Characterizing the inquiry experience in a summer undergraduate research program in biotechnology and genomics

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ABSTRACT

This study builds on our prior work examining students' learning during 10-week summer undergraduate research experiences (UREs) in laboratories described as being at "the forefront of plant biotechnology and genomics." We continue to be interested in how the laboratory contexts contributed to undergraduates' understandings of contemporary science and development into science practitioners. In this paper we report findings about summer interns' practice of inquiry skills. Our research questions were: What inquiry skills do interns most frequently practice (1) independently and (2) under the guidance of their research mentor? (3) What inquiry skills do interns practice in the URE that they do not commonly practice in their undergraduate education? (4) What relationships exist between interns' engagement with inquiry, the independence they experienced as researchers, and their feelings of project ownership? Interns practiced a wider range of inquiry skills under the guidance of their mentor than independently as they conducted their research projects. The most frequently practiced skills in this URE were the most frequently practiced skills in the interns' prior experiences as science undergraduates. Interns' perceived independent practice of inquiry skills correlated with their perceived autonomy in the research design, and feelings of project ownership, but did not correlate with their perceived project ownership. Limitations and future directions for research in this URE are discussed.

Keywords: science education, undergraduate research experience (URE), inquiry skills, nature of scientific inquiry (NOSI), nature of science (NOS), science apprenticeship

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Numerous government and professional organizations have issued calls for the transformation of undergraduate science, technology, engineering and math (STEM) education over the past twenty years (e.g. National Science Board 1986; Boyer Commission, 1998; National Research Council, 1999 & 2003; Project Kaleidoscope, 2006). These calls are a response to reports of US students' poor performance in international rankings of scientific literacy; low enrollments and high attrition in undergraduate STEM programs (particularly for women and minority students); and an increase in the national and global demand for technically trained workers (National Science Foundation, 1998; NSB, 2006; NRC 2007). In a synthesis of 20 such reports released from 2003 to 2006, PKAL (2006) issued the following "recommendations for urgent action" (pg. 1):

- use *inquiry-based teaching* and learning techniques to develop interest in STEM fields for all students currently in the pipeline,
- 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.

Undergraduate research experiences[1] (UREs) have the potential to address all four of these recommendations. Hence, the development and expansion of undergraduate research programs has been a major response to these calls for reform in undergraduate STEM education (Boyer Commission, 2002; Fortenberry, 2000).

The Council on Undergraduate Research defines undergraduate research as "an inquiry or investigation conducted by an undergraduate student that makes an original or creative contribution to the discipline" (CUR, n.d.). 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 STEM fields an URE 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 scientific community (Hakim, 1998).

Undergraduate research experiences have been promoted for attracting/retaining a talented and diverse pool of undergraduates in STEM career pathways; learning the process and nature of scientific research through inquiry; and bridging undergraduate and graduate education (Boyer Report, 1998; NRC 1999, 2003). The National Conferences on Undergraduate Research and CUR (NCUR/CUR, 2005) jointly endorse undergraduate research as a collaborative, investigative pedagogy that integrates teaching and research to provide students with an enriched inquiry-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.

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[1] "Undergraduate research experience" (URE), "research experience for undergraduates" (REU) and "undergraduate research opportunity" (URO) are variously used in the literature. We use URE as the more general and inclusive term and reserve REU for the specific NSF program of that name.

Though there is a large body of exhortatory literature regarding UREs, there is still much to learn about the effectiveness of UREs in terms of aspects of student learning and enculturation into the world of authentic science practice. This manuscript reports on a segment of our research focusing on the URE's. Our broader research aims are to more fully describe how particular URE's function to facilite student development as scientists. The larger research project is investigating URE-students' learning of science subject matter; development of their abilities to do inquiry; their understandings about the nature of scientific inquiry (NOSI) and the nature of scientific knowledge (NOS); their epistemological development and the interactions between those aspects. In order to understand student learning of inquiry through participation in an URE, it is necessary to know what inquiry skills and what elements of the nature of scientific inquiry (NOSI) these students experience. In this paper we describe undergraduate researchers' perceptions of their experiences related to inquiry skills outlined in the *National Science Education Standards* (NRC, 1996). In addition, we looked at the relation between their perceptions and the judgments of the mentors with whom they worked. Our research questions were: What inquiry skills do interns most frequently practice (1) independently and (2) under the guidance of their research mentor? (3) What inquiry skills do interns practice in the URE that they do not commonly practice in their undergraduate education? (4) What relationships exist between interns' engagement with inquiry, the independence they experienced as researchers, and their feelings of project ownership.

Inquiry

Although the NSES address both using inquiry as an approach to learning, and learning about science inquiry, we have focused on learning about science inquiry in this manuscript. Inquiry as content means that students should develop both 1) *abilities to do* scientific inquiry and 2) *understandings about* scientific inquiry (i.e. the nature of scientific inquiry) (NRC, 2000). According to the NRC, by the time a student graduates from high school, she should have fundamental *abilities* that reflect research 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 have fundamental *understandings* that reflect the philosophical and 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).

Even though the NRC publication Inquiry and the National Science Education Standards (INSES) focuses on using inquiry as a teaching approach, the document does clarify that students can be engaged with an inquiry at different levels. The *INSES* distinguished "full" inquiry from "partial inquiry" to distinguish work done with more or less teacher guidance vs. student self-direction. Brown, Abell, Demir and Schmidt (2006) have conceptualized a model for describing laboratory/classroom inquiry experiences where a given instructional piece may or may not include all commonly identified features of inquiry and may fall anywhere along a continuum of guidance from teacher direction to student self-direction. Their inquiry continuum model provides a useful tool for characterizing individual inquiry lessons along these two dimensions, degree of inquiry and degree of guidance.

