seeds, measuring aspects of the seedlings' growth, entering this data into the computer, taking photographs of important seedlings, and transplanting important seedlings to soil. Once her mentor had shown her what to do, she had been left alone to carry on her work. She did not learn any new techniques until it was time to use the camera and computer set up in week 3. Because there was little other work for her to do, Vicky carefully timed completion of her daily work to avoid finishing early (which was looked down upon by the other interns). To pass the time, she made up little games, like removing pipet tips from the tray so that the empty spaces made a sunburst pattern, and chatted unceasingly with me about everything and anything during my observations.

The purpose of Vicky's work was to identify seedlings with longer than normal shoots because they may have a double mutation. Beyond that, Vicky did not know much about her project in the 3rd week of the program. For example:

V explains that she is using MS media but doesn't know what's in it or what MS stands for. (Vicky, Observation 1)

She puts the plates into the fridge and I ask her why they have to go in there. She says she doesn't know. They have to go into the fridge first for 3 days then

into the growth chamber. She suggests that perhaps they have some “settling in” to do. (Vicky, Observation 4)

I ask V why she has to plant so many seeds. She is not sure other than to produce replicates. Or, “maybe to play it safe in case they need to produce seeds from some of the plants.” (Vicky, Observation 1)

V listed the observations she has to make: find the plate, count the number of ungerminated seeds and log this into the computer. She has to do this every few days, so many plates per day. She must also include any notes about things she may have noticed. I ask her why she has to do this and she says she’s not sure. She offers that perhaps they are not sure what results they’re looking for so the more early information they have about the seedlings the better. (Vicky, Observation 1)

The first two examples demonstrate that Vicky did not know simple information about her procedure, for example, that *Arabidopsis* seeds require a cold treatment before they will germinate. The third and fourth examples demonstrate that Vicky did not know why she was collecting certain types of data and therefore how they would eventually be analyzed. Each of these questions had a simple, standard answer that could have easily been explained in the process of instructing the intern. For example, a large sample size is necessary for discerning an accurate ratio of phenotypes. The ratio will suggest a particular inheritance pattern. For example, a simple 3:1 ratio means that there are no other genes or mutations influencing the phenotype. Vicky’s mentor did not explain these things to her, and Vicky did not think to ask, nor did she make the connection on her own to the subject matter of her genetics course. When it was time to analyze the data, Vicky sat and listened while her mentor and PI discussed the results and their meaning.

Vicky’s mentor, a post-doctoral researcher named Ajay, was new to the institute and the program. Ajay’s main criterion in developing a good project for a summer intern was meeting the time constraint of the 10-week program. The screening project fit that criterion and Ajay was pleasantly surprised when Vicky finished up in only seven weeks. Ajay’s mentor-centric attitude that conducting repetitive, boring work was an appropriate use of the intern reflected

his own personal experiences as an undergraduate and a mentor of undergraduates at his former institution.

Vicky had resigned herself to the nature of her work, though she suspected that other interns were having a different experience than hers:

As V photographs her plates, we chat about her experience. She asks me what I am learning from observing the other interns. I evade the question. During this time she makes the following observations:

“I really feel like so far I haven’t learned any new skills that would help me if I go on.”

“Research last summer at my school was like following a cook book. I’m not sure if it’s like that here, or if they [the other interns] are taking more of the lead in the research. Like: ‘Here, PCR this. Go!’ – and then they have to figure it out. I’m just helping out in the lab doing what needs to be done.” V wants to know if other interns are experiencing the cook-book model she experienced last year or a more autonomous model.

V says she is fine being the lab help. Now she thinks that this “kind of is her own project” but it’s “kind of not molecular.” She also said, “In the end it’s good on the resume and I learned good techniques. That’s all that matters. It’s not as if I specifically love seedling development.” (Vicky, Observation 2)

It is unclear whether Vicky would have liked to take more of a lead in a research project, or if she was in fact satisfied her role. She wanted to learn how to use cool equipment like the multichannel pipet and confocal microscope; she also wanted to develop marketable skills that would help her get a job after graduation. In her exit survey she commented that she had hoped to learn how to develop and carry out a research project on her own. On the other hand, by the end of the program she stated that she had gained the following insight (congruent with her absolutist’s views of the role of the learner and instructor):

MRP: I see your [written] answer there but has that changed at all? Has that been developed by your experiences here?

Vicky: I don’t think it has been changed. But I think I added something. And that is that I work much better if I do not figure things out for myself. If somebody just tells me what to do. Because there were a few times where Ajay was just like, “Figure this out on your own.” And I felt like I was sitting there like an hour like “OK, I’m looking things up on line,” or

“OK I’m doing this, I’m doing that.” But if he just told me, I’d be like “OK, I’m going to remember that - you just showed me XYZ.” But if I have to figure it out, I’m going to go through “maybe it’s this, maybe it was this.” And then when I go to remember it, all I remember is “maybe it was this, maybe it was this, maybe it was this.”

MRP: You remember the process rather than the conclusion?

Vicky: Exactly. Exactly. So if someone just shows me, “Here’s the conclusion,” that’s perfect. (Vicky, Late Interview)

Vicky’s experience is an example of a lost opportunity to become engaged in research. Though she had a great deal of day-to-day independence, her autonomy score was lower than most (Figure 5.1). Her work was so simple and uninteresting that it required little to no thinking. Though her program inquiry score fell in the middle range for the cohort (Figure 5.1), she had few if any opportunities to practice more advanced inquiry skills like troubleshooting, evaluating evidence, developing an explanation or argument, and it is unclear if she would have risen to such challenges were they available. She had little interest in the research topic and her personal interests in learning new techniques were not met. Vicky made shallow gains in understandings about NOS (experiment; Figure 5.2) and modest gains in understandings about NOSI (community of practice and justification; Figure 5.3).

### **Tanis and Arthur: Double Jeopardy**

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 troubleshooting 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 an 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.

### **Helen and Franck: Too Much of a Good Thing?**

Helen's hypothesis-testing project was designed by her mentor to test which of a set of candidate genes was involved in a cellular process known as RNA editing<sup>4</sup>. In this sense her project was descriptive. She could detect a gene's involvement by blocking its activity and then monitoring how this did or did not influence the editing process. If knocking out a candidate gene's function enhanced the RNA editing process, then one could conclude that the candidate gene's normal function was to "down regulate" RNA editing. If knocking out the gene impaired the editing process, then one could conclude that the gene's normal function was to "up regulate" editing. Therefore, the test for each candidate was a test of a null hypothesis (no effect on the editing process) and two alternative hypotheses: up-regulation or down-regulation.

Helen's research project was highly sophisticated, requiring facility with a number of advanced techniques. The project also required a great deal of subject matter knowledge in order to understand the techniques involved as well as the molecular biology of gene-knock-out and RNA editing. The procedures, which had been carefully laid out and tested by her mentor, involved cloning the candidate gene into a special knock-out vector, transforming bacteria with the vector, transforming plants with the bacterium, extracting RNA from infected plants and using a specialized nucleic acid sequencing method to measure editing at 8 different loci. Each

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<sup>4</sup> RNA editing is a cellular mechanism that helps to mitigate the negative effects of mutation. Editing enzymes recognize certain errors in the RNA sequence and repair these before the process that translates the RNA into a functioning protein.

of these procedures involved a multitude of steps, wait-time, and further steps for verification that things actually worked as they were expected to. Helen managed to test ten candidate genes in ten weeks, and her work earned her a research award from the Institute.

Helen was a rising senior with four semesters of prior research experience and several courses in advanced molecular biology and chemistry. She was hand selected by her mentor, Franck, because of her academic record. The project was a significant piece of Franck's postdoctoral research, which he intended to publish once completed. Franck had mentored many interns in the past. He had found his last intern to be too inexperienced to conduct satisfactory work and therefore a waste of his time and effort. However, Franck was very happy with Helen's dexterity and efficiency in the lab, her ability to quickly grasp new techniques and concepts, and her motivation to excel at research. Helen was, for the most part, satisfied with her experience, but she did feel constrained by "too much mentoring" (Helen, Late Interview). She was used to greater independence in her laboratory work and chaffed at the high level of monitoring by her mentor. At the same time, she confessed that she often found it difficult to relate her work at the bench to the project's overall aims – most of her discussions with her mentor dealt with executing and understanding the ins and outs of the various techniques. She had no input or choice in the research question or design of her project. She also felt she had little freedom to trouble-shoot problems or figure things out on her own, including interpreting data and developing explanations. It was not until Franck left for vacation during the 8<sup>th</sup> week of the program that Helen began to enjoy some freedom in problem-solving or trouble-shooting, and to try her hand at analyzing her data. In our conversation about how much more she enjoyed the last weeks of the program, Helen commented:

When you're working under the supervision of a mentor you kind of feel like you're just there to do the busy work. But when you're actually by yourself, like, you have to think and stuff and it actually feels like it is your own project. (Helen, Late Interview)

Helen's research experience was truly cutting edge and highly productive, yet she felt she learned very little about how to frame a research question or a hypothesis and how to design an investigation in molecular biology. Helen was not testing her own hypothesis, she did not invest the mental energy in thinking through the possible outcomes in order to see what was the most likely, or anticipated outcome, and what all the potential alternatives might be. Her mentor did this for her, before the internship began. Furthermore, it is likely that Helen would not have been able to realistically anticipate likely outcomes and potential alternatives, having had little exposure to the very advanced subject matter framing her project; RNA editing is a very current research topic. Her autonomy score was among the lowest, and her program inquiry score was also relatively low (Figure 5.1). She also made no gains in understandings about NOS or NOSI.

#### **Taylor and Faith: Striking the Right Balance**

Taylor was a fifth-year senior with four prior semesters conducting molecular research and an advanced molecular methods course. Her research project in the Program was to characterize the effects of a fruit-ripening mutation. She did this in part through physiological experiments in the greenhouse: timing fruit development, measuring hormone production, measuring aspects of plant growth after exposure to ripening hormones. She also used molecular techniques in the laboratory to find the specific location of the mutant gene, clone it, and then sequence it to determine the exact nature of the mutation. The multifaceted nature of Taylor's project gave her first hand experience with a number of new ideas: multiple phenotypic effects of a single mutation (a genetics concept known as pleiotropy), multiple explanations for a phenomenon (NOS), and experiencing the need for multiple approaches to fully address a research question and justify one's findings (NOSI). Such outcomes were typical of multifaceted-observational investigations. What made Taylor's research experience atypical,

however, was the opportunity to grapple with anomalous data and work *with* her mentor in developing a plan to investigate the anomaly (rather than just observe this process). Taylor and her mentor, Faith, began by discussing and reviewing all of the steps that Taylor had taken, setting up new trials to investigate parameters such as temperature, volumes, incubation times, and specific enzymes. Once these were exhausted, they turned to alternative explanations. One promising alternative the pair discussed was that the mutation of interest caused variable splicing around an intron<sup>5</sup>. Trouble-shooting, trying to figure out what went wrong in an investigation and attempting to fix it, was something that most interns experienced. However, this typically took the appearance of reviewing one's steps to see where a mistake was made or a faulty reagent used, or of "tweaking" a protocol. Taylor was among the very few interns who actively participated in the process of modifying a hypothesis, revising an investigation based on anomalous data, and using scientific knowledge and background knowledge to do so. A rising senior with a great deal of prior research experience in which she had practiced many of the techniques employed in this research project, Taylor amply demonstrated her ability to organize her time, work independently, and evaluate results. Faith recognized Taylor's abilities and frequently engaged her in decision making by asking for her input:

I think she had something to prove to herself, that she could go to grad school, that she could do this. You know she worked in a lab that was very much the guy comes in, gives her stuff to do, and he leaves. Um, so I think it helped her for me to give her a little lee way and be like, "Ok, what do you think we should do next?" She even said, she had a great idea before she left! She said, "Well we tried these stages, why don't we try" - she went back, this is fantastic initiative, she went back to the original papers and said, "All right, maybe we're looking in the wrong stage. Why don't we look in [stage name]?" (Faith, Interview)

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<sup>5</sup> Introns are sequences of genetic material embedded within genes that normally get spliced out of the RNA molecule transcribed from the gene, before the RNA is translated into a functioning protein. A mutation that causes the cell to fail to recognize an intron results in an RNA transcript that is too long, with disastrous results for the final protein.

Faith was a postdoctoral researcher with a long history with the summer internship program. Because she had a great deal of work to accomplish this summer, she specifically chose a very experienced intern. As soon as she recognized that Taylor could in fact be the partner she had been hoping for, she treated her as such, sharing responsibility for the work and its outcomes with the intern. Taylor viewed Faith as a role model, a sort of future self. She spent the last week of the program investigating and contacting PIs in laboratories in her home state conducting similar research for information about graduate school. Taylor's experience demonstrates that a multifaceted project can provide a rich learning experience about scientific inquiry and practice. It also shows what a good mentor can contribute, given a highly qualified intern. Though she made only slight gains in understandings about NOS (creative; Figure 5.2) and NOSI (anomalies; Figure 5.3), Taylor's autonomy and program inquiry scores were among the highest in the Program (Figure 5.1).

#### **Betty and Gabriella: Two Novices Can Make a Right**

The case of Betty and Gabriella is an example of a balanced intern-mentor transaction where the intern and the mentor were both novices in their roles. Betty's research project involved both tool development and hypothesis testing. The question that framed her research could be paraphrased: "Which of these candidate proteins acts as a substrate for the protein XYZ<sup>6</sup>?" Betty's task was to cull a list of proteins, previously identified by her mentor, using a more specific technique examining protein-protein interactions *in vivo*. It was a rather new technique and had not yet been used in this laboratory with this protein system. Thus, much of Betty's laboratory work focused on tailoring the general protocol to meet the specifics of her project's materials and lab conditions. The overall procedure involved four major steps that were laid out in detail by her mentor upon Betty's arrival: DNA extraction, PCR amplification,

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<sup>6</sup> Pseudonym

bacterial cloning and infusions to transform plants. Once the plants were transformed and expressing the proteins of interest, data-collection was a simple matter of using a special microscope that measured the strength<sup>7</sup> of the interaction between the protein XYZ and the candidate protein. However, each of the smaller steps in the protocol required data collection, usually in the form of gel results, to verify that the step worked (for example, did the DNA of interest insert into the plasmid in the correct location?). Thus Betty gained experience in reading results, evaluating the quality of her work based on her results, trouble-shooting failures, and revising her approach – for example, selecting a different positive control or testing a longer incubation time. Much of this work was done independently, especially in the later weeks of the program. She also learned about the importance in molecular research of verifying each step before proceeding to the next.

Betty was a rising junior with no prior research experience. Gabriella, a new PI fresh from her own postdoctoral experience, had mentored a single undergraduate at another institution. In working with Betty, Gabriella tried to think about how she had felt as a student, and how she would like to be treated by a mentor. After initially training Betty on the techniques and equipment, she spent most of her time working in her office down the hall. However, Gabriella frequently checked in throughout the day and made herself available when Betty sought her out. Betty found this arrangement to be both uncomfortable and motivating. It forced her to seek help when she needed it, but it also allowed her to test herself and her own judgments. For example:

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<sup>7</sup> This cloning procedure results in a bioluminescent reaction, using the same biochemistry as in a fire-fly, when the two proteins bind together. The intensity of the light produced can be detected and measured by a microscope equipped with a special sensor. The greater the intensity of the light produced, the greater the affinity of the two proteins for one another.

...when Gabriella comes in and is like, “OK, I want you to do this, this and this,” she doesn’t assume – she makes the perfect amount of assumptions. She doesn’t assume that I know nothing and she doesn’t assume that I know everything and she has enough faith in me to leave me in the lab by myself. I like that because that makes me really want to do well. It makes me pay attention and not just sit there and listen to her tell me what to do. (Betty, Early Interview)

I think that’s why me and Gabriella got along so well. She was like, sort of not too hands off because she was accessible. But she let me work through things. You know um and that’s sort of the same relationship I would like to have with an instructor. When you feel comfortable asking questions, they don’t make you feel stupid, but that you have enough faith in my ability to push me a little bit, make me feel uncomfortable. And yeah, at the beginning I was like “Why isn’t Gabriella in here all the time, why am I always by myself?” But in the end, it was a blessing. (Betty, Late Interview)

Betty’s research experience is an example of a highly successful, balanced intern-mentor transaction in which a research novice was provided some autonomy. Though the research question was very simple (“Which of these are substrates?”), the tool-development aspect of the project was challenging, and the challenges were surmountable. Both intern and mentor were pleased with the outcome: a procedure well on its way to being optimized for the laboratory’s on-going work, and verification of several of the original candidates as substrates for protein XYZ. Though her program inquiry and autonomy scores were in the middle of the range (Figure 5.1), Betty learned about the uncertain and finicky nature of molecular work and had many opportunities to practice independent decision making, trouble-shooting, taking initiative, utilizing available resources, data analysis and self-evaluation. Though she made modest gains in understandings about NOS (theory-laden; Figure 5.2), she made large gains in understandings about NOSI (community of practice, justification, multiple purposes, and scientific methods; Figure 5.3).

#### **Angela and Young: And the Award for Best Supporting Mentor Goes to...**

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 very 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?