A focus soley on activities associated with doing inquiry may fail to acknowledge how important it is for learners to understand the rationales for doing these various activities. (Bybee, 2000). As Lederman (2004) and Schwartz and Crawford (2004) point out, inquiry practice alone may not promote development of desired understandings about NOSI and NOS in most students. These authors recommend explicitly addressing NOSI and NOS within an inquiry context, and providing students with opportunities for discussion and reflection in order to promote the desired understandings. An URE can provide both the inquiry context and opportunities for discussion and reflection as student and mentor work together on an authentic scientific problem.

Existing research on UREs

Ironically, despite a strong history of support for UREs in STEM education, and the frequency with which UREs are recommended in undergraduate curricular reforms, there is very little actual research that has looked at the results of participation in UREs Seymour *et al.* (2004) reviewed the early literature in order to establish what is known about the benefits and qualities of effective STEM UREs. Of the 54 papers included in their review, these authors identified 9 they felt the claims about hypothesized benefits were well supported by the study. Seymour *et al*. called these studies “Type 1.” This literature offers support for a number of benefits for URE students. The most commonly cited benefits involve preparation for a career in science: increased research and laboratory skills, increased understanding of the research process and how scientists think and work, increased readiness for more advanced research, increased interest in the discipline and clarification or confirmation of the decision to pursue a STEM career or graduate degree. Another common theme among the Type 1 literature involved students’ development of a sense of belonging; for example, feeling part of a learning community, bonding with faculty and peers, building confidence in one’s ability to do research and persistence in a STEM field, particularly for underrepresented students.

Kardash (2000) is the only study among the Type 1 literature to have focused explicitly on the performance of specific research skills. The list of skills reflected some of the NRC’s (1996) list of important inquiry abilities, as well as general understanding of concepts and the bigger picture related to the student’s research project. Kardash developed this list from recent literature on assessing and evaluating UREs and from discussions with URE faculty mentors on what they felt were the most important research skills URE students should acquire. Kardash administered her survey to 57 undergraduates who had participated in summer or academic-year STEM research at a Research I institution in 1997 – 1998. She asked students to rate their abilities to perform the 14 research skills before and after their participation in UREs and the degree to which they felt the URE had enhanced these skills. She also asked the mentors to rate students’ abilities at the end of the URE.

The skills that students felt were most enhanced through participation in their URE were: orally communicating the results of their research projects, observing and collecting data, relating results to the bigger research picture, and understanding contemporary concepts in the field. However, 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.” In terms of abilities, Kardash found that students rated themselves significantly higher at the end than they had at the beginning of the URE in nearly all of the skills, especially in interpreting data, relating results to the bigger picture and orally communicating results. The skills with the lowest ratings before had the lowest ratings and shallowest gains after: 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).

Kardash's findings were strengthened by the fact that mentors' ratings of students' abilities were very similar to those of the students for 11 of the research skills. The set of skills interns rated highest was the also the set rated highest by mentors. Likewise, the set of skills rated lowest by interns matched the set of skills rated lowest by interns.

Research conducted subsequent to Seymour *et al.*'s (2004) review supports and elaborates on the Type 1 themes. For example, Lopatto (2004) developed the Survey of Undergraduate Research Experiences to evaluate UREs supported by the Howard Hughes Medical Institute. Lopatto derived his survey questions form 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 in 2003 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 was able to demonstrate that these two groups were widely divergent in their mean overall ratings of learning gains and satisfaction with their research supervisor.

Russell's (2005) evaluation of the NSF's Research Experiences for Undergraduates (REU) program went further to linked 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 during 2002 and 2003. Approximately 4,500 undergraduate researchers (response rate of 75%) completed a web-based survey. Over 80% of the survey respondents had GPAs of 3.0 or better, were in their junior or senior years of undergraduate study, and over 70% had some kind of research experience prior to their participation in their current REU. Russell found that most of the survey respondents had been motivated to participate in the REU because of their enthusiasm for research or because they wanted to make a more informed decision about whether or not to pursue graduate school or a career in the discipline.

Survey items were derived from review of the other URE evaluation surveys and discussions with NSF program officers. Participants rated their perceptions of how much the REU 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 REU, 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 ethnographic methods in their investigation of how students benefited from participating in summer UREs. Seymour *et al.* (2004) conducted interviews during with 76 undergraduate researchers in the summer of 2000. Transcripts were coded for observations about student learning gains and other benefits as raised by interviewees (there were no preconceived codes). Codes were grouped around themes, eventually establishing parent categories. Frequencies of codes within the dataset permitted comparisons of the different issues that had been raised by interviewees. These authors used interviews to elicit undergraduate researchers' and their mentors' views. Their analysis of student's transcripts yielded 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, in congruence with Kardash's findings, students made far fewer observations regarding developing research questions and experimental design. Students also reported 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 observations 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 one's 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.

Hunter, Laursen, & 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 (illustrated by relative frequencies) 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 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 the development of laboratory and research skills features prominently in much of the URE literature reviewed above, the picture of the URE as an inquiry learning experience remains incomplete. Students reported developing confidence and proficiency through practicing certain inquiry skills, but it seems that these are, 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 UREs, or it may be that students are 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 about and through inquiry. Their findings suggest that students had more opportunities to participate in simpler aspects of inquiry (such as data analysis) than more advanced aspects (such as developing research questions and methods). Their findings also suggest the ways in which students developed greater knowledge and understanding of scientific theories and concepts as they engaged in URE activities: problem solving, explaining their research project, 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 work indicates that involvement in the research design, independent work and interactions with mentors contributed to students' satisfaction and confidence in their abilities to do science, but does not address how these factors might also have contributed to their learning.

None of the work reviewed specifically attended to students developing knowledge about the nature of science or the nature of science inquiry, although some of the items in Lopatto's (2004) and Russell's surveys can be seen to reflect important understandings about NOSI and NOS. In particular, students reported developing understanding of 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 NOSI or NOS. We know of only a single study, that of Ryder, Leach and Driver (1999) included in Seymour *et al*.'s Type 1 literature, that explicitly addressed URE participants' developing views of NOSI or NOS. 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. 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 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).