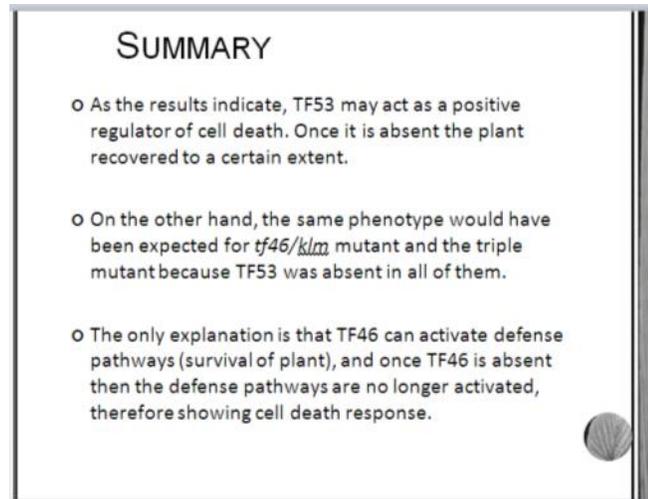
Angela: I - yes?  
MRP: Could you explain that to me?  
Angela: Well that's always, like I don't have the definition of genotype in my head but like last time (*referring to her early interview*) I had trouble answering you what a gene was, and I think I still do [have trouble]. But I think I have a 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: Mhm (*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.



**Figure 6.3: Final Slide of Angela’s Student Symposium Presentation**

Angela’s research experience fell into the intern-centric category because her mentor’s goal from the outset was to teach. He selected Angela from the intern pool because of the 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 6.3) 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 5.2), she did make modest gains in understanding aspects of NOSI (anomalies and multiple purposes, Figure 5.3).

## **Discussion**

### **Research Project**

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 vignettes featuring Vicky and 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, as Helen's vignette illustrates. 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, as the vignette featuring Betty and her novice mentor, Gabriella, demonstrates. 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 and Shanell (who were situated in intern-centric transactions) where they 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.

This chapter has demonstrated how project type and transaction type can influence learning and other outcomes of UREs, and suggests ways in which mentors can structure the URE to foster student learning and development. Findings also help to understand the interactions that take place within a URE that can lead to feelings of satisfaction or dissatisfaction and stimulate students to continue to pursue research opportunities or turn away from further research (Lopatto, 2004; Russel 2005a). Project type and intern-mentor transactions can be productive areas of focus for program developers, especially those interested in recruiting and supporting the least experienced students.

## **CHAPTER 7**

### **Illustrative Cases**

#### **Introduction**

The types of research projects and intern-mentor transactions observed in this URE help to explain some of the differences in outcomes observed across the intern cohort. To further illustrate the complexity of interactions that occurred between the intern, mentor, teaching and learning laboratory research, I developed two special cases to illustrate some of the complex interactions between the research, the intern and the mentor that unfolded as the work progressed. Every intern-mentor pair was a unique case of teaching and learning through laboratory research. However, Elliot's experience was noteworthy because he was the only intern to develop his own investigation to test his own scientific question. Monique's experience was also interesting to me because in the beginning, hers looked to be an ideal situation for both intern and mentor: an experienced intern with aspirations for graduate training in plant biology situated in an intern-centric transaction with an experienced mentor involving one of the few projects designed explicitly to cover the full range of inquiry. However, as the internship unfolded this turned out not to be the case, and I wanted to understand why.

#### **Elliot and Mandy**

##### **The Intern**

Elliot was a tall and lanky young man from the Midwest. Though he spoke with a soft voice, and took his time to thoughtfully answer questions, Elliot was talkative and animated during our interviews and during my observations of his lab work. Elliot's mentor laughed out loud when I told her that he had described himself as "shy" in his personal statement. "He is the least shy undergraduate I've ever met," she declared. "He is definitely an impresser" (Mandy, Interview).

Elliot attended a small state college, “a good little school” situated “in the middle of cornfields.” He entered college with over 44 hours of advanced placement credit, and thus most of his general education requirements met. He chose Biochemistry as a major because he was not ready to make a decision between Biology or Chemistry, and this seemed like a practical compromise within a system that forces one to choose early. Elliot explained that he liked to keep his options open to give himself time to explore.

Elliot’s interest in plant biology developed during a first-year course in Botany at his home institution. He had originally anticipated a career in veterinary or human medicine. However, he found that with plant biology, “something just clicked.” Elliot recalled shadowing a vet, but “daydreaming about plants” the whole time. By the time he entered the Program as a rising Junior, Elliot had completed three plant biology courses and one molecular biology course, along with three semesters of plant-related research. Now, in his second week in the internship, Elliot had already found the campus’s public greenhouse (because he wanted to see the *Welwitschia*), and the campus's arboretum; both were somewhat out of the way for most interns.

Elliot’s keen interest in plant biology brought him to the Program. A secondary reason for applying to this program in particular was the feeling that his undergraduate laboratory experiences were weak, especially in his plant biology courses where they mostly “just looked at things” (Elliot, Early Interview). He expected this program to be “more and better” than his prior research experiences:

Elliot: I knew I wanted more experience. And this would be a place to get it. I guess I’m expecting more molecular biology, that kind of level, and so far it has been. And I’m not saying that’s good or bad. Actually I will say that’s good, because I tend to lean toward the more macroscopic level.

MRP: How do you think it’ll be different from your prior experiences?

Elliot: More molecular. And more and better equipment. Just more and better of everything. (Elliot, Early Interview)

Elliot explained that his interests leaned more toward the "macroscopic level," but that molecular research had become such an important part of biology, he felt he needed to gain some experience with it.

Each of Elliot's three semesters of prior research was quite different. As a greenhouse manager at his home institution, he experimented with coffee grounds (upon the suggestion of a professor) in controlling a pest-outbreak. Another semester, Elliot used an X-ray flourometer to test different soils for the presence of hard metals. The research question was something he worked out with his professor who had just bought the machine and "wanted to do something with it" (Elliot, Early Interview). It was Elliot's idea to test soil with the intention of then going out to look at the plants growing in the sampling areas and perhaps say something about their tolerances for different substances in the soils. He had read up on bioremediation and found it to be an exciting application of plant biology. Most recently, Elliot had been working in a plant evolution lab where he intended to fine-section cycad stems to examine the cellular structure of the wood. This work had not yet gotten off the ground because the laboratory did not have the correct blades for the work, and Elliot still needed to learn how to use the microtome, the tool for sectioning tissue. This research question developed directly from Elliot's own desire to learn:

First, I just wanted to see the inside of a cycad. It's a different kind of wood. I wanted to know why. And how. I wanted to know all of that. And then I wanted to see why it was retained in select areas of the ginkgo. And I also had a hypothesis for that. But that- I haven't been able to test it yet. (Elliot, Early Interview)

Thus, Elliot had some experience in his past two years of undergraduate work, beyond classroom-laboratory experiences in biology and chemistry, in practicing aspects of inquiry. In particular, he felt that he had ample experience in collecting and summarizing data (though not analyzing it), using primary literature, thinking about alternative explanations for data, modifying hypotheses, and trouble-shooting. Elliot's prior research also demonstrates some

experience designing and investigating his own questions and a willingness to seek advice from scientific authorities. His self-reported pre-program inquiry score of 29 was close to the mean ( $29.9 \pm 10.6$  out of a possible 56). Elliot also had emerging or informed views on six of the seven aspects of NOS investigated (NOS = 14, Figure 5.2; his views of theory-laden NOS were naïve), and emerging or informed views of many aspects of NOSI (NOSI = 7, Figure 5.3). His views on the multiple purposes of scientific investigation were robust: scientists investigate for a variety of reasons: what is interesting, important, useful to society, and politically motivated.

The three stories of prior research were congruent with Elliot's approach to learning, and both would help me to understand his approach to research in this Program. Elliot placed a priority on the opinion of experts and had an absolutist's view of the role of the instructor. Yet he was transitional in his views in other domains, particularly the role of the learner to understand and apply knowledge and the role of evaluation to test understanding and ability to apply what one's learned. Elliot took a mastery approach to learning and investigation: he started with his own questions about an interesting problem and went to work to develop an answer, using what resources were available to him. Elliot's ability to ask good questions and work at investigating a problem independently were pleasant surprises for his mentor, Mandy:

I guess I thought that he wouldn't be so self motivated. I expected to be um, kind of telling him more what to work on. I had a list of 4 or 5 projects he could start with, but as soon as he met with Dr. N. he went off and designed his own project that was completely different. And so, I mean, I guess I expected that here are some projects and he'll have the opportunity to choose which project he's doing so there's some like personal interest in what he's doing. But um, yeah, he went totally beyond those expectations. (Mandy, Interview)

### **The Mentor**

I met Mandy during my first observation of Elliot. When I arrived, the two were discussing Elliot's plan for the day: embedding leaves for sectioning, setting up a PCR and gel, doing some work with branch analysis. Mandy was young, athletic, and had boundless energy.

Even when she stood still, she appeared to be in motion. She listened intently with her head cocked to one side, used a lot of body language when she spoke, and laughed a lot. One morning Elliot commented under his voice to me, “that’s what she’s like when she’s NOT on coffee. Imagine what she’s like when she is!” (Elliot, Observation 2).

Mandy described herself as from the “west coast and so pretty relaxed” (Mandy, Interview) about things. She had just finished her first year of graduate work and was now at the early stage of outlining her own research and thus had no pressing deadlines. This made Mandy unique among the mentors of the program; it was unusual for a graduate student in such an early phase of her work to take an intern. She told me that she had volunteered because “there are a lot of ideas that I have that he can help me figure out” (Mandy, Interview). She had mentored high school students when she was a research technician, and had found it to be fun. She also saw this as an opportunity to gauge whether she could work with an undergraduate on research in her future career.

When I asked her how she viewed the goals of the Program, she first explained to me that as an undergraduate she had been more engaged by college athletics than academics, until she discovered undergraduate research. She had learned that investigating questions was fun and that “biology isn’t just a body of facts, it’s something to be tested and worked with” (Mandy, Interview). Undergraduate research had been a motivating experience for her, helping her to engage more with academics. For example:

I always kind of hated learning new skills in like a class setting because it was so inefficient and like the whole idea of being in a research lab is that you’re using these skills and learning them but towards a purpose. That makes it more - that made it a lot more exciting for me. (Mandy, Interview)

In her view, the purpose of the Program was for students to test whether they were interested in a research career and for mentors to provide an engaging learning experience. Thus, an ideal research project was not one that “goes really smoothly and everything works,” (Mandy,

Interview) because a lot of learning occurs when things do not work. At the same time, seeing results at the end is a satisfying experience. Striking the right balance for a ten-week internship can be a challenge.

Mandy drew upon her own experiences as an undergraduate researcher in developing her approach to working with Elliot. She described her approach as “training in action.” Since she felt that it would be boring for Elliot to learn new things by watching her do it, she would do a new technique along with him the first time, explaining as they went about the work. After that, she would let him work independently, but stayed close to observe and provide feedback. This also describes her approach to Elliot’s day-to-day work. She knew that it was important for a mentor to be patient and to encourage as many questions as necessary and to be there to answer them. She also felt that it was important to anticipate areas where a novice might become confused or frustrated. Mandy told me that her biggest challenge was gauging whether or not she was explaining things clearly, because sometimes Elliot would ask her questions that made her feel like he “wasn’t getting it” (Mandy, Interview). To make sure, she would try several different approaches: telling, writing, drawing diagrams and flow charts, videos from U-tube.

Mandy’s perspective on the goals of a URE were that it should engage students in research and be an exciting learning experience. It should help students learn whether they are interested in pursuing a research career. I asked Mandy what else she believed interns needed to gain from undergraduate research in order to be successful in graduate school. Her response helps to put Elliot’s research experience in context and foreshadows some of its outcomes:

Mandy: I think that, well this emphasis on research being something that comes about through thinking about questions in biology and testing these questions. And just kind of the process of research not being this regimented scientific method. I think that’s something important to stress when you’re in a research environment.

MRP: Did you guys talk about that at all, by the way? You know, THE Scientific Method?

Mandy: Oh. I don't think it ever came up. Yeah, the scientific method- I don't think we ever had a formal conversation about that. But I did explain to him that in research things are extremely flexible and most of the important discoveries, like people's larger discoveries, they weren't from the actual question they were asking. It was like they asked the question and they saw something weird in their experiment and they asked a question about that. There's kind of a flow to research that is not like, "I'm going to discover this and then I'm going to do this."

### **The Research Experience**

Elliot felt that his lab placement was a good fit. He and his mentor were both deeply interested in topics of evolution and paleobotany. Mandy's commitment to providing an engaging experience meant that she tuned the research toward Elliot's interests, offering him the opportunity to contribute to the design and development of his project. Elliot was the only intern in the 2009 cohort to investigate his own question, design his own investigation, and was one of the few offered choices by his mentor.

Elliot also had a very heterogeneous research experience. He and his mentor worked together to devise four small investigations that blended both of their interests and incorporated some techniques that Mandy thought might be "cool" for Elliot to experience. Mandy described Elliot's project and work as "free form" in the beginning. The pair spent the first few weeks of the program testing ideas, exploring options, and refreshing Elliot's knowledge of simple techniques, such as pipetting and PCR. Here is how Elliot described how the project developed over the course of the summer:

We had an idea of what we wanted to study. We wanted to study this apical cell development issue, is the best way I can put it. And as we started to work, we started to see other things we wanted to do. It wasn't until probably the fifth or sixth week that [the PI] suggested doing *in situ*'s<sup>1</sup>. (Elliot, Late Interview)

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<sup>1</sup> *In situ* hybridization is a technique that localizes a particular DNA or RNA sequence, typically in thinly sectioned tissue.

Three of Elliot's investigations were molecular in nature and directly related to Mandy's overall interest in understanding apical development in lower plants. The fourth was an anatomical, macroscopic-level project and designed by Elliot. Though Mandy ultimately selected the methods for the molecular investigations, she and Elliot both felt that they collaborated to design these projects together. Mandy offered Elliot choices, such as which genes, strains, or mutations to use in the investigations. These projects were indefinite, or uncertain as to their outcomes. In each case, the purpose of the investigation was simply to "try and see." For example, Mandy had never attempted to make a transgenic strain of moss before and did not know whether she and Elliot would be successful. The expectation was not that Elliot would then be able to work with it, rather just to see if it could be done. The following quote describes the rationale behind some of the molecular work. It also illustrates the level of detail at which Elliot already understood his project in the second week of the Program.

And then for [species of moss], I'm looking at LTPs, lipid transport proteins, to try to see what they do there. We know they're expressed in the tunica of *Arabidopsis*, but moss doesn't have that arrangement for meristem, so – and they're there. We know they're there. But we're not even sure what they do in *Arabidopsis*. So we'll see what they do in [species of moss]. And for that we're going to mark with YFP<sup>2</sup> and see where they are. And then hopefully I would like to – if there's time – over-express that gene and see what happens. But [my PI] says one of two things: it'll either kill it or just, you won't have any idea what's going on, but do it anyway. (Elliot, Early Interview)

The pair's first approach to visualizing the location of LTP's mentioned in the quote above, was to use a cloning procedure that involved a sequence of molecular techniques. Mandy's approach to teaching Elliot how to do this cloning procedure is a good example of much of Elliot's experience in the internship. As with much modern molecular lab work, the instructions and materials for the cloning procedure came packaged in a kit. In teaching Elliot how to use the kit, Mandy ran through each item and each step described in the instruction

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<sup>2</sup> Yellow fluorescent protein.

manual. As she did so, she made many suggestions, slight changes, and warnings, and Elliot made note of these things in his notebook. Others in the lab (graduate students) frequently chimed in bits of advice as they overheard discussions between Mandy and Elliot. Mandy then worked alongside Elliot to execute the new technique, demonstrating, observing and providing feedback. This process of working together was repeated multiple times throughout the summer as Elliot's research project continued to evolve. As with most interns, Elliot asked procedural question regarding new techniques and tools. However, he also took good notes and relied on these and protocols to answer questions for himself first, rather than simply asking Mandy, who was usually nearby. As Elliot became familiar with the new techniques and tools, he was able to do much of his day-to-day work independently. The following excerpts from my first observation of Elliot in week four of the Program illustrate how he worked through a task in which he had recently been trained.

E pipets some ethidium bromide into the flask of melted agarose like a pro – he holds the jar of ethidium bromide and its cap in the same hand and touches nothing with the tip of his pipet except the liquid he is dispensing. He swirls the flask and pours the gel, places the comb in and says: One down.

The gel box that he is using has a hand-written label on colored tape: "Fickle Box." I point this out and E says: If you use the wonky lid with the fickle box it works.

He notices that he put his gel bed into the box in the wrong orientation before he poured. He will wait for the gel to solidify before he fixes it.

...

M checks in. He tells her what he's done and she tells him what she's going to do now. E explains that he's trying to decide if he should go down to the sectioning room before he runs the gels. She thinks about it.

M: Do you want to start the gel, do embedding and then check the gel?

E: Sure.

They continue to discuss more to do: gel purify, PCR, greenhouse. E explains what shade cloth is. M explains what humidity domes are. E promises to think about both some more.

...

E figures in his notebook. He draws gel outlines. He flips back a few pages to consult a gel image taped into the notebook and the notes he's written around the image to label his new drawings. E finishes: Now I'll keep these straight. E leafs through his notebook to find the "gel recovery period."

...

M points out that E's gel is in the wrong orientation. E says "Yep" and puts on gloves. E gingerly touches the gels to check for doneness then reports that he's going to the fridge to pull out stuff. He returns with 11 tubes.