Research on student learning via UREs that explicitly focuses on learning through, and learning about, inquiry in specific and clearly described settings is needed to clarify the picture of the URE as an inquiry learning experience.

Theoretical Framework

Learning science is both an individual process and a social process. The theoretical focus on the social dimensions of cognitive development has its roots 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 wielding of these now cognitive tools, the learner develops higher order thinking skills and processes.

Symbolic tools are social constructions and can not be fully acquired in the absence of social interactions (Gauvain, 2001). One of Vygotsky's most productive ideas was the zone of proximal development. This 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 "scientific" knowledge of the culture provided by adults (Chaiklin, 2003). Here "scientific" knowledge refers to formal, systematic knowledge born of adult reasoning and generally held by the culture or community as true (Karpov, 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).

Rogoff construed 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 enculturation experiences through which they are learned. Thinking of learning as an 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 field 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). The apprenticeship metaphor 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).

Undergraduate research experiences (UREs) are mentor-apprentice experiences in which the apprentice is introduced to the methods of the field by an expert (Kinkead, 2003). A URE can be a cognitive apprenticeship if the student's participation is considered legitimate work by members of the community of practice (Lave & Wenger, 1991) and if the work is scaffolded by the mentor in ways that promote cognitive skills as well as manual skills. Therefore, a URE in science should permit students opportunities to engage in authentic, mentored inquiry activities in which they learn experimental design and implementation of procedures as well as reasoning, critical thinking and other scientific problem solving skills. Students should have opportunities for both guided and independent practice with feedback from their mentor. In studying how and what URE students learn (or fail to learn) about science, it is therefore important to characterize the ways in which the URE is and is not congruent with a cognitive apprenticeship.

Methods

Our full study collected a range of data; in this manuscript we report on our analysis of the questionnaire we developed to capture participants' perceptions of interns' laboratory practice and learning. We gave the questionnaire to interns at the start and end of their URE's and to their mentors at the end of the experience. We sought to determine: What inquiry skills interns most frequently practice (1) independently and (2) under the guidance of their research mentor? (3) What inquiry skills interns practiced in the URE that they did not commonly practice in their undergraduate education? (4) What relationships exist between interns' engagement with inquiry, the independence they experience as researchers, and their feelings of project ownership?

Internship Context

We studied the 2008 cohort of interns in a NSF-supported summer research internship in the field of biotechnology and genomics at a Plant Research Institute housed at a Research 1 University. The Institute is a modern facility at the fore-front of its field, characterized by highly collaborative and international research. Thus, this summer URE is an intense, 10-week program of research experiences in world-class laboratories conducting some of the most cutting-edge research in the biotechnology field. The goals of this internship (paraphrased from the website) are to provide students with 1) a broader knowledge of plant genomics research, including techniques, applications and future directions and 2) a better understanding of genuine scientific research, in terms of both the individual's practice and responsibility within the lab, and as a valued member within a research group. Successful applicants (interns) are placed within laboratories where they are assigned a project directly related to the lab's ongoing research. Each laboratory is headed by a different Primary Investigator (PI), and is a distinct setting in terms of population (size, demography and nationality), atmosphere, and on-going research, providing a range of communities of practice in which the interns are immersed. The program offers many opportunities for both formal and informal scientific discussions as well as information and advice on careers and graduate opportunities. In the summer 2008 iteration, interns engaged in authentic aspects of research mentored by a graduate student or post-doctoral associate, participated in lab meetings, attended weekly research presentations by PIs within the Institute, presented their own findings at the end of the program in a formal symposium format, and lived communally in a program house on the University campus.

The program offers no formal training or program orientation for mentors. Expectations for the experience mentors are expected to provide to interns are communicated via the program's website, as paraphrased above.

Participants

The summer internship program funds 15 – 20 interns each summer from an average pool of 300 applicants. As an NSF REU, this program strives to meet the NSF's recommendations in its intern-selection process: gender balance, at least 30% minority participation, inclusion of some first- and second-year undergraduates, and inclusion of students from small undergraduate institutions (NSF, 2007). Other criteria for selection include GPA, interest in plant science and prior research experience.

Fifteen interns participated in the 2008 summer URE. All majored in a biological field; three were pre-medical student and one was working toward science teacher certification. Three of the interns were rising Sophomores, 5 were rising Juniors, 6 were rising Seniors and 1 was a recent graduate. Ten interns were female and five were male. Three of the interns were minority students. Eight of the interns had two or more semesters of prior undergraduate research, 2 additional interns had participated in some form of research in a previous summer. Of the remaining 5 interns, two had participated in some research as high school students and 3 had no prior research experience. These five interns were classified as research novices.

Mentors for the interns were post-doctoral researchers, laboratory managers, or graduate students. Most (11/15) were male and most (10/15) were scholars or students visiting the US from a variety of other countries. All of the mentors participating in the 2008 summer URE were invited to participate in an interview about their experiences (see below). Eleven of the mentors elected to participate. Only 1 of these 11 had no prior experience mentoring an undergraduate researcher.

Data Sources

Application materials. Students' application materials provided a general introduction to students and were the source of information for selection decisions made by the Program. Transcripts provide summary information about the student's performance as an undergraduate (GPA), relevant course-work, and performances in those courses. Students' application materials also included a list of prior research experiences and relevant laboratory techniques.