E to me: This week I really feel like I'm doing stuff. It's great.

...

E talks out loud while he figures out what to do next: "gel purification", "old sample #3." He checks back in his notes. He picks up two tubes and returns to the gel area. He slides the gel bed out and turns it around. He removes the comb and checks to make sure that the wells look OK. He consults his notebook and then goes to M to check something with her (she's across the lab working at the hood). I cannot hear but it is clear that she is explaining something, he asks questions. They return. She's explaining that DNA is negatively charged. She confirms that the gel is in the right position in the box (wells should be positioned closest to the negative electrode). They talk about a mix-up from last week. M says: That's OK. Sometimes the cables get switched.

E to me: So that was weird. Sometimes I just forget things or I think I forget things, but really I'm confused.

E puts a tip onto his pipet, carefully draws up some sample at eye level, and pipets the sample out onto a piece of parafilm. The sample forms a bead of liquid on the waxy surface of the film. He tells me that M showed him this technique for mixing.

He says: some techniques work better in practice than what you learn in a classroom setting.

He repeats for each sample, changing the tip each time. He puts on a new tip and resets the volume on the pipet. He adds loading dye to each of the liquid beads on the parafilm. He puts on a new tip and resets the volume. Now he sucks up from the first bead and moves to load a well on the gel, but stops.

E: That was close!

He had forgotten to add running buffer to the gel box. He does this and then loads the well. He cleans the tip of his pipet in the running buffer (unnecessarily) before he discards it.

E tells me he likes to check and double check over and over.

E repeats the steps with two other tubes while chatting with me. He explains that he doesn't need a size ladder this time because what he is doing is purification. He'll be physically cutting the band(s) out of the gel. He already ran a check gel earlier with a ladder to confirm that the band shows up where it's supposed to on the gel (i.e. is the correct size).

...

E almost forgets running buffer again in this second gel. As he pours buffer I ask why he needs to run the sample again and at first he says he doesn't know. Then he works out a reasonable explanation as to why the DNA couldn't be purified from the check gel: that was a very small sample. This is all the rest of

it. E explains that after we purify then we'll amplify it and then after that he does not know what comes next. He's happy with that because he's sure he would not remember when the time comes anyhow. E checks that the buffer is now bubbling (a sign that power is running through the apparatus), then labels each gel rig with tape. (Elliot, Observation 1)

These excerpts demonstrate that Elliot was both confident and cautious about his work, that he was learning from earlier mistakes, using his notebook as a cognitive tool, and that he was reflective about his thinking – e.g. “is this a case of forgetting or a case of confusion?” The excerpts also demonstrate that Elliot had some understanding of the procedures and why he was doing them, but that he was still learning.

One area where Elliot needed the most support throughout the internship was in mapping out his activities for the immediate future. He had multiple projects running at the same time, and therefore needed a lot of support in planning his activities efficiently in order to balance these several projects, use shared equipment, and fill in the wait-times associated with many of his procedures. Furthermore, the “free form” nature of his early work meant that he did not have a clearly defined, overall research plan. Though Elliot enjoyed the variety in his work, and the relaxed attitude of his mentor, he found that the lack of an overarching plan made it difficult to understand the purpose of each smaller task: “Last week it was just a bunch of random things that honestly I'm not sure I can repeat, because I didn't know where they fit in” (Elliot, Early Interview). Thus, where they were in the research plan was a major theme for Elliot and Mandy; their early interactions were dominated by Elliot's questions of “Where am I?” and “What am I doing this for?”

By early July, Mandy realized that Elliot was having a difficult time keeping track of where he was in the research plan and was getting confused between his multiple projects. Therefore, she drew up an outline or flow chart for the second half of the program to help Elliot navigate the various projects. As she explained to me in her interview,

... we were working with two different species, three molecular biology projects and for like, different aims. So in *Sellaginella* we were trying to look at where a gene was expressed through a protocol called *in situ* hybridization. And in moss we were trying to make [specific enzyme] mutants and reporter lines that are like, stable transgenic plants. So we were using similar protocols but toward different aims in different species and I think that might have been too much to keep straight. Elliot would be like, "Oh wait, what are these plasmids for again?" And I would be like, "These are *Sellaginella* plasmids. We are using them to make a probe." And he would be like, "Right. Right. I have an outline right here." So as long as I went back to the diagrams, he could keep track of things. But I think that's normal when you start in a lab. Like, having more than one experiment is actually a pretty complex process. (Mandy Interview)

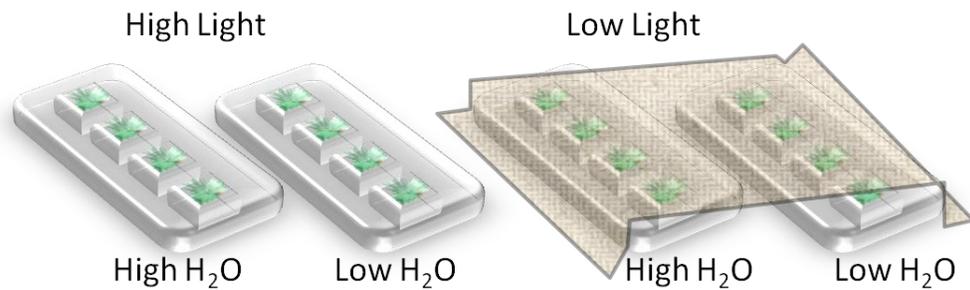
Elliot had complete control over his fourth investigation, which examined the branching pattern in a primitive plant under various greenhouse conditions. This was possible because the self-designed investigation did not involve molecular biology or techniques with which Elliot was unfamiliar. It was a straight-forward investigation testing the effects of two variables (water and light) on the plant's growth on a macroscopic level. Elliot's ownership of this project afforded him many opportunities to independently practice various aspects of scientific inquiry. He drew on his background as a greenhouse manager and a robust understanding of an experiment to design a balanced investigation, and to trouble-shoot when things did not go as planned. To determine how to collect data and manipulate it for analysis, Elliot consulted with a botanist, Dr. N., who encouraged him to adapt a method used in analyzing the branching patterns of streams and rivers. As Elliot collected his data, he entered it into Microsoft Excel and used the program's graphing features to search for patterns in the data. Thus, Elliot practiced investigation design, data manipulation and analysis, and testing alternative explanations to a greater degree and with greater independence than any other intern.

Elliot's work on this project provides an illustration of a research novice's approach to an independent investigation. Though Elliot had three semesters of prior research experience, much of it was informal in nature, and his work on this independent project clearly

demonstrated that he was still a research novice in comparison to a graduate student like Mandy, for example. Though Elliot's project was an experiment, it is difficult to describe it as hypothesis driven. Elliot had no idea how, or if, light or water might influence the branching pattern of his plants. His aim was to simply see if either variable affected the pattern, should he be able to find a way to describe it. Thus, this project was also exploratory – the aim was, again, to “try and see.” Here is how Elliot described the hypothesis to his project in his research proposal:

Hypothesis: A pattern will be found in *Selaginella* on some level, whether it is species specific, genus specific, or environment specific. Depending on this pattern, the cause and development immediately following bifurcation will be able to be studied with ease. (Elliot, Research Proposal)

In describing the rationale behind his independent research project, Elliot had no difficulty explaining the “enation theory” for the evolutionary origin of leaves, how vascular traces defined true leaves, and what microphylls were, demonstrating his command of the subject matter that helped to define the bigger picture of this project. Yet in choosing water and light as variables for his experiment, he made no effort to define the water and light requirements for his plants, nor could he explain or predict how water or light might affect the plant's branching pattern. This failure to link the parameters of the investigation with any sort of rationale nearly resulted in project failure. The following excerpt from my field notes demonstrates how this lack of knowledge and the arbitrary nature of his parameters influenced his trouble-shooting when it looked like his plants were dying. Earlier in the day, Elliot had transplanted his plants and set up his trials on a bench in the greenhouse. He had even collected some data from them before returning to the lab for lunch. Just before these notes begin, Elliot scavenged a piece of shade cloth from elsewhere in the greenhouse and placed it over the two trays of plants serving as the low-light treatment (Figure 7.1).



**Figure 7.1: Experimental Set-up for Elliot’s Greenhouse Investigation.**

E works silently in the bright afternoon sun, squinting at the white notebook page. His brow is sweaty. It’s super hot and humid in here – perfect for the corn seedlings all around us. It feels like July in Illinois.

...

E tells me that he notices a difference in his plants from earlier that same day to now. Branches are limp and changing color.

He touches the soil to feel for water and says: OH!

I feel it too. The soil is very wet but the water is surprisingly hot to the touch.

He believes the plants are burning from the roots.

E: Maybe it’s early enough to modify the experiment. But I’m not sure how.

E sits and thinks for a while. He sees that the clear plastic dome he replaced over the tray for the high water treatment is already beginning to mist up with condensation droplets and says: I see what’s happening. The water is providing shade.

My problem with this explanation is that 1) water is clear and 2) the dome for the low-water treatment was also covered with just as much condensation. I don’t discuss this with him.

Instead I ask: How does the soil in the high-water treatment feel?

E reaches in and feels the soil: It’s not as bad and these plants don’t look as bad.

E sits still in quiet contemplation. Then he says: I know what I have to do. I have to make sure it’s not just the transplanting. Because if it’s the transplanting they’ll all be like that soon.

Nothing happens for a few more moments as E continues to examine the wilted plants in high-light, low-water.

E: Oh! I think I understand what’s happening. They are getting the same amount of light but there’s enough water to create a cover of condensation in the high water treatment.

MRP: Do you think the water standing in the tray absorbs any heat? (Nearly two inches of water stands in the high-water trays and a half-inch in the low-water trays.)

E: Most definitely but the evaporation also causes a shade cover.

I ask him to lift the shade cloth and observe the other two treatments.

MRP: Does what you see match your predictions? (It does not. Both the high- and low-water treatments under the shade cloth show heavy amounts of condensation [he had just put the shade cloth down])

He looks, but doesn't respond to me. He quietly thinks.

E: So far the only thing I can think of is position effect. This one is closer to the window and much hotter than the others. (The four trays sit in a row, with the high-light, low-water treatment closest to the clear window. All four trays sit under a lightly white-washed, glass roof and a bright sunny sky).

I ask him if he felt the soil in the low-light treatment. He does not do this but says, continuing his own thoughts: This just gave me an idea of what I need to do. I need to bring a thermometer tomorrow and measure the temperatures.

...

E pokes at the branches gently, makes notes.

E: I wonder if it has something to do with time of day. I had this dome off at least 2 hours later than the others. I haven't touched the ones in the shade.

I ask E if the greenhouse conditions were the same this morning and he said they were the same.

MRP: where does *Sellaginella* grow naturally?

E: In shade

MRP: So it's not entirely a surprise that they're frying in the sun?

E: Well what I don't understand is why those are frying (points to high-light, low-water) and these are not (points to high-light, high-water).

...

E's PI enters and nods a greeting from across the room. He ruffles through his corn seedlings with both hands.

As E quietly contemplates, he notices a shadow cast by one of the roof beams over head. He says that he thinks this might be the issue and moves the trays into alignment. I consider asking him if he thinks the shadow will move as the sun changes position in the sky, but I don't want to push it.

...

PI is right next to E now. The fan noise prevents him from overhearing our conversation. E does not ask him anything - no advice. PI doesn't notice the dying plants or E's glum expression.

E wants to wait until tomorrow to see if the other plants end up looking as bad. He thinks they will, but that it will just take them longer to die. I ask how long it will take to get more plants. He doesn't respond (it's week 6 of the program).

When it seems to me that he is going to leave things as they are for one night, I cannot contain myself. I suggest that he might want to switch his plan from high-light vs. shade to shade vs. deep shade and put two trays on the floor,

under the two shaded trays. E says he was thinking about doing that anyway but will probably gamble and keep things as they are for now. Later he changes his mind. (Elliot, Observation 3)

Though he did not answer some of my leading questions, Elliot was familiar with *Sellaginella* from his days as a greenhouse manager. He knew these species grew in shady and most environments. However, in designing his project, he had not considered that too much light might damage the plants or influence temperature, which might also damage the plants. He also had not considered that standing water might drown the plants' roots. He had not expected the greenhouse conditions to be so harsh and had no acceptable alternative because no growth chambers were available. Elliot's struggle to find an explanation external to the experimental design reflected a tension between an unwillingness to alter his original design and a desire to salvage his project. Altering the design would mean that he would have to throw out that morning's data. It also meant that he would have to admit that his design was flawed. He did not seek advice from the PI, nor did he discuss his troubles with Mandy. She was surprised to hear things were not going as planned when I asked her about it several days later. All of Elliot's low-water plants died in the next two days. During my final observation, Elliot told me that he had discussed the project with Dr. N., the botanist, who reinforced the idea of transplant shock. Dr. N. also suggested that the plants like to be moist, not saturated. Elliot consolidated the remaining plants under the shade cloth and provided them with water as needed in order to salvage his project. Though he was able to collect more data from these survivors, Elliot was not able to relate his findings to differences in water or light conditions.

Another illustration of Elliot's novice approach comes from an observation of his data analysis. For example:

Elliot has his data arranged in several tables within an Excel sheet. One graph represents a set of simple curves described by quadratic equations. Another graph represents a set of curves that look like wave functions. E says that he does not believe the negative numbers that the computer-fit curve describes

for some values of X (the number of branching events along a given stem). “Negative numbers just do not make sense.” E is not confident in any of these curves because they extrapolate beyond the four or five points that he has for each. (Elliot, Observation 1)

There is some evaluating or weighing of evidence in this excerpt: Elliot did not trust that either figure provided the description he is looking for because negative values for X did not make sense. The different forms of figures (quadratic vs. log rhythmic, etc.) represented alternative explanations for the data - however, it was not the case that Elliot was testing the explanations against the data based on knowledge, understanding or expectations – this was simply trial and error to see what might fit as a possible explanation. Eventually Elliot was able to fit a curve to the data and performed a statistical analysis comparing a line of best fit between log-transformed and non-transformed data for his presentation. However, as he stated in presenting these findings, the results were inconclusive.

### **Outcomes**

**The mentor’s perspective.** The most important attribute of the ideal intern was, in Mandy’s view, asking questions when one does not know what is going on. She also valued proficiency once trained and a willingness to think independently. Mandy felt that Elliot displayed all of these characteristics, exceeding her expectations for independence. Mandy also felt that Elliot already displayed the most important characteristics of a scientist, because he had come in asking questions. Because he had also designed some of his own experiments in college, she felt that he was both “an experimenter” and a “questioner.” Elliot’s work and progress as an intern reinforced these impressions for Mandy. She cited his independently designed branch analysis project as an example:

I think he came in as a scientist. But I think once he started designing his own branching experiment...he took the plants and he took complete control over them. He knew exactly how to set them up, although some of them died at first. But he like um, he trouble-shooted how to [keep them alive]. It was his own work and he like, engaged in how to analyze these plants and what to do

with them and when to go and look at them. He was just completely responsible for them. Every once in a while I'd be like, "How are the greenhouse experiments going? You should explain to me what you are doing." It was completely his own project. And I think that definitely makes a scientist. Someone who can engage in a research question and work on something, obviously you can collaborate and stuff, but like, have it be your own. (Mandy, Interview)

Thus, in Mandy's view, Elliot learned important aspects of inquiry through independent practice: trouble-shooting an experiment's design, summarizing and analyzing data in order to develop an explanation, searching for relevant literature, making connections between the research and science subject matter.

Mandy also felt that Elliot learned some subject matter knowledge through the practice of inquiry as well. Though Elliot came into the program with an unusual amount of botanical background knowledge (for example, evolutionary lineages within the plant kingdom, and organization of plant meristems), Mandy felt that Elliot built on this knowledge by filling in much of his spare time between tasks to embed and section plant tissues and explore their internal anatomy:

He started sectioning all sorts of stuff - I was just sectioning *Sellaginella* meristems. But then he would start sectioning through the microphylls and trying different stains and we even got some algae from the lake... Yeah so I think he learned a lot of like anatomy from slicing the material up on his own. I mean like, "Where is the meristem, where are the bozonoplasts?"... He actually found a lot of them. He was like, "This one is chock-full of them. This is definitely a marker of *Sellaginella* [species name]" and I was like, "Good. All right." (Mandy, Interview)

Elliot also built his subject matter knowledge through failures in the lab. Mandy, who described learning this way herself as an undergraduate researcher, offered a story of Elliot learning through failure that involved the antibiotic-screen step in the cloning procedure. Because the ampicillin that they were using was not reactive, they ended up with a lot of false positives – many more surviving colonies of bacteria where there should have been very few. This stalled their research for several days. Mandy felt that the experience really helped Elliot to

understand the purpose of the screening step and the cellular mechanisms involved in antibiotic susceptibility and resistance.

I asked Mandy what she thought Elliot's biggest challenge had been as an intern. Her answer described an internal challenge, rather than some aspect of the research:

I think at first his biggest challenge was probably coming off as very responsible and confident when he was at the same time learning new things...Like, he's definitely an impresser. So I think it was hard for him to find that balance between like impressing people and asking questions and making things clear. (Mandy, Interview)

Mandy believed that Elliot become more confident and comfortable in the lab and in his abilities to do molecular research as the internship progressed.

Much of Elliot's work did not result in what Mandy referred to in her interview as "tangible rewards" – clear outcomes that addressed the research question or met the project goal. This was due to a combination of factors: the indeterminate nature of much of the research, the 10-week time constraint, and the challenges Elliot faced in executing his independent investigation. However, one facet of Elliot's project, involving *in situ* hybridization to localize lipid transport proteins in the apical meristem of *Sellaginella*, did yield tangible rewards:

Some of the *in situ*'s look like they are evidence for what is called the enation hypothesis, which is like how leaves in these early land plants evolved because they evolved separately. And we saw that like some of the leaves had the full probe being expressed in them and this was a probe that was supposed to be like specific for the outer cell layer of tissue so this was evidence for these leaves being derived from just the outer cell layer. [My PI] thinks it's really exciting because it's like molecular evidence for the enation hypothesis, which is paleontological. (Mandy, Interview)

Mandy was also excited about these findings and planned to pursue this line of investigation in the near future. Mandy and Elliot had set out to determine if LTPs were expressed in particular cells of *Sellaginella* meristem, as was the case in maize, and discovered 1) that they are differentially expressed and 2) the expression supports a specific, well-known but controversial

explanation for the evolutionary history of leaves in plants. Mandy was sure that pursuing this work would eventually lead to a publication.

Though Mandy had experience mentoring high school students at another institution, this was her first time as a mentor in the Program. She discovered that her perspective on the goals of the internship, and her translation of those goals into a research experience for Elliot, differed from those of other mentors in the Program. This came about because she had overheard comments at the student symposium that seemed to question the merit of Elliot's branch analysis project. These comments caused her to question her views on the role of the mentor. In her interview Mandy explained the tension between providing an experience that would engage the intern's interests in order to get them excited about research, and a research project that would produce publishable results:

Mandy: I've been thinking a lot about what is the role of the mentor. To have students work toward a very concrete research project that's moving toward publication, or is it the role of the mentor to just like engage students in research?

MRP: And where are you falling now?

Mandy: It's sort of mid-line. Um, because you want to see something productive and publishable, because that is real research, but you want students to be really engaged in what they are doing and not just following a grocery list. Yeah. I still haven't- ultimately I think it would be very cool to work with students on projects that they're designing and like co-design with them and have it be a very, like fruitful project that's publishable, but at the same time, something that they were very engaged – that's very hard to do in 10 weeks!  
(Mandy Interview)

**The intern's perspective.** In comparing his internship experience to others in his cohort, Elliot felt fortunate to have been placed in a lab where he and his mentor had similar views on the intern/mentor transaction:

One thing I learned was how lucky I was to be in the lab that I was in. I talked to a couple of people who were still doing only PCRs and gels in the 6th and 7th week. And I talked to people who were screening mutants based only on the phenotype, and the phenotype wasn't yet [fully described], so they had no idea what they were looking for. I talked to people who would leave lab at two

o'clock every day because their mentor says, "You're done." I- I just couldn't do that. So, I know that's not exactly the question you're asking, but I learned that I got in a lab that thought like I did. (Elliot, Late Interview)

Elliot felt that Mandy gave him just the right amount of independence. When he worked independently, Mandy was always nearby, but kept in the background until Elliot decided for himself that he needed her. When they worked together, it "felt more like collaboration than mentoring" (Elliot, Late Interview). Elliot explained the difference by again, comparing his experience to those of his peers:

Like, when Mandy and I do something together, it honestly feels like we're doing it together... I don't want to say that I'm doing, because I've talked to other interns and even other mentors, and they say they watch their interns do this, or they help them do this. But, to me it always feels like we are doing it. Which is- it's really nice. (Elliot, Late Interview)

Intern/Mentor collaboration went beyond practicing techniques for Elliot. Defining the research question for each of his smaller investigations and selecting the methods for those investigations were also collaborative efforts accomplished through lengthy discussions with his mentor and occasionally his PI. Thus, Elliot felt that he had started out in the lab as an apprentice, and by the end had migrated along the continuum toward equal, though he also felt like he was not quite there yet: "I'm in that weird middle ground between apprentice and equal" (Elliot, Late Interview).

Though he did not elaborate on the specifics, Elliot was in agreement with Mandy that he learned a lot of molecular biology content through practicing it – how PCRs and cloning actually work, how proteins interact. Elliot likened learning molecular biology through practice to begin immersed in a wave – if you can keep your head above the water, it will move you along, motivating you to learn more. The following quote is an example of Elliot's ability to reflect on his knowledge:

I came in with one quarter of the molecular biology knowledge I have now, and it was extremely weak. And I didn't realize how weak it was until I got

here...But what it's shown me is that old Chinese proverb, the more you know the more there is to know... And instead of just saying, you know, "your molecular biology is weak"...I'm shown how it is weak, and that's actually motivating, once it's no longer overwhelming. (Elliot, Late Interview)

Elliot also gained practical knowledge in learning specific techniques, particularly those he frequently practiced independently. For example, he felt extremely confident in his ability to use the microtome to conduct his own investigations in the fall. He also felt "fluent" in stream analysis, the approach he used to collect and analyze the data from his branching pattern investigation.

Elliot felt that he learned other things through practice; he called these gains "personal results."

MRP: "Personal results?" Can you enumerate those?

Elliot: Experience is a huge one. Um, that's just the biggest one. Experience in the lab. Um, experience in experimenting. Experience in failing. That's great.

MRP: Why?

Elliot: Well, then you know how to handle it and more importantly how to keep going. I failed at growing cultures for like two weeks straight. So I was like, "OK. Let's do the same thing over again and make sure that wasn't a fluke." Then, "What happened next? Ok, maybe this was bad. Let's try it again. Maybe this was bad, let's try that again. Maybe this was bad, let's try it again." We just tried over and over. At the same time, every time we got a positive culture, we would keep going with that, and if that would fail, then we still had this running. (Elliot, Late interview)

Elliot's lesson in coping with failure was also a lesson in how to trouble-shoot in molecular biology: repeat the procedure, testing each component separately until a culprit is discovered.

Elliot felt that he practiced independent trouble-shooting nearly every day of his internship.

Trouble-shooting through failures, like the one he described above, also involved modifying one's hypothesis (albeit loosely interpreted), and developing alternative explanations. These experiences also led Elliot to believe that he frequently practiced developing scientific questions:

Elliot: OK. Gosh. Every time something didn't work, it was up to me to determine the question to find out why it didn't work. Every time something did work, sometimes I would ask what comes next, because obviously I wouldn't know. Other times I would determine where to go from there.

MRP: So is that troubleshooting? Or is that coming up with questions that lead to hypotheses that lead to experiments?

Elliot: It depends on which one. If it's a failure, it's troubleshooting. And those are still questions. But if it's a success, then it's, then it's- then you keep going. (Elliot, Late Interview)

Elliot's internship experience taught him other things about the nature of research that he had not realized before the internship. The first was how long it takes to produce data in molecular biology research. The second was the fluid, on-going nature of scientific research.

For me, it's just the appreciation of the amount of time that it takes. I mean, you think, ten weeks; that's a long time; you can get a lot of stuff done. But then, at the 9th week, you're like, "I haven't done anything." Even though you've done a lot. You've done a lot, but you haven't done anything. There's still so much more to go. (Elliot, Late Interview).

Elliot also came to realize something about how lines of work can develop in molecular biology:

I also didn't realize how many different things, and how many different genes and proteins and things, were being researched because they're there. I always thought it was a lot more, "Here's what we want to do; now what does that kind of thing?" Not, "Here's a new gene, here's a different gene, what does this gene do?" (Elliot, Late Interview)

And, regarding graduate training, Elliot learned from Dr. N., that networking was important to one's career – more important than the choice of graduate institution: "It's not where you go. It's who you work with" (Elliot, Late Interview).

Mandy fit Elliot's view of the ideal mentor. However, their early interactions were not without some conflict for Elliot. This too, was a learning experience for him. In his early interview, Elliot explained that he needed a context when learning facts and details – to help him remember and apply what he was learning: "What am I doing? Where am I? How does this relate to – I like being able to see where I am and how it fits in." He described Mandy's mode of thinking as the very opposite of his own, sequential in nature: "She builds step by step

and then gets to, ‘This is what I’ve done.’ I like, ‘This is what I’m going to do’ and then the steps” (Late Interview). After trying to learn and understand “her way” without much success, Elliot started to ask Mandy for the understanding that he needed:

Elliot: So usually around her first or second step I’d be like, “Hang on a second, what are we doing?” And then she would explain the first two steps again. And I’d be like, “No no - what’s the overall picture? What are we doing?” And then she’d be like, “Oh. Hang on.” ... Knowing how you learn helps too.

MRP: Is that something you discovered here?

Elliot: Something? Yes. I mean I had an idea coming into it, obviously. But I would say yes. Because I really had a situation where every day I ran into the same person who learned a different way than I did and who explained it to – If I learned the same way she did – who would have explained it perfectly. But I didn’t. (Elliot, Late Interview)

**The author’s perspective.** This intern-mentor transaction resulted in positive outcomes for both parties. Mandy was able to test some ideas through Elliot’s work and identify a fruitful direction for her own future research. Elliot reaped both “tangible” and “personal rewards.” His *in situ* results were exciting to both his mentor and PI, he gained valuable experience in molecular research, he developed a relationship with a well-known botanist who was already helping him to network, and he practiced advanced aspects of scientific inquiry both independently and in collaboration with his mentor. Elliot also learned something about himself (“it helps to know how you learn”) and about the nature of scientific research through his internship.

A number of factors contributed to the success of this pairing. Mandy’s view of the purpose of the internship was to engage her intern in research, and she did this by allowing him to pursue his interests. Elliot’s interests were more important to Mandy than the results of his work, perhaps because she was not at a point in her career where she needed results. She gave him choices in the research question and design, taking a collaborative approach to mentoring which helped Elliot to feel like a respected member of the lab – more of an “equal” than a

student or a worker. Mandy also gave him space to practice and think independently, which suited his approach to learning.

Elliot thrived in Mandy's "try and see" approach to scientific investigation. It was congruent with the exploratory approaches in used in his prior research. Elliot was a highly motivated student with initiative. One reason that his research experience matched his interests is that he *had* interests, supported by background knowledge. He was also a "questioner" and an "experimenter;" he came up with his own questions and ideas and found ways to address them, whether by talking to people, reading literature, or tinkering with equipment. Elliot was both a conscientious and a reflective learner. He took measures to ensure the quality of his lab work (asked questions, took notes, double-checked his work). He also viewed failures in his laboratory work as learning experiences.

Though Elliot's branching investigation did not yield tangible results, it gave him the opportunity to test ideas, analyze data, trouble-shoot, and network. Observing Elliot at work on his independent investigation demonstrated that he still had a long way to go in developing the necessary skills to practice independent scientific inquiry, even in the non-technical context of his self-designed project. Here, it was not the sophistication of the tools, techniques or subject matter knowledge that served as a barrier to the intern in executing a successful independent investigation. Rather it was the intern's inexperience with connecting the research to a rationale. In the end, Elliot converted his balanced experimental investigation to an observational one, and this did not alter his research question. My point here is not to undermine the benefits of Elliot's self-designed investigation, but rather to suggest that the road to independent scientific inquiry is very long and requires much practice, experience, and exposure.

Elliot's choice to shed the water and light experimental conditions in order to salvage his investigation suggests that these variables were not really important to him. It may simply have been the case that because these variable could be easily manipulated, Elliot decided to "try and see" what would happen if he did. Elliot chose not to discuss the matter with his mentor, and perhaps this was a result of "the impresser" in him. Another reason may be that Mandy was not the right expert for this problem; Dr. N. was clearly the more desirable source of botanical information. While it is unclear whether Elliot learned from the flaws in his original experimental design, it is clear that he spent a lot of time thinking about his anticipated results. The following quote integrates understandings about plant physiology and anatomy with his personal observations to formulate a potential explanation, a future hypothesis:

MRP: I know you do not have your results for this yet, but do you have an expectation here? "I think this is what I'm going to see..."

Elliot: Yeah. I have an idea. In roots, there's a gravitropic response, and for [species name], at least, as a ground creeper, it has indeterminate growth in its tips. So my thought is, it can tell which way is up and down, in the apical cell. And somehow, based on what I've seen in the branching – it's almost a serpentine pattern – by telling which way is up and down, it can tell which way is left and right. So it can tell which one to divide as a lateral, and which one to keep growing as a primary, main shoot. (Elliot, Late Interview)

Elliot's internship influenced his understandings of the nature of scientific research, particularly the validity of observational science and several aspects of NOSI. Elliot made greater gains in NOSI than any other intern in his cohort (Figure 5.3). His understanding developed from naïve or emerging to informed or robust in four areas: multiple methods of investigation, justification of knowledge claims, the role of the community of practice, and the role of anomalies. For example, Elliot's view of the methods of scientific investigation developed from emerging, where scientists follow the scientific method, but in a taken-for-granted or unconscious way ("people don't actually think, 'Ok. Question. Next, hypothesis. Next?' They just do that." [Elliot, Early Interview]) to the view that science practice is more like

an intuitive and cyclical process where the results of one investigation lead you to another question. This view was echoed in his understanding that in research, some anomalies are problems that need to be investigated – perhaps leading to new avenues of research.

Like what I just described in [my PI]. That to me is a scientist. Someone who can look at one thing, focusing so hard on that, and then just go a completely different way because he gets this other idea and goes with that...Research to me isn't just focusing on one thing. Research is I'm going to study this, and if that leads somewhere else, go! (Elliot, Late Interview)

A final factor that may have influenced Elliot's learning gains as an intern may be that he had some capacity to reflect on his learning and his knowledge. Elliot was a student in transition from an absolute way of knowing to a transitional way of knowing. For example, in making decisions, he tried to balance internal and external sources of knowledge, though he still weighted the advice of experts above all other sources. His view of the role of the learner was also transitional - to understand, to figure things out, not just memorize facts or blindly follow steps. However, his view of the role of the instructor was that of an absolute knower – to “figure out” how their students learn best and then communicate information appropriately. This may explain some of the early conflict Elliot experienced with his mentor's teaching-style. However, Elliot felt that they did eventually “figure each other out.” His ability to reflect on his learning and how he learns best, pushed him to take initiative with his mentor and ask for the kind of help he needed, in a sense partnering with her in developing his understanding.

### **Monique and Christian**

#### **The Intern**

Monique appeared for her early interview with the air of a student psyched up for an oral examination. She was a lithe and energetic track star, ROTC captain, biology major, and

rising senior from the southern US where she attended “old, small HBU<sup>3</sup>.” She said this with a self-conscious smile: “I didn’t want to go to HBU. I didn’t want to see people all the time that looked just like me. And I got into some of the best schools.” She landed at HBU for financial reasons and because she wanted to stay close to home. She also explained that she had come to love her school, despite what she called its “bad reputation,” because of her first-year experiences:

Monique: I had to warm up to the school.

MRP: At what point did it turn for you?

Monique: It took me a year. It was research. It was my first research experience there. And professors that really don’t hold your hand and really push you and really care about your education. That’s when it clicked for me. (Early Interview)

Monique’s application materials described an ideal candidate for the Program: African American, attends a smaller institution with limited resources to support undergraduate research, GPA above 3.0. Her science coursework bespoke a breadth of upper-level courses, nearly all resulting in another “A” on her transcript, including two courses in plant biology. However, all of these courses were organismal in nature; most of Monique’s exposure to molecular biology came from her research experiences.

Despite her school’s smaller size and limited research status, Monique had already participated in two summer research internships at her home institution, both continuing throughout the following academic year. The first was in a molecular virology laboratory, where she learned a variety of techniques and conducted routine laboratory work like pipeting, plating cell cultures, and preparing stock solutions. Her second research experience was in a plant physiology laboratory. In her early interview, Monique described her experiences in this laboratory as a “team effort” involving a lot of discussion back and forth with her mentor:

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<sup>3</sup> Historically Black University

...she would give me a piece and I would sit down, fill out the protocol, analyze the protocol, and I would say, "Hey, Dr. A., I think we should do this and that. And then I'll go into her office and pose questions ... And it's always something clicking, like, you know, "Well if it's like this, then maybe this could be a problem too," and we write it down and go back in. It gets like a team effort...she gives me something and I suggest more. (Monique, Early Interview)

Her prior research experiences led her to present at a number of undergraduate conferences. She discussed these experiences in terms of their competitive aspects: placing, receiving honorable mention, daring to put oneself out there, and becoming a stronger competitor. For example,

People ask questions. They make you think about your research. Maybe they make suggestions, this or that, or they might ask you why, why something is. It's a critical thinking process, I think, and it makes you stronger for the next competition. (Monique, Early Interview)

Monique's extensive prior research experiences and her experiences presenting at conferences caused her to feel that she had ample experiences with most aspects of scientific inquiry, including those more advanced aspects like posing questions, designing investigations, constructing and defending arguments, modifying a hypothesis and making connections with the bigger research picture. Her self-score for pre-program inquiry (40) was among the highest in the cohort<sup>4</sup>. In contrast, her pre-program NOS (1) and NOSI (5) scores were among the lowest (Figs. 5.2 and 5.3). The only aspect of NOS for which she held an understanding beyond naïve was the role of creativity in deciding what to investigate and how to design an investigation. She held a mixture of naïve and emerging conceptions for most aspects of NOSI, but an informed view of the role of the community of practice. Monique understood that scientists build on existing knowledge by critically examining the work of their peers, typically through reading the literature.