Likert Data and Procedures. To develop a survey of inquiry skills for this study, we used that of Kardash (2000) as a starting point. We then modified the list to more explicitly reflect the lists of "important abilities to do inquiry" and "the 5 essential features of inquiry" outlined in *INSES* (NRC, 2000). The final survey consisted of 15 items (see Appendix). Participants were asked to rate the frequency with which they had engaged in each of the survey items on a scale from zero (never) to four (very often). Interns completed the survey as a part of the pre-assessment to indicate the frequency with which they had practiced each skill independently in their prior undergraduate science education. Interns again completed the survey at the end of the program and were instructed to focus explicitly on their experiences in the summer URE. The post-assessment was completed twice, first to indicate the frequency with which interns had practiced each ability independently, without aid from their mentor, and then to indicate the frequency with which interns had practiced each skill in collaboration with or under the guidance of their mentor. We could thus examine and compare interns' perceptions of their experiences of independent practice with their guided practice. Interns completed their surveys electronically and then e-mailed them to the primary investigator who then discussed the completed surveys in pre- and post-program interviews with the interns. During the interview, 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 us to clarify the language of items and develop a pool or examples that better reflect undergraduate students' perspectives and experiences. Interviewing participants about their responses clarified the meaning of items for the interns, and helped them to recognize some of the taken-for-granted aspects in their classroom laboratory experiences as elements of inquiry – for example, attending to the given question around which a laboratory activity is designed. These discussions were particularly informative for interns' ratings of their program experiences, where the purposes of the intern's activities were not always obvious or explained to them. I found that in many cases, interns had difficulty identifying some of their activities as specific elements of inquiry. In many cases interns corrected their responses to items during the interview.

The 11 participating mentors also completed the same survey about their own intern's experiences in the URE during their post-interview. Mentors also completed the survey twice – once for their perception of the intern's independent practice of these skills, and once for their perception of the intern's guided practice. Interns' responses were not shared with the mentors. We compared interns' responses on individual items and their inquiry scores to those provided by the mentors.

In addition to the survey, interns were asked three Likert-style questions, on the same scale of 0 – 4 during their post-program interview:

1) Averaging over the 10 weeks of this program, how much independence did you have in your day-to-day work in the lab?
2) Averaging over the 10 weeks of this program, how much autonomy did you have in the design and development of your research project?
3) How much ownership do you feel you have over your research project?

These data were analyzed with the survey data as described below in order to address our research questions about relationships.

Analysis

Survey data were treated in two ways. First, average ratings for each survey item were computed for interns' pre- and post-program surveys. Intern's completed the post-program survey twice to distinguish between independent and guided practice. Post-program surveys for independent and guided practice were treated separately (Tables 1 and 2). The same was done with the data collected through the mentors' surveys. These average rating were then ranked in descending order to sort frequently practiced skills from those practiced infrequently. Second, a total survey score was computed separately for each of the participant's surveys. This provided four inquiry scores for the 11 intern-mentor pairs for whom we had complete data. The inquiry scores permitted us to compare (a) interns' and (b) mentors' perceptions of the interns' (c) independent and (d) guided practice. These data were compared using paired *t*-tests (two-tailed) and Minitab statistical software (2007). We then averaged these four scores for each of these 11 interns to compute a combined inquiry score. The combined inquiry scores is a conservative estimate of the degree of inquiry (both independent and guided) involved in the intern's research project. These combined inquiry scores was plotted against perceived autonomy to characterize the variability in interns' research projects as inquiry experiences.

To address our questions about relationships between intern's experiences with independence, autonomy and ownership, a number of simple linear regressions were conducted involving background factors (GPA and pre-program inquiry scores), interns' post-program independent inquiry scores, and interns' ratings of their day-to-day independence, autonomy and ownership (Table 3).

Results & Discussion

Inquiry skills

Table 1 summarizes average ratings for the 15 survey items with regard to independent practice, and are sorted according to the results of the interns' post-program surveys. Interns' average ratings for nearly every item were greater in their pre-program survey. This is not surprising as the pre-survey reflects the sum of the intern's prior experiences as undergraduate students; many of these interns were upper-class students and many had prior research experiences. No skills were rated at or above an average of 3 ("often") in either of the interns' surveys about their independent practice. In their post-program survey, the skill with the highest average rating was using primary literature (mean = 2.73). A total of six skills were rated at or above an average of 2 ("sometimes") in the post-program survey. Five of these skills were among those most highly rated in their pre-program surveys: troubleshooting an investigation, using primary literature, data analysis/interpretation, deciding how to summarize evidence, and relating results to the bigger picture. This suggests that most of the skills interns practiced with independence in this URE were skills they had frequently practiced in their prior experiences as undergraduates. Interns rated one additional skill at or above an average of 2 in their post-program survey: orally presenting the results of an investigation. This was the only skill whose average rating was higher in the interns' post-program survey than the pre-program survey, suggesting that this is one area where the URE provided more opportunities to practice than interns' prior experiences. All six of these items can be viewed as simple inquiry skills, indicating that interns were more likely to practice simpler inquiry skills independently than they were to practice more advanced inquiry skills.

Most (10/15) of the mentors' average ratings inquiry skills for independent practice were lower than those provided by the interns. Mentors gave only two skills an average rating of 2 or above. Of the six skills most highly rated by interns in their post-program survey for independent practice, three were also among the skills rated highest by mentors: troubleshooting an investigation, data analysis/interpretation and deciding how to summarize evidence. Also near the top of the mentors' list were: determining what evidence to collect, making connections between explanations and scientific knowledge, and developing a reasonable and logical argument to communicate an explanation. Thus, the mentors' data on independent practice corroborates some, though not all, of the skills interns claimed to practice frequently, and includes others that the interns did not consider frequently practiced. This might reflect the difference in perspective between an undergraduate and a postdoctoral researcher, or it may reflect interns' lack of understanding or a miscommunication between intern and mentor as to what was actually being practiced.

Table 1: Means and standard deviations for ratings of interns' independent practice of 15 inquiry skills prior to (interns' perspective only) and as a participant in the URE program (both interns' and mentors' perspectives). Items are sorted in descending order according to the interns' post-surveys.