Monique entered college anticipating a medical career. However, she discovered early

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<sup>4</sup> The mean pre-program inquiry score was  $29.9 \pm 10.6$  out of a possible 56

that the medical path was not for her; she did not enjoy being a “walking mnemonic” – this was how she and her classmates referred to premedical students because they expended so much effort on memorizing subject matter in preparation for the MCAT examination. Monique’s experiences in the plant pathology lab piqued her interest in a graduate career in plant biology. She applied to this Program so that she could learn more advanced techniques, how to think critically, and become a more independent researcher. She wanted to be able to go back to her home institution and meet her research advisor half-way:

I can think critically. But I don’t think of the things that they say, or the things that they do, the things that they want you to know. I don’t think as far as that. I want to be able to think for my own, and research more things on my own on the computer, then ask the question. I want to meet them 50-50. (Monique, Early Interview)

Working and thinking independently were major self-goals for Monique, and were important themes in both of her interviews. During our early interview, Monique was still working on her research proposal. She confessed that she was having a hard time with it because it was a lot of information to digest and explain: the links between insects, plants, secondary compounds, how this content is translated into her research plan and anticipated findings. And, because her goal was to become more independent, she wanted to figure it out on her own: “It’s a little difficult. But I’m going to figure it out. I told [my mentor], ‘Christiaan, I’m going to figure this out’” (Monique, Early Interview).

Monique’s personal epistemology was that of an absolute knower. Her competitive stance, wanting to be pushed and showing that you can meet a challenge or goal, describes Monique’s mastery approach toward learning. It also suggests that she favored external forces for motivation. For example, she loved pop quizzes because they forced her to prepare and think ahead. She liked to anticipate the questions her professors, or conference judges might ask. During both of her interviews with me, she often paused to ask me how I thought she was

doing. When she found it difficult to answer a question about proteins, and I expressed a desire to move on, she insisted that we come back to the question later: “I knew you were going to ask that. I should have looked it up...We are NOT going to skip this question” (Monique, Late Interview).

Monique tutored younger students at her home institution. In the following quote from our early interview she explained what she’s learned from working with younger students in the laboratory and as a tutor.

So when you train these students [in the laboratory], you want to be very slow with students and you want to ask them questions. You want to ask them, “OK, I explained this to you. Can you recall or can you try your best to relate the information to me so that I can make sure that you understand?” Because when I teach people – I’m also a tutor – I don’t stop and do the work for you. I ask you what don’t you understand and see what you can do on your own and then I help you fix it. The same thing in the lab. If you don’t understand something, ask a question, and I’m always here for you. But you have to be very patient with the students. Not everyone learns at the same pace. You can’t teach students in one way. (Monique, Early Interview)

Monique’s approach to teaching and training younger students serves as a good description of how she herself had been trained, and the approach she was anticipating from her mentor, Christiaan.

### **The Mentor**

Christiaan was in the final year of his postdoctoral fellowship and making plans to return to his home in northern Europe in the fall. I had first met Christiaan the previous summer when I was conducting a program evaluation and my pilot research in his laboratory. At the time he was busily mentoring a high school student through a research project similar to Monique’s. “Busy” also described Christiaan in summer 2009. In addition to finishing up his own work, which consisted mostly of writing, he was mentoring a first-year graduate student, a European undergraduate on an exchange program, and Monique. Despite these other commitments, Christiaan volunteered to mentor Monique for the summer because he found

mentoring to be a good learning experience and to be fun. Like Young, he felt that every student had something to teach him about being a mentor:

... like for me personally it's just good to have a variety of students because you know what you can expect, you know that one needs this type of trick to have them work, the other one needs some other type of trick. (Christiaan, Interview)

Christiaan had a soft way of speaking that sometimes dropped to a whisper so that one had to lean in close to catch every word. He also had a quick, though not biting, wit; and if you weren't paying close attention, you might miss a smart punch line. He was very easy to get along with. Monique agreed: "We're pretty close. He's an awesome guy. He's really easy to talk to. And I think that we'll - we get along great. I love him. He's an awesome mentor" (Monique, Early Interview).

Before Monique arrived, Christiaan and his PI selected a project "laying around" that they thought would be appropriate for an intern. They expected it to be interesting and fun as it involved both living plants and animals. It also involved a nice mixture of molecular and non-molecular techniques. Unlike most of the research projects in the Program, Monique's was a hypothesis driven experiment, and Christiaan anticipated "black and white" results that would be easy for an intern to interpret. The project fit Christiaan's idea of the ideal research project for an intern:

The ideal project is something where you can go through most of the steps of research, like planning and the actual work part and analyzing the data and maybe some kind of write-up with a report or presentation. I think that kind of project for 10 weeks would be great if you can get it in right. But a lot of times you don't so it's more like, OK, what are we doing, are we developing skills? Are we learning techniques? So my idea was kind of to have a well rounded project that has several new things in there. (Christiaan, Interview)

In Christiaan's experience, the ideal project didn't always work out as planned, so focusing on developing skills or learning techniques were his general fall-back plans.

Christian's view of the goals of the internship Program were to develop inquiry skills,

specifically experimental design and data analysis. Christiaan's approach to mentoring was to spend a lot of time working side by side with the intern in the beginning, asking them questions that would help him gauge their understanding of what they were doing and how it was progressing. Once he developed a sense that the intern understood the work, he would leave her to work independently, trusting that she would come to him with any questions. His method reflected his own experiences as a graduate student: his mentor worked side by side with him at first and then left him alone to figure things out on his own. He enjoyed working independently and surprising his mentor with "cool" results, and wanted to give his interns a similar experience. Christiaan's approach had worked very well in the past, especially when the intern matched his ideal:

The ideal intern is somebody who takes initiative, who quickly grasps what you want, who figures out everything by themselves. I had this student during this spring semester - he's a really quiet guy but if you tell him, "Well why don't we do this experiment, this experiment, this experiment," ...Like he would do everything, come to me and show me the results. And he would say, "Why don't we do this experiment and this experiment so that we can figure out this?" ... I mean that's of course perfect. (Christiaan, Interview)

### **The Research Experience**

Christiaan's lab was not Monique's first choice. However, she decided to make the best of it because she was made to feel so at home, and she discovered that the insects were not that disgusting or boring after all. Monique's experiment tested weight gain of specialist and generalist herbivorous insects on plants genetically modified to express only one of two naturally occurring toxins, employing both a positive control (wild type expressing both toxins) and a negative control (a genetically modified strain expressing no toxins). The project involved growing the plants, culturing a variety of insects, chemical analysis of leaf tissue to describe toxin levels, RNA extractions to confirm gene expression, and larval feeding trials. The expectation was that the specialists, having evolved to metabolize the naturally occurring toxins,

would perform better than generalists on plants expressing the toxins. However, it was unknown whether the two toxins differentially affected the various herbivorous species. The project was the final piece of a paper already written and waiting to be sent off for publication.

During my first observation of the pair in week three of the Program, Christiaan demonstrated his approach to mentoring a research intern: asking questions that test knowledge and memory, working together through demonstration at first, then stepping aside and letting the intern work independently. Christiaan and Monique were working together on the protocol for chemical analysis of leaf tissue. When I entered, they were both laughing at their mutual inability to subtract 89 from 96 and standing side by side over a rack of (now 89) tubes. Christiaan began by asking Monique to summarize what they had completed of the protocol yesterday and what they would do next. As she worked to remember and explain, he nodded in agreement or interjected to gently correct or modify her explanation. For example,

C asks her if she remembers why they have to add internal standard. M answers but her answer is correct for sulfonase, not internal standard.

C: Right, but that's for sulfonase.

C then explains what the internal standard permits.

M: So we're using the standard to double our concentration.

C: Right (But based on his explanation her answer is not right). It's a check so that if you do something sloppy, say you spill some of the sample, the internal standard will tell you how much of the sample has been lost. Then we just do a calculation - we don't have to throw the whole sample out. (Monique & Christiaan, Observation 1)

When Monique later dropped and spilled some of the contents of one of her tubes, she exclaimed, "Oh God!" Christiaan told her not to worry and emphasized again the purpose of the internal standard.

Christiaan demonstrated various manual techniques, emphasizing three times that the work was very repetitive and would require concentration in order to keep track of one's place while maintaining a quick pace: "keep your eyes on the tubes or constantly count to eight" (Christiaan, Observation 1). As Christiaan demonstrated how to pipet and keep track of the

work, his movements were deft, rapid, and sure. He swirled the bottle with his left hand to keep the viscous liquid from settling, pausing an instant to insert and withdraw his pipet with his right hand, all the while keeping his eyes on the rack of tubes. He filled eight tubes in a row, then capped them. Monique preferred to take things slowly until she became more accustomed to the manual work. She focused on one tube at a time, uncapping it; then capping, shaking, and uncapping the bottle using both hands; pipetting the next sample; capping the now full tube and uncapping the next: "I'm strictly by the book in this lab. I want this to be perfect" (Monique, Observation 1). Christiaan watched her do the first few tubes, then left to help Lucy, a graduate student, search through freezer boxes for a specific primer.

As the weeks progressed, Monique's work became less technical, consisting mostly of caterpillar feeding trials. For this aspect of her project, she placed cages made out of plastic drinking cups, mesh and rubber bands over individual plants, each bearing a single caterpillar. Caterpillars fed for several days, and were then removed, cryogenically frozen, and weighed. Monique completed many of these trials, learning a new lesson "the hard way" about good technique with each trial: very young caterpillars are fragile and may not survive rough handling, caterpillars can escape from poorly constructed cages, hastily deconstructing the cage can result in a caterpillar lost among the debris, keeping track of where you are in a tedious process is important for accurate labeling, which is critical for later data analysis. Excerpts from my third observation of Monique in week six illustrate her independent practice of a task already repeated many times:

M is rushing around today. She tells me that she has a lot to do, started late because of seminar, and wants to leave by 5:30 at the latest. She has to work with Lucy tomorrow and wants to show her that she usually gets all her work done by 5:30. "I am a very organized person. Lucy is super disorganized."

...

I get to help M remove caterpillars from the cup-cages. M explains what at first glance appears to be a complicated tracking system (chart). I beg off helping just now in order to take notes first. M: It's not that hard. Gretchen helped me

the other day.

The chart has four columns and eight rows of cells, reflecting the spatial arrangements of plants in the tray and tubes in the rack. She will remove each caterpillar from the cup-cage surrounding a plant and place into the corresponding tube. Each cell in her chart corresponds to a tube in the rack and a plant in the tray. As she transfers, M notes the plant name (“salk” or “col-o”) and number (counting from left to right). If there is no plant or no caterpillar she marks an X in the cell on her chart and pulls the tube from the corresponding cell in the rack. C set this chart up for her. M: “It makes things sooo easy.”

M quickly dismantles the cup-cage, lifts the caterpillar off the plant with her forceps, and pushes the caterpillar into its tube. She is brusque and rough with both the caterpillars and the plants. M tells me that she’s not supposed to wound the animals but she pokes them with her needle-nose forceps to get them down into their tubes. I ask her if they are measuring body mass and she said “yeah, that’s weight, right? See, we’re looking at glucosinolates.” She thinks about it and then says, “I need to talk to Christiaan.”

...

Sometimes she encourages me when I don’t think there is a caterpillar on a plant: “there’s lots of damage and poop. He’s in there.” But then at other times, with just as much leaf damage and “poop,” she is quick to say that there must not be a caterpillar in there and moves on to the next one. I think she is inconsistent in this and probably missing some caterpillars. We end up pulling some plants out of the soil to comb through them carefully. We get dirt everywhere. M cautions me that the caterpillars can be very tiny. She shows me how she pulls off the central stem and looks at it up close first. Then she turns over and uncurls each leaf.

...

M: Why am I so confused? Oh - I know why. I didn’t number these. She had started a new tray without pre-numbering the cells on her chart.

...

M finds a caterpillar on the bench and says, “Here he is, #4.” We decided earlier that plant #4 had no caterpillars on it. The caterpillars are the exact same shade of green as the leaves and can be hard to see. M is confused and asks me to wait as she figures things out. She confirms the identity of caterpillar #6 with me (I recognize him because he was smaller than the others). She tries to confirm with me that plants 1 and 2 were empty but I cannot remember. She decides that she’s right, 1 and 2 were empty.

M: But then I have 2 left over. No, one left over.

I tell her that plant #2 had poop and feeding damage and she decides that the left over caterpillar is #2, thanks me, and puts it into the corresponding tube in the rack. (Monique, Observation 3).

As we cleaned up, Monique explained to me that she has done many, many of these

trials and showed me the collection of charts taped into her notebook. She explained that this is why she felt OK about being rough with the caterpillars – it didn't seem to have an effect on her data. She found the work to be tedious and hoped that her data from today's trial would be good enough so that she did not have to repeat it. She also said: "Remember how I told you I was a perfectionist? I let go of that. Lucy messes up all the time and she's a first year PhD student" (Monique, Observation 3).

This excerpt shows that Monique knew how to execute this task and how to use the tracking system that Christiaan provided for her. Yet it also illustrates her haste and that she was a bit confused about what she was doing and why. Each time Monique brought data to Christiaan for his review, he found it to be problematic in some way – for example, too few data points to show a meaningful pattern or mislabeling the identity of the host plants. For this reason, Christiaan felt that he spent a lot of time working with Monique on evaluating the quality of data, but very little time on analyzing the data because "her data was useless" (Christiaan, Interview). This also meant that they could not use her data to construct, support or defend an argument. He questioned Monique and worked with her to correct each problem as it arose, but found that once the first problem was corrected, a new problem would arise. Christiaan had a difficult time understanding why this was so. He felt that the project was technically very simple, that Monique seemed to understand what she was doing (at least she didn't ask those kinds of questions), and she stated repeatedly (at least in the beginning) that she was a perfectionist. He knew that she was hasty in her work and blamed her "sloppy data," in part, on this. And while he recognized that the problem could be remedied if he watched her work, he didn't want to "babysit":

[the labeling mistake] of course is something that could have easily been helped if I had been there and said, "OK, read, write this down. Read, write this down"... but yeah, I'm not going to babysit and sit next to her all the time because it's a waste of my time - of course I'm trying to make sure they don't

get that feeling...(almost whispering) I mean I hope I did at least a relatively OK job. Like, at least, have her *think* that she's really doing all of this. (Christiaan, Interview)

By my fourth observation in week eight, Monique had come to the conclusion that "science doesn't work." She was now having difficulty getting certain seeds to germinate. Christiaan was away at a conference and had told her via e-mail not to worry about it. However, she had wanted to impress him by accomplishing more feeding trials while he was away. Her attempts to find out why the seeds were not germinating (asking Lucy) had failed. All she could do now was harvest more seeds and try again. She consoled herself that the failures were not her fault, rather "science doesn't work. Whatever. Next?" (Monique, Observation 4).

### **Outcomes**

**The mentor's perspective.** Monique was something of a conundrum for Christiaan. He had a difficult time understanding what barriers might be preventing her from mastering the feeding trials and producing clear-cut data:

She really started off saying I want to do everything perfect because that's the way she is. And then a lot of times she doesn't really know, right? And then she says "I want it perfect but I don't know so you have to explain it to me," which is great. But other times, she doesn't reveal that she doesn't understand, or she doesn't ask, right? Like if she's not sure, sometimes she would ask but other times she wouldn't and so it was kind of weird that way. (Christiaan, Interview)

Christian had hoped that Monique would have learned more from her internship (though he admitted that she learned some subject matter) and that he could have gotten some useful data. He was pleased when I informed him that Monique had adequately described the differences between generalist and specialist herbivores and the metabolism of the toxins by the insects during my late interview with her. He hoped that Monique learned a lot about experimental set up because he spent a lot of the time working with her in that area, fixing mistakes. He also felt that he spent a lot of time working with her on understanding her results,

so he hoped that she learned that as well. However, he didn't believe that she understood the experiment, and he did not believe that she could understand its results:

I showed her some initial data, and she really had a tough time. Like she could read a graph, but she couldn't explain it. So let's say that on the wild type plant a caterpillar weighs two milligrams, and on the mutant it weighs twenty milligrams. She could say, "Oh, right. It must have eaten more and it's happier." And I say, "Sure, they're happier, but what does it mean?" Right? And I think if I ask her the same question today, I'd get the same response. (Christiaan, Interview)

In other words, Monique did not make the connection between the data (difference in caterpillar weight between the negative control and the experimental treatment) and the research question (Do the herbivores perform differently when either one of the two toxins is present?). At the end of the Program, Christiaan still felt that Monique would not be able to make the connection, failing to understand the purpose of the two experimental treatments.

Christiaan had considered a variety of possible explanations for Monique's difficulties in generating data and understanding her project: haste, disorganization, lack of interest, the level of challenge posed by the project (too high or too low?), maybe he hadn't explained things well enough, maybe he left her alone too much. Finally, near the end of the interview, Christiaan suggested that Monique was just not that bright. The following example makes this point clearly:

Christiaan: We already had the data for this first trial, so I said, "Why don't you, based on what you know for each of the caterpillar species you're going to look at, make a hypothesis how that fourth bar is going to look like." It took three days. Three days to come up with that. Maybe it was too hard.

MRP: Could it be that she just didn't want to "reveal that she didn't understand" as you put it earlier?

Christiaan: EXACTLY. Totally. It was totally that. It was very easy. I mean you could probably figure out how the bar should look. Ok. If I had my mom, she could figure it out. (*sighs*) She's really not the brightest. (Christiaan, Interview)

Christiaan clearly felt that the task he set for Monique described in the quote above was simple

enough that any novice who could read a bar-chart and understood the basics of the project could predict what the bar for the positive control (the fourth bar) would look like. Interestingly, though, Christiaan did not believe that “brightness” was necessarily important for success in a PhD program. Similar to Harry’s three-part formula for the ideal intern (aptitude, motivation, and industry), Christiaan had a three-part formula for the successful PhD student:

MRP: What in your opinion do interns need to gain from a program like this in order to be successful in that first year of graduate school?

Christiaan: Well you need to have self confidence, I think that’s very important. And you need to be able to work in a lab surely. I mean, if you can’t hold a pipeter, in biology, I mean, that’s it. If you can’t do the practical work, it’s not going to come. Those are the two main things. And of course you have to have a certain level of brightness, but I mean, I wasn’t that bright at all. I’m still not that bright and I got a PhD.

...

MRP: And you didn’t need to be bright in order to design successful experiments?

Christiaan: Exactly.

MRP: You don’t!?

Christiaan: No I don’t think so.

MRP: What do you need to be?

Christiaan: Smart. *(laughs)*

MRP: What’s the difference?

Christiaan: It’s all about knowing the right question. And how you address the right question. So if you know the right research question and you can figure out a way to test that question, it’s a different level of

MRP: It’s a different kind of smart than classroom smart?

Christiaan: Yeah. Oh way! I always call it book smart and like, life smart. Yeah. Oh book smart is so ridiculous! It’s so wasteful.

MRP: What is book smart?

Christiaan: It is being able to read a book and cite it back to front and front to back again.

MRP: Memorizing.

Christiaan: Exactly. Yeah. No it’s so not important in science at all I feel. I mean of course you have to understand the basic stuff of biology, but I even have trouble like citing the four names of the nucleotides. Yeah, if I really need to know it, I’ll look it up!

Christiaan did not feel that Monique was “life smart.” He also did not feel that she had the necessary practical skills nor the appropriate temperament for the graduate student life-style. In his view, an intern who needed “babysitting” was not going to survive graduate

training because “that’s not what’s going on [in graduate school] and that’s not what’s going to happen very often again [outside the internship]” (Christiaan, Interview).

Monique’s data no longer concerned Christiaan because he had decided that he could easily produce the data himself with a single trial. What concerned him more than anything as the Program came to a close, was that he believed Monique would not be able to cope in a PhD program, and he felt some responsibility for discussing this with her before she left.

Christiaan: Yeah, but like she really wants, I mean she wants to apply here for grad school. And to be honest, if she is going to ask my input, I’m going to say don’t waste your money on applying. That’s sad.

MRP: But it’s a life lesson to be aware of where you’re at and what your limitations are.

Christiaan: I feel sad for her because really she, really wants that, right? And if I then look at it, and by judging what she does, it doesn’t seem that she wants that. There is a complete difference between what she says and what she does. I mean, the grad students that apply here have Penn State as a safety school.

MRP: Right. Let’s move on.

Christiaan: But I think about that every day almost!

Though Christiaan had mentored at least three other students in the past, Monique was a new “type” for him. He had not found the “trick” that would work for her and that was a learning experience for him: not everybody matches his view of the “ideal” intern, and in such cases, the mentor needs to become more involved in the intern’s daily work. Christiaan also learned, or at least reinforced a preconception, that not everyone can learn to do real science:

MRP: From your experiences mentoring all these people, have you learned anything about how students learn science?

Christiaan: I don’t know. Because I don’t even know how students learn science.

MRP: That’s the question.

Christiaan: Because I think most of it is by experience. And therefore I think it’s fine to make mistakes, right? You know, “Next time I won’t make the same mistake at least.” And in that case it’s fine. But if you start making the same mistake over and over then it’s something troublesome. What I’d love students to learn is how to like design and create experiments. But I mean, I guess that’s for only very few. (Christiaan, Interview)

**The intern's perspective.** Monique expressed positive feelings about her internship experience in her late interview. She was proud of the subject matter knowledge that she gained:

Um, my learning experience - I had, I learned so much about my project. Caterpillars, the insects, the depth, all the intricate – I don't know – it was complex and I learned all that information in ten weeks. I think the learning has just been the best experience this summer. (Monique, Late Interview)

Monique also expressed positive feelings about her mentor and his approach toward mentoring. First of all, Christiaan had made her feel at home when she had been worried about fitting in at the Institute. He also made her feel comfortable by giving her time and space to think about things on her own and then come to him with questions. She also liked the way he tested her knowledge and memory. For example,

Like if I'm doing HPLC<sup>5</sup> in the room with that big computer, he makes me do it on my own. He stands there like, "No, that isn't right. Try again." It's kind of like a test, like a practical. It helps you learn because I don't want you to do it for me because I'm not going to learn anything. (Monique, Late Interview)

One of Monique's major goals for herself for this summer experience was to become more independent in the lab. Christiaan's approach to mentoring allowed Monique to experience that independence in her daily work. It provided her with opportunities to make mistakes and problem solve, and learn from her mistakes as she discussed them with Christiaan:

I'm really, really independent. He let me work on my own. And then if the results came out wrong, and when I failed, he'd say "OK. Well this is what you do and you're going to write this down for next time." He wouldn't stand there and be frustrated. At least I wouldn't know it. Like he'd just let me fail in the lab and then say, "Hey, let me show you something. Here's a trick. Go about this another way." We'll sit down, we'll brain storm a different way to modify things, take a different approach that would fix the problem. And I learned that way. (Monique, Late Interview)

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<sup>5</sup> High-performance Liquid Chromatography is a common technique used to separate and quantify compounds in a mixture. Monique used this technique in her chemical analysis of leaf tissue.

Christiaan's approach to mentoring was, in a sense, another way of testing her. And when she failed, she felt that Christiaan did not hold the failure against her. Rather, he made her feel like this was a normal part of learning to do science. Monique incorporated these experiences, and what she observed of her PI's behavior, into a new view of an ideal mentor for graduate research:

Just- you don't see your mentor sometimes – and that's a good thing...Of course everyone wants to have someone like Christiaan be their mentor, someone to help guide you around and explain everything to a T. But from what I've seen, the ideal mentor looks like [my PI]. Someone that's like, not always around in the lab making sure that you know. Someone who's not making sure you know, but is involved in your research because, I mean he's your PI. But someone who, if he was your mentor, you probably wouldn't see him a lot. (Monique, Late Interview)

Monique remarked to me several times over the course of our interactions that as an intern in the Program she felt like a graduate student because of the independence granted her by her mentor, and because she felt she compared favorably with the graduate student in her lab. During her late interview, she reframed her prior research experiences, illustrating a gain in awareness of, and identifying with, graduate life:

Back at home it's kind of like all set up for me. My mentor would get her students to plant plants in a pot and then all I would do is come in and spray them. And I kind of knew what we were looking for, and just test to confirm like, my hypothesis. Here? No. You start from scratch. Here you have to do everything. It's like you have to brainstorm what direction you want to go with your project. There's like a bunch of different approaches you can go with your project. So it's not set up, it's not pre-set here. And I like that. It's showing me this is real research. No one's going to hold your hand. Know what I'm saying? Like at school, I'm continuing her research, it's already put together. Here, it's my research, it's from scratch.

...

I knew that real scientific research was a lot of hard work, but I didn't know the depth coming in. Like I didn't know it was that hard to get one set of results. Like trial after trial after trial. It was very different from what I was used to back at home. Because my project was set up for me there...Here they're like, going with the flow. Let's try this and if it doesn't work, we'll come back to this later. (Monique, Late Interview)

I ended my late interview with Monique by asking her if there was anything that she wished she had done differently as an intern. She responded that in hindsight, she wished that she had slowed herself down “just a little bit” to pay more attention to the smaller things that one can overlook when rushing through a task:

But I mean you know how you get the hang of things and you’re just doing it. Those things, if I just take a minute, step back, maybe a few seconds slower then I would have had, you know, it probably would have come out a little better than it did...I mean I need to learn to be more patient with science. But just to slow down. (Monique, Late Interview).

This quote came several days before my interview with Christiaan; he had not yet had a conversation with her about the quality of her work or data or her readiness for graduate school. Thus, Monique displayed some ability to reflect on her own work and take some responsibility for the outcomes of her project.

**The author’s perspective.** The summer 2009 internship program took both Christiaan and Monique outside their comfort zones. Christiaan had his first experience mentoring a student that he could not quite understand. Having had positive experiences with a variety of interns in the past, having reviewed Monique’s application materials, and having selected a project and employing a mentoring approach that he felt was fool proof, Christiaan set out to provide Monique with an intern-centric experience. However, Monique proved to be a greater challenge than Christiaan had expected. He was confused by the marked difference between “what she says, and what she does.” The way in which she had represented herself on paper, and her statements about perfection and motivation, were in direct conflict with the quality of her work and her inability to self-correct. Monique professed to aim for a very high standard, but her performance fell far short in Christiaan’s view, and Monique did not, or was unable to, reflect upon the difference. Though Christiaan worked with her through each research problem as it arose, he did not provide her with the kind of feedback that might have impelled her to do

this reflecting. Reassuring her to “not worry” and “try another trick” over and over again conveyed the message that mistakes are common in science and therefore OK. This message was reinforced by what Monique observed of Lucy’s behavior in the lab. However, the messages that it was common and important in science to reflect upon mistakes and take measures to prevent them, was not conveyed or reinforced. Monique did in fact reflect somewhat on how rushing through her work may have negatively impacted her results in her late interview. However, in the absence of the appropriate feedback, there had been no external pressure to change her behavior.

Christiaan clearly felt that learning what to expect in graduate school and a research career should be an important outcome of the intern’s experience, and he felt that Monique had not learned several key lessons: one must have the correct temperament and attitude to cope with the repetitive work and long days common to most molecular research; mistakes are OK and even expected at first but should not occur over and over; no one is going to “babysit” a graduate student through her research so if you cannot self-monitor and self-correct, you will not be successful in graduate school. It may also have been the case that Christiaan had written Monique off as a certain “type” of student who was unable or unwilling to learn these lessons. In his view, she had neither the practical skills nor was she “life-smart” – two important components of his formula for success in graduate school. Christiaan recognized that spending more time monitoring Monique’s work would remedy the problem of useless data. However, he felt that this would be a waste of his time, and he did not have a lot of time to waste. Thus, his failure to change his approach toward mentoring Monique was, in part, an economical choice. It would cost him less effort and time to do the work himself after the program than it would to mentor Monique in a way that would help her to produce the quality data he needed. It may also have been the case that he felt she would be “weeded out” of the research career

path and therefore putting in the extra effort to work more closely with Monique would not pay off, even for her. Eventually, Christiaan shifted his goals from learning how to design experiments and analyze data to his fall-back plan of “building skills” with Monique.

Monique also stepped outside her comfort zone; this was her first experience so far from home and her first experience in a setting where most of the people around her were not African American. She had been concerned that she would not fit in or that people would think she was, in her own words, “weird.” As I observed Monique at work in the laboratory, I too found her to be a conundrum. A rising senior with four semesters and two summer internships of prior plant and molecular research, Monique fumbled through her techniques like a novice who had never held a pipette. And, like Christiaan, I was struck by the difference between “what she says, and what she does,” and I do not claim to know what might be the reason for it. However, I can imagine that stating you are a perfectionist up front provides safe cover if you are shy about admitting you don’t know, don’t understand, or need help:

I am very timid when it comes to new people, especially [my PI]. [My PI] is very intimidating because you don’t know. You don’t know, like, meeting somebody as important as he is, first off. I didn’t really know how to deal with that situation. Because, you know, at your home institution, it’s very close. I go to a small HBU, you know everyone. This is a big institution. Me coming in from the outside, I was like “Oh my god, I have to be perfect.” But I learned how to let that barrier down, how to put myself out there. (Monique, Late Interview)

I can also imagine that having a role model like Lucy around may be something of a relief. If you are never told that your work is substandard, but are often told not to worry about mistakes, you may come to the conclusion that “science doesn’t work.”

Monique had three personal goals for the summer internship: new techniques, independence in the lab, and critical thinking. She learned many new techniques, though most were not molecular. She was very independent in her daily work in the lab, though day to day independence did not extend to independence in advanced inquiry skills such as developing

research questions, designing investigations, or analyzing the results. Christiaan felt that he asked her continuously to evaluate her data and explain it but she never developed the ability to do so on her own. And, because her data were essentially meaningless, she could not use it to construct, support or defend an argument. Despite this, Monique's self-reported, post-program inquiry scores were among the highest<sup>6</sup> (independent= 46, guided = 37) whereas the scores awarded by her mentor were very close to their means<sup>7</sup> (independent = 15, guided= 26). This disparity in scores further illustrates the difference between the way Monique represented herself and the way she was viewed by her mentor.

Monique did feel that she practiced and witnessed critical thinking, and this contributed to a slight advancement in her epistemological thinking. In her early interview Monique stated that she did not want to be a "walking mnemonic" who's only achievement was to memorize a whole text book of facts. She offered research as a counter-example where thinking critically about ideas and concepts was more important than memorizing facts. She viewed critical thinking as "Asking how can you prove this?" or "How do you know if this is correct?" (Monique, Early Interview). She felt that critical thinking was important in research, but uncomfortable in the classroom. Her post-program response indicates that critical thinking had become of central importance to her now:

I think everyone should be able to think critically now, on their own. Instead of just facts, like I said you're learning facts in class and you're just going to read and take the test. You're not really learning. And I just think that um that to be successful in college you have to study smart and not study hard (Monique, Late Interview).

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<sup>6</sup> Intern, independent post-program inquiry mean =  $23.5 \pm 10.0$ ; intern, guided post-program inquiry mean =  $28.3 \pm 8.7$

<sup>7</sup> Mentor, independent post-program inquiry mean =  $18.5 \pm 8.1$ ; mentor, guided post-program inquiry mean =  $29.5 \pm 6.1$

Monique's perspective on the role of the learner shifted from demonstrating that you know the right answer in the classroom and thinking critically in research, to thinking critically in all aspects of one's learning. Monique's shift in focus from learning facts to critically thinking and her quip about studying smart rather than studying hard, are reminiscent of Christiaan's views on "book-smart" and "life-smart." It may be that he influenced Monique's thinking in this area. This change was not accompanied by others that might have helped to advance Monique from an overall absolutist way of knowing to a transitional way of knowing, but it suggests that she had begun to view knowledge and learning from a different perspective because of her internship experience, and in thinking of her future:

Being able to think critically outside the box. If you only think in the box you're not going to get anywhere. You have to take extra steps, extra measures, in order to become successful...I think it's something that I knew all along, but it just hit me. Something that I took for granted. Because like I said, my home institution is small, you have people there to hold your hand. But here it's like, wow! Reality set in. You have to do things here on your own. You have to be able to think critically and pose your own questions. Is there someone giving you a pool of research questions that you can conduct research on? It really set in here that I need to be a critical thinker. (Monique, Late Interview)

Monique also felt exposed for the first time to the world of real scientific research through the Program, a valuable experience as she continued to make plans to attend graduate school. She learned that the "research world" is very different from the undergraduate world. The research world is uncertain and indeterminate, whereas the undergraduate world is set up for you and predetermined. Also, in the research world people ask you questions at conferences because they are interested in what you are studying, they know something about your topic and they want to know more about how you came to your conclusions. They are not just questioning your knowledge in order to judge you in a competition, as it is in the undergraduate world.

Monique's insights into the nature of scientific practice and the research world were accompanied by moderate gains (Figure 5.2 and 5.3) in understanding aspects of NOS or NOSI from her experiences with real research. Her internship experience resulted in movement from mostly naive views about the socio-cultural embedded NOS, the community of practice, and multiple purposes of scientific investigations, to more informed views of these aspects of NOS and NOSI. Thus, while Monique did not make the kinds of gains in practice or understandings that Christiaan would have liked, she clearly did gain in some ways from the program.

Christiaan's attitude at the end of the program was that a career in scientific research was not for everyone, clearly meaning not for Monique. In his experiences as a graduate student and mentor, students learned how to be a scientist and how to do research through experiences, and mistakes were important learning experiences. Failure to learn from your mistakes as an undergraduate was a troubling harbinger of failure as a graduate student. Christiaan gave Monique space to make and learn from her mistakes, but the learning did not happen. However, as Monique put it in her early interview, "Not everyone learns at the same pace. You can't teach students in one way." For students to learn how to design and create experiments in the way that Christiaan had, or in the way that he expected, is indeed "only for the very few." Absolute knowers like Monique, who look to external authorities to tell them right from wrong, may not be able to learn how to do the more advanced aspects of scientific inquiry in the same way that Christiaan had. I think that Christiaan understood there may be another way in which such students can learn to do science, as he suggested that not every student meets his ideal and he needed to be more involved in Monique's work, but in his view, scientific training just doesn't happen that way in the real world.