Survey Items	**Intern Pre-survey (N=15)**		**Intern Post-Survey (N=15)**		**Mentor Post-Survey (N=11)**	
	mean	SD	**mean**	SD	**mean**	SD
g. Use primary literature	**2.86**	1.46	**2.73**	1.28	**1.45**	1.29
l. Figure out what went wrong in an investigation and attempt to fix it.	**2.57**	1.50	**2.33**	1.40	**2.36**	1.57
m. Relate results to the "bigger picture" in your field.	**2.50**	1.34	**2.27**	1.16	**1.18**	0.98
d. Decide how to summarize collected evidence	**2.79**	1.31	**2.20**	1.42	**1.82**	0.60
e. Formulate an explanation for the evidence	**2.64**	1.45	**2.00**	1.13	**2.18**	1.33
n. Orally present results of a scientific investigation	**1.71**	1.20	**2.00**	1.41	**1.00**	0.89
f. Form connections between your explanations and existing scientific knowledge	**2.57**	1.09	**1.93**	1.16	**1.64**	1.29
h. Develop a reasonable and logical argument to communicate your explanation	**2.50**	1.09	**1.67**	1.23	**1.64**	1.03
c. Determine what evidence to collect	**1.93**	1.27	**1.60**	1.45	**1.91**	0.94
i. Defend your argument	**1.71**	0.91	**1.53**	1.51	**1.00**	0.89
j. Formulate alternative explanations based on data/evidence	**1.86**	0.95	**1.53**	0.99	**1.09**	1.14
k. Modify a hypothesis based on new evidence/ambiguous data	**1.86**	1.03	**1.47**	1.46	**0.45**	0.82
b. Select/design the methods for a scientific investigation	**1.71**	1.20	**1.27**	1.16	**0.55**	1.04
a. Pose a testable question to pursue through scientific investigation	**1.86**	1.23	**0.93**	0.88	**0.73**	0.90
o. Write or participate in the writing of a research paper for publication	**0.36**	0.63	**0.00**	0.00	**0.00**	0.00

Note: Interns were asked "In your past experiences as a science student (post program: In your experiences as an intern in this program), how often have you been able to do each of the following independently?" Mentors were asked "How often was your intern able to do each of the following independently during this program?" Items were rated on a 5-point scale: 0 = never, 1 = once or twice, 2 = sometimes, 3 = often, 4 = very often.

Table 2 summarizes average ratings for the 15 survey items with regard to guided practice, sorted according to the interns' perspective. In this case, interns' and mentors' data were in agreement: many more inquiry skills, including a number of more advanced skills, were practiced at or above an average rate of 2. These data reflect the nature of the URE as an apprenticeship into science practice, where interns are introduced to more difficult elements of practice under the guidance of their mentor. Survey items with average ratings below 2 were: modifying an hypothesis, orally presenting results, defending an argument, and participating in the writing of a scientific publication. Mentors rated two additional skills below 2: selecting and designing methods and formulating alternative explanations based on data/evidence. Thus there is some evidence that interns did not have many opportunities to practice several more advanced inquiry skills, even with the guidance of their mentors.

Table 2: Means and standard deviations for ratings of interns' guided practice of 15 inquiry skills as a participant in the URE program (both interns' and mentors' perspectives). Items are sorted in descending order according to the interns' post-surveys.

Survey Items	**Intern Post-Survey (N=15)**		**Mentor Post-Survey (N=11)**	
	mean	SD	**mean**	SD
l. Figure out what went wrong in an investigation and attempt to fix it.	**3.00**	1.13	**3.00**	1.10
e. Formulate an explanation for the evidence	**2.93**	1.10	**2.91**	1.04
b. Select/design the methods for a scientific investigation	**2.67**	1.23	**1.70**	0.94
h. Develop a reasonable and logical argument to communicate your explanation	**2.64**	1.15	**2.36**	0.67
c. Determine what evidence to collect	**2.60**	1.30	**2.64**	1.03
m. Relate results to the "bigger picture" in your field.	**2.57**	1.50	**2.55**	0.93
j. Formulate alternative explanations based on data/evidence	**2.47**	1.06	**1.80**	1.00
a. Pose a testable question to pursue through scientific investigation	**2.40**	1.35	**2.36**	0.92
f. Form connections between your explanations and existing scientific knowledge	**2.40**	1.35	**2.91**	0.94
d. Decide how to summarize collected evidence	**2.20**	1.47	**2.36**	1.12
g. Use primary literature	**2.07**	1.38	**2.00**	0.70
k. Modify a hypothesis based on new evidence/ambiguous data	**1.87**	1.41	**1.18**	1.40
i. Defend your argument	**1.60**	1.18	**1.27**	0.90
n. Orally present results of a scientific investigation	**1.60**	1.35	**1.18**	0.75
o. Write or participate in the writing of a research paper for publication	**0.00**	0.00	**0.18**	0.40

Note: Interns were asked "In your experiences as an intern in this program, how often have you been able to do each of the following with guidance from your mentor?" Mentors were asked "How often was your intern able to do each of the following with your guidance during this program?" Items were rated on a 5-point scale: 0 = never, 1 = once or twice, 2 = sometimes, 3 = often, 4 = very often.

Inquiry Scores and Degree of Inquiry

Inquiry scores were derived for each intern's research project by tallying the results for each post-program survey. The possible inquiry scores ranged from zero to 60. Figure 1 compares the average inquiry scores for independent and guided practice computed from interns' and mentors' surveys. In both cases, inquiry scores for guided practice were significantly greater than inquiry scores for independent practice, as would be expected in an apprentice-style learning experience. Also, independent inquiry scores derived from interns' surveys were significantly greater than those derived from mentors'. This discrepancy may reflect the different perspectives on the meaning of "independent" held by instructors vs. students or novice researchers vs. graduate or post-doctoral researchers. Alternatively, it may be that interns were more aware of their activities when working independently, and presumably not under observation by the mentor. Strong similarity between the guided inquiry scores for both groups lends support to this second interpretation. It seems reasonable to assume that if interns and mentors have different ideas of what "independent" means, they would also have different ideas of what "guided" means.