## Discussion

The cases of Elliot and Monique highlight several related themes that emerged from the qualitative analysis of interns' research experiences. The first of these is the relationship between autonomy and engagement with inquiry. Interns with higher program inquiry scores made greater gains in understandings about NOSI (Chapter 4), and interns with high program inquiry and high autonomy had more opportunities to practice advanced inquiry skills independently, or in partnership with their mentor (Chapter 5). Elliot's case illustrates one way in which a high level of autonomy can be achieved in a research internship, and how that autonomy can lead to gains in the practice of advanced inquiry skills and understandings about NOSI.

Elliot's experience was atypical. The majority of interns in the Program had limited autonomy, related to the second theme: the nature of the research conducted. It was possible for Elliot to experience a high level of autonomy because of the non-technical nature of much of his work. Most interns were engaged in highly technical research with higher stakes, as the mentors on these projects expected to be rewarded with usable data. In order to scaffold interns along the steep learning curve involved in advanced molecular techniques and protocols and to ensure a usable product, most mentors elected to provide their intern with a heavily prescribed research project that was typically straight-forward with little to modify and few surprises. In other words, these projects more closely resembled the simple inquiry tasks described by Chin and Malhotra (2002) than authentic scientific inquiry which is indeterminate and uncertain (Knorr-Cetina, 1983; Pickering, 1995). From this perspective, the cutting edge and advanced nature of the research characterizing the Program might be seen as a barrier to learning how to do many aspects of inquiry, and a barrier to learning about aspects of NOS and NOSI.

Another theme that emerged from the qualitative analysis was the role of the intern's ability to cope with uncertainty and ill-structured problems in learning how to become an autonomous researcher. The ability to reflect upon and learn from one's experiences distinguishes more developed epistemological thinking from absolutist thinking (King and Kitchner, 1991; Kuhn, 1999). For example, Elliot's reflective abilities, characteristic of a transitional knower, enabled him to absorb implicit messages from his laboratory experiences, to learn from his mistakes and to question himself and evaluate his own work. Monique's inability to self-reflect provides an intriguing contrast. Her view of the role of the intern was an absolute knower's view of the role of the learner: to be told what to do, how to do it, and how well she was doing it. As an absolute knower, she was unable to reflect upon her work and its outcomes in order to self-evaluate or self-correct. In her view it was the mentor's role to evaluate and correct. Such an intern could not possibly cope with autonomy in the laboratory.

Finally, the cases of Elliot and Monique highlight an important area of intern-learning through research: the nature of scientific practice. The indeterminate and uncertain nature of scientific practice is one of the more poignant lessons with which all graduate students must come to terms (Delamont & Atkinson, 2001). As Monique pointed out, her undergraduate training did little to help prepare her for the "real" research world, in which one starts from scratch and procedures are not planned out in advance by a knowledgeable authority to work neatly and with certainty. Uncertainty arises in part from a heavy reliance upon black boxes (Latour & Woolgar, 1979; Fujimura, 1988) in biotechnology research to produce data. Much of what interns encountered in the laboratory could be considered a black box: techniques and procedures, tools and equipment, theory and project design. Without the appropriate personal and tacit knowledge, imparted either through instruction or experience, black boxes remained black boxes and the intern failed to learn from mistakes or overcome a significant challenge.

Many interns came to view scientific tools and procedures as having their own material agency – things simply did not work because “that’s just the way science is.” And much like Pickering’s (1995) “mangle of practice” the intern learned to cope with this mysterious force. Much of this work was accomplished through trial and error, a common approach to trouble-shooting. However in several cases of learning through failure (e.g. Elliot, Betty, and Taylor), the intern began to learn how to cope with roadblocks by systematically testing ideas, reasoning through a procedure, and reflecting on one’s work. In a sense, these interns were engaged in learned procedures for opening and mastering black boxes.

The iterative nature of scientific practices was also an important learning experience, as expressed by both interns and mentors. Repeating many trials or tedious tasks with precision, spending many weeks engaged in a single task to collect a bulk of data, and spending long days at the bench to complete a protocol were various ways in which this manifested itself in the Program. Mentors viewed this part of the experience as especially important for the intern’s future career in science.

## CHAPTER 8

### Conclusions and Implications

#### Introduction

UREs have become a popular response to calls for reform in undergraduate STEM education. Undergraduate research has the potential to expose students to authentic and cutting edge scientific inquiry and careers, and real-world experiences difficult to impart in the classroom. 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), critical thinking (Bauer & Bennett, 2008) and understandings aspects of NOSI and NOS (Ryder *et al.*, 1999); develop epistemologically (Rauckhorst *et al.*, 2001; Bauer & Bennett, 2008); 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, what understandings about NOS and NOSI did they develop, and what changes in epistemology occurred during their participation in research practice? Finally, I 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?

## Conclusions

### Engagement with Inquiry

Though interns were exposed to a variety of inquiry and research skills, their independent practice as undergraduate researchers in advanced biotechnology laboratories was largely of the most basic inquiry skills (e.g. collecting and summarizing data). Few interns were offered the autonomy to independently practice more advanced inquiry skills such as posing their own scientific questions or designing methods for investigation. Not surprisingly, interns with greater autonomy in their research did practice more advanced inquiry skills to a greater degree than their peers, and made greater gains in their understandings of aspects of NOSI, though not necessarily NOS. Some interns did make gains in understandings about NOS, but these did not correlate with inquiry practice or autonomy. Thus, undergraduate research *can* lead to advancement in inquiry practice and understandings about NOS and NOSI, though participation in advanced and cutting edge laboratory research does not guarantee such gains. Further, most interns were at least exposed to advanced aspects of inquiry through their guided work with mentors. Thus, the potential for practicing and learning these skills was present, if not always realized.

### Understandings about NOS and NOSI

Most interns made shallow gains in only one or two aspects of NOS. For most interns, the context of a summer research internship involving cutting edge laboratory techniques and tools, did not promote deeper understandings of NOS. Scientific knowledge is constructed through rhetorical and other social processes at the level of the larger scientific community, a level remote from the daily workings of a research laboratory. Furthermore, developing interns' understandings of NOS was not a goal of the program, nor was it a personal goal of any of the mentors interviewed. However, I did observe one way in which interns' NOS

understandings were promoted through authentic research, even in the absence of explicit messages about NOS. Two interns experienced critical events, namely surprising research outcomes, and actively participated in the process of reasoning through a logical explanation for these outcomes. Each of these interns made gains in understanding aspects of NOS that were directly tied to these experiences. These findings suggest that critical events, more so than day-to-day work in an authentic research setting, can contribute to improved views of NOS.

My findings also suggest that day to day work of a certain quality can contribute to improved views of NOSI. Most interns made greater gains in understandings about NOSI than NOS, and gains in NOSI were directly related to gains in inquiry practice. Interns who participated in more aspects of inquiry, particularly advanced aspects, and who enjoyed greater autonomy in their research made greater gains in understandings about NOSI.

### **Epistemological Development**

In contrast to the findings of Rauckhorst et al. (2001), I found no evidence for gains in epistemological development through participation in this summer URE. Rauckhorst et al. (2001) found that interns who joined their mentor in designing the research, developing learning goals, and setting expectations for intern and mentor roles, made the greatest gains in epistemological development. Most interns in this summer URE did not participate in research design, and the Program did not emphasize or address learning goals or setting expectations for roles. It may also be that the cognitive demands placed on interns in this particular URE were not of the type that would promote development of epistemological thinking. As discussed above, most interns did not independently practice more advanced aspects of inquiry that would challenge their abilities to reason through a problem, evaluate a knowledge claim, or coordinate multiple perspective, for example.

Personal epistemology was one factor uncovered by this research that helps to explain

interns' overall NOS and NOSI scores. The intern's level of epistemological thinking appeared to set an upper boundary for what could be understood about these socially derived constructs. This finding is of special significance for situations involving younger learners with naive or absolutist views of the nature of learning and knowledge. These learners may have an especially difficult time grasping the tentative and contextual nature of scientific knowledge and its social construction. At the same time, it may be the case that an explicit focus on actively developing learners' understandings about aspects of NOS and NOSI might promote their epistemological development.

### **Research Projects**

The nature of the intern's research project was another factor that helps to explain gains in inquiry practice and understandings about NOS and NOSI. Interns' research projects were of several types: non-investigations, simple-observational investigations, multifaceted observational investigations and hypothesis tests. The type of research project in which the intern engaged influenced the aspects of inquiry, NOS and NOSI to which the intern was exposed. For example, non-investigations were not framed by scientific questions or hypotheses that were apparent to the intern. Such projects did not involve crafting or defending an explanation or argument. In contrast, multifaceted observational investigations involved several smaller projects tied together by a common focus or theme. Each smaller investigation involved its own question, data set, analysis, and explanation linked to a body of scientific knowledge. In this way multifaceted investigations involved numerous opportunities to experience these elements of inquiry.

Furthermore, most research projects were carefully designed by the mentor to be straight-forward and to generate concrete, analyzable outcomes. Mastery of the advanced technology and techniques that characterized the Program's research offerings required

significant guidance, effort and time. Few mentors expected the intern to reach the level of proficiency in under ten weeks necessary to wield these tools independently. To ensure a successful and satisfying research experience for the intern, most mentors heavily prescribed the experience. Thus, there were few instances where the research plan reflected the messy and indeterminate nature of the scientific enterprise (Knorr-Cetina, 1983; Pickering, 1995). In this way, the advanced research setting served as something of a barrier to developing more sophisticated understandings about NOS and NOSI, and perhaps developing epistemologically. Vignettes and cases presented in Chapter 6 and 7 demonstrate that in those situations where interns were permitted to grapple with messy and indeterminate problems, the intern made greater gains in their understanding about NOS and NOSI.

### **Intern-Mentor Transactions**

Situations in which interns were permitted to grapple with tools and ideas, either independently or in partnership with the mentor, occurred when the mentor viewed the intern as an apprentice. These situations were characterized as either balanced or intern-centric transactions between intern and mentor. Balanced and intern-centric transactions lead to positive outcomes for interns, and typically greater gains in inquiry practice and understandings about NOS and NOSI. Mentor-centric transactions, in which the intern was viewed more as an assistant or lab-hand, typically lead to negative outcomes for the intern and fewer gains in inquiry practice and understandings about NOS and NOSI. Mentor-centric transactions developed when the mentor viewed the intern as a means to an end, rather than a scientist-in-training, and when high-quality data were deemed more important than the intern's learning.

### **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.

This Program, and others like it, needs 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 eat 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.)*

<p><b>In your past experiences as a science student, how <u>often</u> have you been able to do each of the following INDEPENDENTLY?</b></p> <p><b>Independently = On your own</b> (or with a partner or group) – the key is that <b>the work was self-directed</b> and not teacher-directed.</p>	<p><b>0 = Never</b>  <b>1 = Once or twice</b>  <b>2 = Sometimes</b>  <b>3 = Often</b>  <b>4 = Very often.</b></p>
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.)
  - l) 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<sub>C</sub>.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<sub>c</sub>.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<sub>c</sub>.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<sub>c</sub>.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<sub>c</sub>.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<sub>c</sub>.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<sub>c</sub>.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<sub>c</sub>.8)
  - If not, explain why and provide an example (modified from VNOS<sub>c</sub>.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, 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. 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<sub>c</sub>.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<sub>c</sub>.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 evaluate 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: Intern, Late-program

1. Describe the lab you were in – size, personnel, atmosphere?
  - How much did you interact with others in the lab? (scale of 0-4)
  - What were those interactions like – formal? Informal
  - How do you think this atmosphere may have influenced your experience/learning/progress?
  - Did you attend lab meetings? If so, what did you get out of these meetings?
  
2. Describe your research project.
  - What is your research question? What are you looking at?
  - How did you go about doing this project?
  - How did it develop over the course of the summer?
  - What is the next step? What *could* you do next?
  - What will the data be used for?
  - What is the bigger picture?
  - How well did this project match your interests?
  - Probe intern about written research proposal
    - How closely does the proposal reflect what you actually did?
    - How did you go about writing it?
    - Probe terms/ideas
  
3. Do you feel like your prior research experiences or coursework prepared you for this experience?
  - In what ways did you feel prepared? In what ways did you not feel prepared?
  - How have your experiences here connected with or built upon your prior knowledge? *Subject matter, conducting research?*
  - What was similar/different between the science you practiced here and the science you've practiced in school (undergraduate)? *Value added?*
  - Do you feel that you've gained anything from this program in terms of your next year(s) in school?
  - Do you feel you've gained anything from this program in terms of grad school preparation? What aspects of the program?
  
4. One of the goals of this program is to give students an idea of what real research is like. Do you have a better sense of what real research is like now? Can you describe this to me – what has changed for you?
  
5. I have a short series of questions about scientific inquiry – look at the printout and read along with me.
  - 1) A person interested in animals looked at hundreds of different types of animals who each either eat 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<sub>c</sub>.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<sub>c</sub>.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<sub>c</sub>.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<sub>c</sub>.1)

c) What does the scientific method mean to you? (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?

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

- What is an hypothesis? Where do hypotheses come from?
- What is hypothesis drive science?
- After scientists have developed a scientific theory, does the theory ever change? (VNOS<sub>c</sub>.6.)
- How are facts and theories related? Explain.
- What theories framed your research project?

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

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

IV) How certain is the scientific knowledge found in text books? (VNOS<sub>c</sub>.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)
- How did this play out in your project?

V) Is there a role for creativity and/or imagination in scientific investigation? (modified from VNOSC.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 VNOSC.8)
- If not, explain why and provide an example (modified from VNOSC.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, 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.

- 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? (VNOSC.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)

- Think about your mentor and PI
- 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 VNOSC.10).

6. Now I would like to revisit your answers to the learning styles questions from the beginning of the program *to see if you would like to change your answers to any of these now.* (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.

Ask intern: Do you still feel the same way, would you change the choice you made if you could? Why? Then have Intern re-answer this question but with an example from the URE.

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.

Is this the same advice you would give to an intern in this program? Why/Why not?

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.

Ask the intern to address this question thinking about her mentor's instruction

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?

In what ways, if any, did you learn from peers in this program? Lab mates?

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 evaluate students' work in college courses.

Do you still feel the same way about this question? How would you answer this question regarding this URE?

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?

Can you give me an example from your experiences as an intern?

7. Mentoring
- Describe the approach your mentor took in mentoring you through this project.
  - What in particular did your mentor do very well?
  - What in particular could your mentor have done better to help you.
  - What in your view does the ideal mentor do?
8. One of the goals of this program is to give students a better understanding of the field of plant biotechnology and genomics through your participation in this program?
- Summarize the field in a nutshell.
  - What aspect(s) of the program helped you to develop this knowledge?
9. How do you think scientists make a genetically engineered plant?
- What are genes and proteins?
  - What is a gene?
  - What is a protein? How is a protein made? Is there a relationship between gene and protein?
10. This survey is very similar to the survey you filled out at the beginning of the program. However, this time, your answers should reflect ONLY what you have experienced as an intern in this program. Please do not include any experiences you've had prior to the BTI SI Program as you answer each question.

Answer each question twice:

- first to reflect your **self-directed** work (work you did on your own, independent work)
- second to reflect your **mentor-guided** work (work that was mentor-directed or work that you co-participated in, this includes observing your mentor performing tasks).

**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)

<b>As an Intern in the program, to what extent (how often) DID you do each of the following:</b>	<b>a) self-directed</b>	<b>b) mentor-guided</b>
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

### 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 your 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)

<b>As an Intern in the program, to what extent (how often) DID you do each of the following:</b>	<b>a) self-directed</b>	<b>b) mentor-guided</b>
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 E

### 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
<b>Empirical NOS</b>	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.
<b>Experiments</b>	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.
<b>Validity of Observational science</b>	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 <i>good</i> 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 <u>amassed</u> to produce evidence that supports or refutes a claim.	Data are <u>interpreted</u> to provide evidence that supports or refutes a claim

<p><b>Role of Communities of Practice in NOSI</b></p>	<p>Little or no awareness of the scientific community's influence on what scientists do.</p>	<p>Awareness of usefulness of literature – background knowledge, building on methods (but not scrutinizing or criticizing methods)</p>	<p>Practices and standards for developing scientific knowledge. May mention peer review here, but does not explain it.</p>	<p>Practices and standards for accepting scientific knowledge – importance of critical peer review in acceptance of scientific claims.</p>
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## APPENDIX F

### Epistemological Reflection Model

**Table 2.1** from Baxter Magolda (1992), *Knowing and Reasoning in College: Gender-Related Patterns in Students' Intellectual Development*, p. 30.