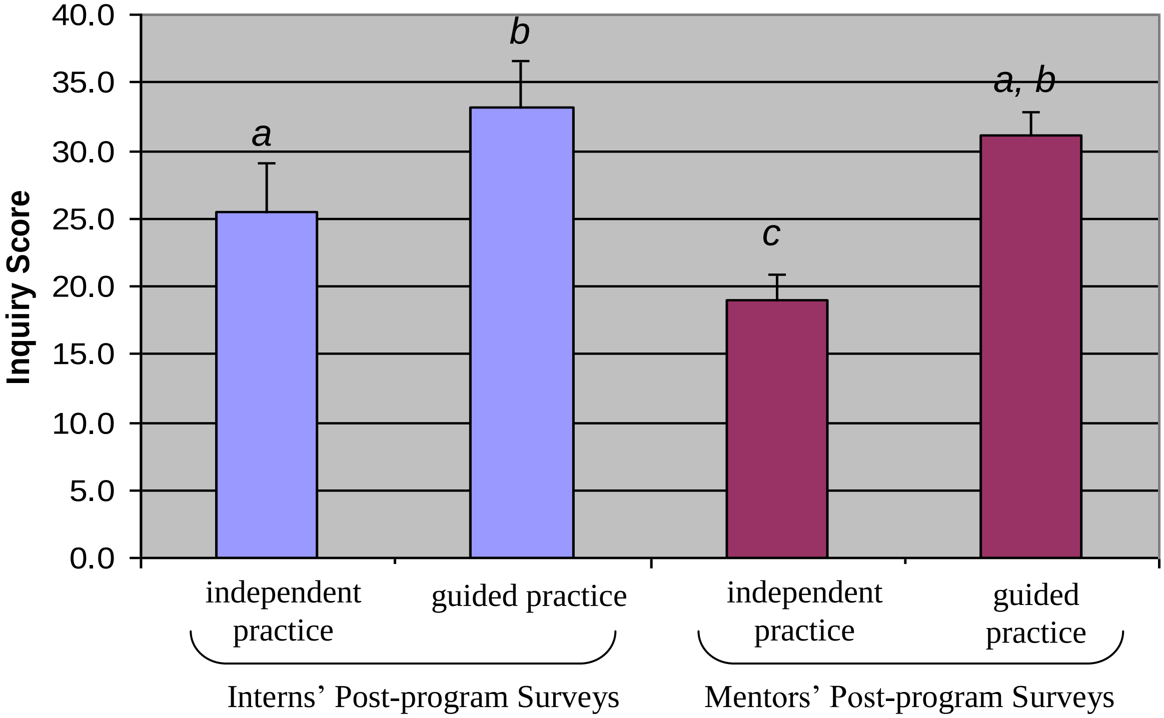

Figure 1: Average inquiry scores generated from post-program surveys of interns and mentors. Bars with different letters are significantly different at the *P* = 0.05 level (two-tailed *t*-test for difference between population means). Individual inquiry scores were the sum of each participant's responses to the 15 survey items.

To provide conservative estimates of the degree of inquiry involved in each intern's research project, the four scores associated with each of the 11 intern-mentor pairs with complete data were averaged, producing a combined inquiry score. These scores ranged from 7.5 to 36.3 with a mean of 26.9 (SD = 8.0), demonstrating the variability between individual research projects within the program. Interns' ratings of their autonomy in the design and development of the research project (on a scale from 0 – 4) also demonstrated the variability between projects, ranging from 0 to 3.5 (mean = 1.6, SD = 1.2, N = 15). Using Brown *et al.'s* (2006) inquiry continuum as a model, we plotted combined inquiry score versus autonomy to summarize the variability along these two dimensions (Figure 2). These data clearly demonstrate that most interns' research projects could be characterized as partial inquiries in which the intern had little autonomy to design and direct the progress of the investigation. Furthermore, data labels indicating semesters of prior research experience demonstrate the lack of a pattern between this element of the intern's background and the degree of inquiry involved in the intern's research project.

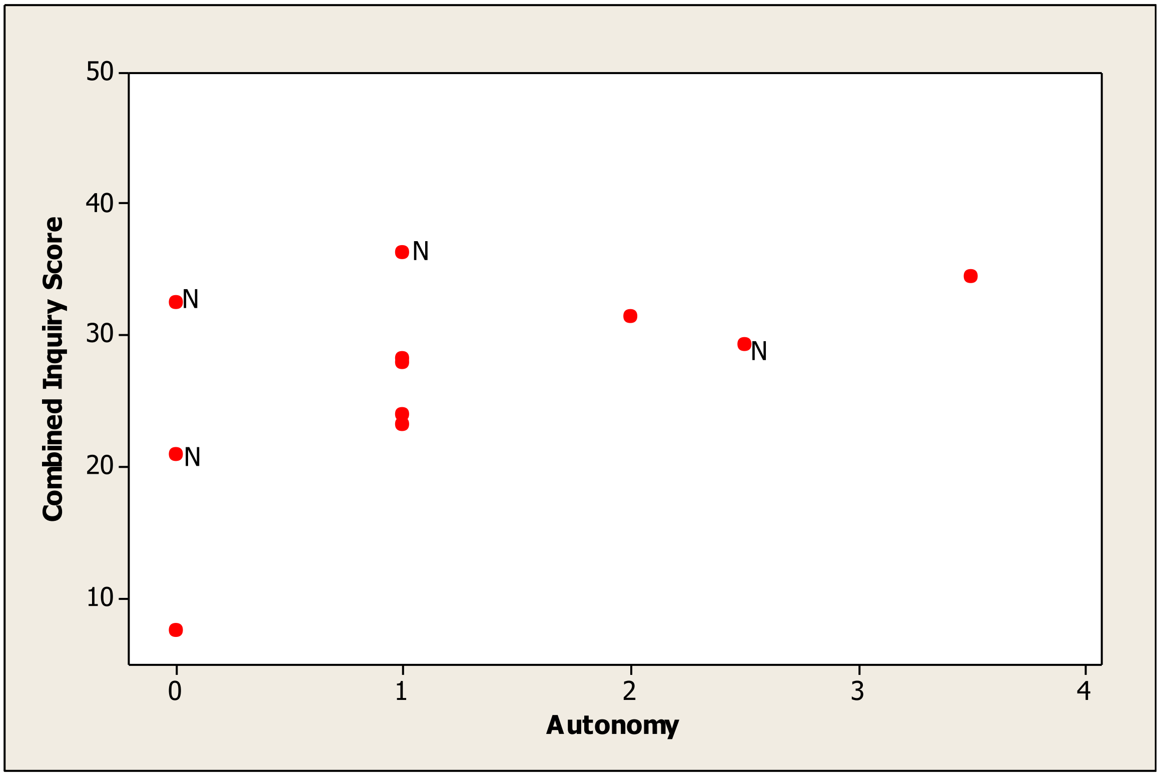

Figure 2: Degree of inquiry (combined inquiry score) vs. autonomy in the intern's research project for the 11 intern-mentor pairs with complete data sets. Combined inquiry scores reflect the average of the inquiry scores derived from all four post-program surveys associated with each intern (both independent and guided practice from the intern's and the mentor's perspective). Autonomy reflects the intern's response to the question "Averaging over the 10-week program, how much autonomy did you have in designing and developing your research project?" on a 0 to 5 scale where 0 = none and 5 = complete or 100%.

Independence, Autonomy, and Ownership

Table 3 summarizes the results of simple linear regressions between interns' independent inquiry scores, background factors, and self-ratings for day-to-day independence, autonomy and ownership. Two background factors were investigated: GPA and prior inquiry experiences (as estimated by pre-program inquiry scores). Neither of these factors correlated with post-program independent inquiry scores, day-to-day independence, autonomy or ownership. This suggests that these elements of the intern's background did not play a significant role in the development of the intern's research project. Further, interns' day-to-day independence in their laboratory work did not significantly correlate with either autonomy or ownership. However, interns' self-rating of their post-program independent inquiry did significantly correlate with both autonomy (explaining over 50% of the variability) and ownership (explaining nearly 36% of the variability). Interns who felt they experienced a greater degree of independent inquiry also rated their autonomy and project ownership higher than interns who felt they experienced a lower degree of independent inquiry. Likewise, interns who felt they experienced a greater degree of autonomy also felt greater project ownership than interns with less autonomy in designing and developing their research project. The four interns with the highest ratings for autonomy (2 and above) also differed from the remaining interns in their high ratings for a number of more advanced inquiry skills: developing an argument, modifying an hypothesis, selecting and designing methods, defending an argument and presenting orally.

Table 3: Results of simple linear regressions between interns' independent inquiry scores, background factors (GPA and prior inquiry scores), and self-ratings for day-to-day independence, autonomy and ownership.

Comparisons	**R^2**	***P***
Prior inquiry score vs. independent inquiry score	16.1	0.155
Prior inquiry score vs. day to day independence	12.7	0.23
Prior inquiry score vs. autonomy	12.8	0.21
Prior inquiry score vs. ownership	8.5	0.31
GPA vs. independent inquiry score	0.7	0.76
GPA vs. day to day independence	3.7	0.51
GPA vs. autonomy	0	0.98
GPA vs. ownership	16.1	0.14
Day-to-day independence vs. autonomy	20.2	0.107
Day-to-day independence vs. ownership	6.4	0.38
Independent inquiry vs. autonomy	**51.5**	**0.003**
Independent inquiry vs. ownership	**35.9**	**0.019**
Autonomy vs. ownership	**52.1**	**0.002**

Note: Prior inquiry scores and independent inquiry scores were represent the sum of interns' responses to the pre-program survey and post-program survey respectively. GPA was provided by the interns' application materials. Day-to-day independence, autonomy and ownership were rated by interns during post-program interviews on a 5-point scale where 0 = none and 5 = complete or 100%.

Conclusions and Implications

Inquiry Skills

We found that interns in this URE were more likely to independently practice the simpler inquiry skills common to their prior science educational experiences, than the more advanced inquiry skills that characterize authentic scientific practice. These findings reflect those of Kardash (2000) and Seymour *et al.* (2004). The one area where this URE affords interns opportunities to hone new skills is in orally presenting the results of their investigation. Interns presented their research at a public symposium at the end of the program and practiced these presentations with peers and lab members prior to the event.

The set of inquiry skills with which interns gained experience increases if we consider practice guided by their mentor. Thus, in endeavoring to understand what students learned or failed to learn through practice, it is important to consider both their independent and their guided work. In a modern biotechnology and genomics research setting, it is likely that students require a level of technical proficiency with laboratory skills before they can reasonably select and design methods for addressing research questions on their own. It is also likely that newcomers to a specialized scientific field do not yet have the required subject matter knowledge necessary to formulate appropriate questions and hypotheses. As a cognitive apprenticeship into science, the URE should provide students opportunities to independently practice those inquiry skills in which they can demonstrate proficiency. Likewise, a cognitive apprenticeship should provide students with guidance and feedback as they practice those skills with which they are less familiar. Our survey findings demonstrate that this URE fits an apprenticeship model in this regard. However, our survey can not inform us as to whether students had begun to develop proficiency in these more advanced skills. Our qualitative data analysis will fill in the picture of what guidance and guided practice looked like in this URE to further develop our ideas of how the URE aligns with the theoretical frameworks of cognitive apprenticeship and legitimate peripheral participation.