<b>Domains</b>	<b><i>Absolute Knowledge</i></b>	<b><i>Transitional Knowing</i></b>	<b><i>Independent Knowing</i></b>	<b><i>Contextual Knowing</i></b>
<b>Role of learner</b>	<ul style="list-style-type: none"> <li>Obtains knowledge from instructor</li> </ul>	<ul style="list-style-type: none"> <li>Understands knowledge</li> </ul>	<ul style="list-style-type: none"> <li>Thinks for self</li> <li>Shares views with others</li> <li>Creates own perspective</li> </ul>	<ul style="list-style-type: none"> <li>Exchanges and compare perspective</li> <li>Thinks through problems</li> <li>Integrates and applies knowledge</li> </ul>
<b>Role of peers</b>	<ul style="list-style-type: none"> <li>Share materials</li> <li>Explain what they have learned to each other</li> </ul>	<ul style="list-style-type: none"> <li>Provide active exchanges</li> </ul>	<ul style="list-style-type: none"> <li>Share views</li> <li>Serve as a source of knowledge</li> </ul>	<ul style="list-style-type: none"> <li>Enhance learning via quality contributions</li> </ul>
<b>Role of instructor</b>	<ul style="list-style-type: none"> <li>Communicates knowledge appropriately</li> <li>Ensures that students understand knowledge</li> </ul>	<ul style="list-style-type: none"> <li>Uses methods aimed at understanding</li> <li>Employs methods that help apply knowledge</li> </ul>	<ul style="list-style-type: none"> <li>Promotes independent thinking</li> <li>Promote exchanges of opinions</li> </ul>	<ul style="list-style-type: none"> <li>Promotes application of knowledge in context</li> <li>Promotes evaluative discussion of perspectives</li> <li>Student and teacher critique each other</li> </ul>
<b>Evaluation</b>	<ul style="list-style-type: none"> <li>Provides vehicle to show instructor what was learned</li> </ul>	<ul style="list-style-type: none"> <li>Measures students' understanding of the material</li> </ul>	<ul style="list-style-type: none"> <li>Rewards independent thinking</li> </ul>	<ul style="list-style-type: none"> <li>Accurately measures competence</li> <li>Student and teacher work toward goal and measure progress</li> </ul>
<b>Nature of knowledge</b>	<ul style="list-style-type: none"> <li>Is certain or absolute</li> </ul>	<ul style="list-style-type: none"> <li>Is partially certain and partially uncertain</li> </ul>	<ul style="list-style-type: none"> <li>Is uncertain – everyone has own beliefs</li> </ul>	<ul style="list-style-type: none"> <li>Is contextual; judge on basis of evidence in context.</li> </ul>

## APPENDIX G

### Annotated Code List

#### Family: Aspects of Inquiry:

Code	Explanation	Example
<b>AltExp</b>	Alternative explanation: considering more than one explanation for findings/results	EMObs1Ln179: E demonstrates some curves he made with his data in Excel. We discuss what the curves might mean.[...].One graph represents a set of simple curves described by quadratic equations. Another graph represents a set of curves that look like wave functions. .[...]. E said that he does not believe the negative numbers that the computer-fit curve describes for some values of X. E is not confident in any of these curves because they extrapolate beyond the 4 or 5 points that he has for each.
<b>BigPic</b>	Bigger Picture: relevance, "Why is this project interesting or important?"	HPObs1Ln128: H keeps mixing up the two temperature treatments as she talks to me about her project and what she's going to do next. <i>This makes me think that she's missed the global warming connection that the lab makes when justifying its line of research.</i>
<b>ComExp</b>	Communicate an explanation: overlaps with writing, presenting	Mobs4Ln407: T wants to work on her presentation early so she has time to pack and also to sit back and watch all the others stress. They (presentations) are very competitive at her school.
<b>ConnectSK</b>	Connect to scientific knowledge: linking aspects of the research to subject matter knowledge.	SNObs2Lns2450247: N asks S why she thinks the sample has 2 bands. S suggests that it's because the plant is diploid. N nods and points to another sample saying: but this one is too. I can't remember what your gene looks like. Are we spread out across an exon? S thinks about this and says that she thinks so, yes. N suggests that there may be an insertion in one copy's exon that is big enough to separate into two bands.
<b>Data</b>	Working with data: collecting, sorting, organizing data. Preparing inscriptions (vs. using inscriptions [=tool])	VAObs1Ln10: V talks about the observations she has to do: find the plate, count the number of ungerminated seeds and logs this into the computer. She has to do this every few days, so many plates per day. Also includes any notes about things she may have noticed.
<b>DefArg</b>	Defending an argument: using logic, reasoning, data, prior knowledge to defend or justify an argument or explanation	JHObs3Lns368-376: H: The big difference between the 2 mutants is colocalization amounts. That really well reflects how much PI: So I don't get these numbers. 28% of DMC1 foci also have RAD 51? H explains PI considers this. H further explains PI makes a note on his pad H: This is the same data I've shown before.

		<p>PI: You need wild type numbers too.  H: That's what you said before. I'm working on it.</p>
<b>DevArg</b>	Develop an argument: using logic, reasoning, data, prior knowledge to construct an argument or explanation	<p>JHObs3Ln404-409: H: Sometimes a bad hypothesis is better than no hypothesis.  PI analogizes to pulling apart a woolen sweater. C extends the analogy to 2 sweaters.  H: I'm not saying my hypothesis is right but if we can disprove it that may tell us where to go.  PI: How can you prove it?  H: I don't know.  PI asks how much data he's looked at to develop this idea. PI tells the group that he asked C to present today because he (PI) wants to think more about this mutant.</p>
<b>Exp/ProjDesign</b>	Experimental design in general, design of a particular experiment, design of the intern's research project	<p>VAObs1Ln10: V explains that her project has lots of backup controls. Like saving the seed sets from which she is working.</p>
<b>Explanation</b>	Developing an explanation for data, a result/outcome, a phenomenon	<p>QBObs4Ln552: 11:27AM. Q shows me a list of genes he's worked with. He shows me means that reflect upregulation, others that reflect downregulation. He shows me his own excel file with bar charts.</p>
<b>Interpret data</b>	Interpreting data (developing an explanation for or with data, some cases of using an inscription). Analyzing data.	<p>QBObs1Ln64: It's the same curve each time - same shape but I cannot see if the scale has changed. Q tells me they're all the same dye in this column so they all have the same absorbance spectrum. It's good that the curve is the same shape. That means that there was uniform labeling.</p>
<b>ModHyp</b>	Modify or revise a hypothesis based on new data or an outcome	<p>VAObs2Ln165: V tries to explain what of the conversation she understood. Some of it. "Only 9 or 10 is the crucial thing for me but I'm not sure what that means. They said 9 or 10. It seems that on every plate we have there's a mutant, but we shouldn't have that if our theory is correct."</p>
<b>PrimaryLit</b>	Primary literature	<p>EMObs1Ln56: M brings out a journal page with an image.</p>
<b>Reasoning</b>	intern reasoning or being encouraged to reason through a problem or an answer to a question. Mentor modeling reasoning.	<p>JHObs1Ln63-70: J doesn't know why the compounds are photosensitive. H asks him what he does know. J struggles to answer and H tries to draw out his knowledge. Not getting where he wants, H says, "Take a step back. You have 2 antibodies. What does the 1st do?"  J answers and H concurs.  H: What does the 2nd antibody do?  I: What <i>does</i> the 2nd antibody do?  H waits and then says we talked about it...  J can't remember.  H says that's OK and then explains, drawing on the scrap paper (I have this diagram). "That's photosensitive because..."</p>

		J is supposed to answer this but says, “Yes. Why is it photosensitive?” J is admitting that he does not know this. H then explains. Then “So you say it is photosensitive and you need to say why.”
<b>SciQuestion</b>	scientifically oriented questions, testable questions (both large and small).	EMObs1Ln169: E explains that there’s a paper that talks about abnormally large chloroplasts in a species of <i>Sellaginella</i> called bozanoplasts. He tells me that it would be cool to find them in his samples because the paper just came out (it’s only 2 years old) ‘If we find them then we definitely know that this species is the same as the one in the paper.’
<b>TroubleShooting</b>	figuring out what went wrong with a procedure or task and trying to fix the problem. A form of problem solving (but not all instances of problem solving)	EMObs1Ln187-189: There are no bands on the gel besides the ladder.[...]M looks at the image and says, “That’s OK. We can look at the conditions that PCR was set up and ....” (missed what came next) E explains something. M: “That’s OK. It would be crazy if you had success every time.
<b>Writing</b>	scientific writing (research proposal, research paper or poster) or quasi-scientific writing (lab report)	JHObs1Ln30: They sit together at the bench and consult J’s proposal. H edited it and I can see lots of margin notations and some highlighted text. The highlights indicate text that J should excise. J asks H to clarify some comments. One refers to short hand for gene names.

#### Family: General Skills/Aspects of Research

Code	Explanation	Example
<b>Materials</b>	research organisms or entities, reagents, general supplies that are not tools, or that are not being used as a tool in this instance	QBObsLn151: R returns with 2 bottles and says: “We’re going to make 2 separate solutions because there are no 200 ml bottles.” They discuss materials some more. Then R gets water.
<b>Math</b>	calculations of any kind	WJObs1Ln118: L: We’ll throw the others away but later. I made all these solutions for you, I know you don’t like calculations.
<b>Notebook</b>	formal laboratory research notebook	WDObs1Ln137: A opens her notebook and draws a plasmid image, still wearing her gloves. She labels it, thinks for a moment, then writes some notes.
<b>Problem solving</b>	Differentiated from trouble-shooting. Problem solving is figuring out a way to cope with a challenge	HPObs1Ln59: H has to count the seedlings in order to calculate % germination but is not sure how to go about doing that in a systematic way. Sometimes this step helps her to find more dwarfs. H: “Maybe if I split it up into quadrants?” She proceeds to count but not in quadrants. She starts at one end of the tray and touches each plant with her index finger. She seems to have trouble with a clump but moves on.
<b>Resource(info)</b>	informational resource – textbook, guidebook, binder of protocols or recipes, on-line database, expert advice	QBObs1Ln141: 10:42 B asked Q what he put in his SSC. Q tells him. B asks if he knows how much and Q says yeah. They both go over to his notebook and Q shows him the recipe, telling him that he got the recipe from LabRat.com. B says: Excellent. good. That will work.”

<b>Techniques</b>	There is overlap between techniques and procedures. For example, a mini prep is a technique involving several different procedures (that might be considered techniques in others instances – for example, running a confirmatory gel).	JHobs1Ln126: 2:08. J watches as H pipets. J sets the timer as soon as H pipets (J pre-set the timer and only had to push the start button). J sets pipet for H as H gently shakes the plate. J puts a tip on his pipet in preparation. Gives a 30 second warning. Draws up the wrong buffer. Discards this as the alarm goes off. He re-preps the pipet as B draws solution out of the dish into a little tube. J pipets into the dish and H swirls. J sets the timer.
<b>Tools</b>	equipment (microcentrifuge, gel imager, pipet), but also things like informative labels for reagents and samples (some examples: label = simple cognitive tool, protocol = procedural tool, Excel/computer/calculator = computational tools)	WJobs1Lns224-226: W takes the scrap and goes into J's office to ask him a question. He comes back in with her and says, "didn't you write it down in your notebook? W: Yeah I did but I wanted to make sure... J explains something about stock solutions and powers and working solutions and concentrations. He seems to realize that she is not getting the concept of stock solution vs. working solution. He points to the notebook. It seems to me that W has made a mistake in diluting last time. J leaves
<b>WorkPlan</b>	has to do with the timing and order of daily/weekly activities. Sometime overlaps with project design	QBobs1Ln103: Q's scrap paper is a to-do list. He made this himself 1st thing this AM or last night.  EMObs1Ln42: M and E discuss again setting up a gel. E says "OK, I'm kind of lost which one we're doing. M refers to "the one that worked" last week. She suggests that he look into his notebook and tells him (her tone is sort of "don't worry") that its Monday. E opens his notebook and she points to a gel image and they discuss.
<b>WorkStyle</b>	individualized elements of practice: organization, hand movements, preferences and particularities...	WJobs1Ln164: J leaves tubes in a row on the rack with their lids open and awaits W. As he does he again straightens her stuff out on her bench to clear space for her. He also turns on a work lamp located under the shelf at her station.

### Family: Socio-cultural Aspects of Science Practice

Code	Explanation	Example
<b>Black Box</b>	something (tool, technique, procedure) is a black box when its limits or outer boundaries are known/understood but its internal components are not (mindlessly or automatically employed without knowing why or understanding the mechanisms that make it useful)	QBobs1Ln139: As Q copies from 1 file to another, #s appear below on the same spreadsheet. QBobs1Ln145: He rolls back and then begins to explain that the spreadsheet "should be > 180" etc. for particular quantities like "pmol of Cy" and "nucleotides per Cy 5 molecule." The spreadsheet also tells him how many ul of the sample to use for specific pmol of dye: "ul of Cy per ul" Q: This is a pretty sweet spreadsheet. It keeps me from having to do a lot of complicated crap on my own so I definitely appreciate that.

<b>Failure</b>	an instance, evidence or story of something going wrong or not working.	WJObs1Ln132: She pipets twice from the culture tube into each microcentrifuge tube. J makes a comment: You're pipetting like that? That's clever. W: Well the first time it didn't work.
<b>Nature of the Research</b>	subjects indicate something in general (usually negative) about every-day practice in the field ("that's just the nature of the beast" kind of statement).	WJObs1Ln21: she tells me that its hard (I'm not sure what is hard) because it's a molecular biology lab so there's a lot to do but all at one time and then there's a lot of waiting around and hanging out and the work can easily be done by just one person.
<b>TacitK</b>	tacit knowledge, understanding or skill born out of experience or intuition, knowledge that one is unconscious of, that cannot be articulated, or that one chooses not to articulate	WJObsLn135: A reads the next line in the protocol and J says: No, don't use top speed." They go over to the microcentrifuge together and he tells her to set it for just 5 minutes.

### Family: Teaching/Learning

<b>Code</b>	<b>Explanation</b>	<b>Example</b>
<b>Independent Work</b>	intern working independently (reading, writing, practicing.	EMObs1Ln147: He puts a tip onto his pipet, carefully draws up some sample at eye level, I think at first that he rejects the sample, but I'm wrong. I see a moment later that he's pipetted the sample out onto the waxy surface of a piece of Parafilm. The sample forms a bead on the Parafilm. He resets the volume on his pipet and ejects the tip. He puts on a new tip and does the same with the second sample. He puts on a third tip and resets the volume on the pipetter. He adds loading dye to the liquid bubbles on the Parafilm. He puts on a 4th tip and resets the volume. Now he sucks up from the first bubble and moves to load a well on the gel, but stops. E: That was close. He adds running buffer to the gel box. Then he loads the well. He cleans the tip in the running buffer before he discards it (I wonder why).
<b>InternAsks Question</b>	includes the question (explicit or implicit) and the response it generates.	WJObs1Lns75-80: W: Is that good? J: Ah, give it a little more. When you can see the top wells it is good. W: you want to see the wells? J: Eventually W: Is it OK if I can't see the wells? J: It's OK. Its better if you can but its OK.
<b>KnowledgeOf</b>	subject displays knowledge of something - technique, using a tool, experimental design, subject matter etc. Telling or showing me what one knows about something.	EMObs1Ln89: The gel box that he is using has a hand-written label on colored tape: Fickle Box. I point his out and E says, "If you use the wonky lid with the fickle box it works." He notices that he put his gel bed into the box in the wrong orientation before he poured. He will wait for the gel to solidify before he fixes it. He preps the second box and the microwave dings.

<b>LA</b>	Learning about (declarative knowledge, explanations)	EMObs1Ons62-67: E: Ok, Gel? M: Gel. No wonder you're so confused! They discuss what will be put into the gel. M explains how something molecular happens, then what they need to do to clean up the sample. E confirms: So we're going to run a confirmation gel? M: Check gel.
<b>LtD</b>	learning to do or learning to use	HPObs1Ln18: She reran the same gel a couple of times to make it better. I asked her what "better" means and she says that if she runs it longer she can see all the bands. There are gels labeled A through F reflecting this process (6 images of the same gel put back into the rig to run longer). She used her notebook to write down what went wrong with every gel and will rerun the gel. Finding problems, rerunning.
<b>MentorAsks Question</b>	includes the question (explicit or implicit) and the response it generates.	JHObs1Ln63: J doesn't know why the compounds are photosensitive. H asks him what he does know. J struggles to answer and H tries to draw out his knowledge.
<b>NotLA</b>	lost or missed opportunity to learn about something, demonstration of lack of knowledge, understanding or learning	HPObs1Ln116: H tells me some of the challenges with what she's doing: it's hard to make a judgment about the phenotype (dwarf or normal) of some plants.
<b>NotLtD</b>	lost or missed opportunity to learn how to do something, demonstration of lack of knowledge, facility or learning	QBObs1Ln83: Q changes the names on computer file and explains: This spreadsheet will be saved as a text file. Then he will import it into Excel. There is an Excel file already set up to do the conversions for him automatically.
<b>NotTA</b>	lost or missed opportunity to teach about something	VAObs2Lns586-587: A opens a drawer in the machine, not the door above it. V laughs and looks at me and I shrug. This is because V opened the door to place the gel on the platform, which is the bottom of the drawer. A: It's a little dry on the bottom (to explain the air bubble trapped beneath it). A silently clicks buttons with the mouse and B watches to see what he clicks on. He is done in under 1 minute. He does not bother to print out the image.
<b>NotTtD</b>	lost or missed opportunity to teach how to do or use something	WJObs3Ln 386: W tells her that J does all the conversions for her. M suggests brightly that she takes notes when he does that and keep a list of all conversion factors for herself.
<b>TA</b>	Teaching about (declarative knowledge, explanations)	WJObs1Ln101: J stands at the end of the bench as he explains: colonies, restriction enzymes to find out how they sit. You assume the kind of pattern you would see if it is forward. You assume the kind of patter you would see if it is backward.
<b>TtD</b>	teaching to do or use something	WJObs1Ln209: A goes to check the samples. I hear the lid. J must have hears it from across the hall because he's there to meet her in seconds. J tells her what to do next. W pulls out 4 fresh mcf tubes.

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