We also found that a number of the inquiry skills outlined in *INSES* (2000) were not practiced frequently by these interns in their prior science educational experiences or as interns in this URE, even under the guidance of their mentors. Interns identified the following skills as those practiced infrequently or not at all in both their pre- and post-program surveys: modifying an hypothesis, defending an argument, participating in the writing of a scientific publication. Mentors also identified selecting and designing methods and formulating alternative explanations based on data or evidence as infrequently practiced skills. This URE culminated in an oral presentation rather than a scientific paper so we feel that this item is not a useful component for future surveys in this setting. The remaining skills practiced infrequently in this URE are among those at the heart of authentic scientific practice (Chin & Malhotra, 2002): how scientists develop and reframe their thinking and revise their methods in relation to ongoing evaluation of evidence, how they use evidence as well as criteria established by the scientific community to justify their findings and by this process, construct scientific knowledge. Thus we suspect that the under representation of these elements of science practice in this URE may impact students developing understandings about NOSI and NOS. Ryder *et al.* (1999) demonstrated that undergraduate researchers developing understandings about some aspects of NOSI and NOS and were tied to the nature of their research setting and experiences. In our qualitative analysis, we will attempt to link interns' practice of inquiry skills with their developing understandings about NOSI and NOS.

Degree of Inquiry, Independence, Autonomy and Ownership

A cognitive apprenticeship should challenge learners to engage with skills and concepts that are just beyond their reach as independent learners, and support movement toward greater proficiency and fuller participation in authentic tasks. We attempted to capture this element of an apprenticeship with our questions about day-to-day independence, autonomy and ownership. Figure 2 illustrates that most interns' projects can be characterized as partial inquiries with little opportunity for autonomy, regardless of prior inquiry or research experience. Interns' scores for their degree of independent inquiry and autonomy strongly correlated with their ratings of project ownership, whereas day-to-day independence in their laboratory work did not (Table 3). Interns with the highest ratings for autonomy did not differ from others in terms of their GPA, semesters of prior research experience or pre-program independent inquiry scores. However, they did differ in their post-program independent inquiry scores, and this difference can be tied to higher ratings of a several more advanced inquiry skills. This part of the analysis suggests a causal effect for engagement with inquiry on feelings of autonomy and project ownership. However, it remains unclear why these four interns were afforded different opportunities for engagement with inquiry, and whether these affordances contributed to their learning.

Future Work and Limitations

The work described here provides a framework upon which we will pin our further investigations of interns' learning through and about inquiry. Our next step is to analyze interview transcripts and field notes of laboratory observations for evidence of students' learning (proficiency in inquiry skills, understandings about NOSI and NOS) and to link learning gains with elements of the intern's practice, degree of inquiry, autonomy and ownership.

We will also investigate the nature of mentoring and its influence on interns' learning through practice. In what ways might the mentors' different approaches or intentions toward their intern's work influence the intern's experiences and learning? We found that as a group interns overrepresented their independent inquiry practice compared to mentors. We also found that several intern-mentor pairs provided discrepant scores for either independent or guided practice. Russell (2005) noted that research mentors in her study undervalued the importance of independent laboratory work and involvement in designing the research project compared to URE participants. In what ways might the differing perspectives of interns' and mentors' influence their interactions? Hunter *et al*'s (2008) ethnographic approach permitted these authors to identify interns' and mentors' differing perspectives on developing attitudes and behaviors important for a career in science. Our qualitative data may help us to better understand interns' and mentors' differing perspective on independent inquiry and autonomy.

CUR describes the URE as a collaborative effort between apprentice and mentor. Though we expect that our qualitative analysis will shed light on intern's motivation and other personality traits linked to effort and efficacy, we did not include items addressing these qualities in our survey. Kardash used four motivation questions to good effect in her work (2000). These attributes, as well as interns' intentions are likely important factors in understanding the nature of intern-mentor interactions and interns' learning through practice. We have also come to be concerned with using a single question to estimate constructs like autonomy and ownership from the perspective of the intern alone. It is likely that participants, including mentors, hold various meanings for these concepts. We plan to develop survey questions in this area for use with both interns and mentors in the next iteration of this URE program.

Finally, we found that our survey did not work well as a stand-alone instrument. Most of the interns reported during their interviews that they did not like filling out a Likert-style survey. Several said that they felt one can not learn much about another individual from their survey responses and so they did not invest much effort or time in completing the survey. The interviewer felt it was necessary to discuss participants' responses to each item to clarify its meaning for the participant and in many cases this caused the interviewee to revise her/his response. Transcripts from this portion of the interviews are permitting us to improve the language of the survey and add illustrative examples, but we have come to feel that learning about how students misconstrued the items through the interview process was a valuable component of our investigation into their inquiry learning.

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Appendix: Likert Survey of Inquiry Skills

Please provide your answers to each of the following on a scale from 0 to 4 where:

0 = Never; 1 = Once or twice; **2** = Sometimes; **3** = Often; and **4 =** Very often.

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

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

In your past experiences as a science student, how often have you been able to each of the following independently?	**Independently means on your own,** or with a partner or group. The key is that the work was self-directed and not teacher-directed
a. pose a testable question to pursue through scientific investigation	0 1 2 3 4
b. select/design the methods for a scientific investigation	0 1 2 3 4
c. determine what evidence to collect	0 1 2 3 4
d. decide how to summarize collected evidence (in a graph, figure or table, or statistically)	0 1 2 3 4
e. formulate an explanation for the evidence (data analysis/interpretation)	0 1 2 3 4
f. form connections between your explanations and existing scientific knowledge	0 1 2 3 4
g. use primary literature (scientific journals)	0 1 2 3 4
h. develop a reasonable and logical argument to communicate your explanation	0 1 2 3 4
i. defend your argument (respond to written or oral questions/criticism/critique)	0 1 2 3 4
j. formulate alternative explanations based on data/evidence	0 1 2 3 4
k. modify a hypothesis based on new evidence/ambiguous data	0 1 2 3 4
l. figure out what went wrong in an investigation and attempt to fix it	0 1 2 3 4
m. relate results to the "bigger picture" in your field	0 1 2 3 4
n. orally present results of a scientific investigation	0 1 2 3 4
o. write or participate in the writing of a research paper for publication	0 1 2 3 4