The Role of Student-Advisor Interactions in Apprenticing Undergraduate Researchers into a Scientific Community of Practice

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Abstract

Among science educators, current interest in undergraduate research (UR) is influenced both by the traditional role of the research apprenticeship in scientists' preparation and by concerns about replacing the current scientific workforce. Recent research has begun to demonstrate the range of personal, professional, and intellectual benefits for STEM students from participating in UR, yet the processes by which student-advisor interactions contribute to these benefits are little understood. We employ situated learning theory (Lave and Wenger, 1991) to examine the role of student-advisor interactions in apprenticing undergraduate researchers, particularly in terms of acculturating students to the norms, values, and professional practice of science. This qualitative study examines interviews with a diverse sample of 73 undergraduate research students from two research-extensive institutions. From these interviews, we articulate a continuum of practices that research mentors employed in three domains to support undergraduate scientists-in-training: professional socialization, intellectual support, and personal/emotional support. The needs of novice students differed from those of experienced students in each of these areas. Novice students needed clear expectations, guidelines, and orientation to their specific research project, while experienced students needed broader socialization in adopting the traits, habits, and temperament of scientific researchers. Underrepresented minority students, and to a lesser extent, women, gained confidence from their interactions with their research mentors and broadened their future career and educational possibilities. Undergraduate research at research-extensive universities exemplifies a cycle of scientific learning and practice where undergraduate researchers are mentored by graduate students and postdoctoral researchers, who are themselves apprentices to faculty members. As such, research mentors of undergraduate students should be aware of the dual scientific and educational aspects of their advising role and its significance in shaping students' identities and career trajectories.

Keywords

Undergraduate research Mentoring Undergraduate science education Identity

Journal of Science Education and Technology 20, 771-784, 2011

Among science educators, current interest in undergraduate research (UR) is influenced both by the traditional role of the research apprenticeship in scientists' preparation and by concerns about replacing the scientific workforce. Thousands of science, technology, engineering, and mathematics (STEM) students participate in UR annually (Russell 2005) — 20% of the students at research universities alone (Boyer 2002), and higher at many colleges (Research Corporation 2001). National organizations promote UR experiences and both public and private foundations invest millions of dollars annually in UR (Research Corporation 2001). Widespread investment and interest in UR demonstrate its value in science education and the belief that apprenticeship is an optimal way to train future scientists.

Recent research has documented the intellectual, personal, and professional benefits to STEM students from participating in well-designed UR experiences (Bauer and Bennett 2003; Hathaway, Nagda, and Gregerman 2002; Hunter, Laursen & Seymour 2007; Kardash 2000; Nagda, Gregerman, Jonides, von Hippel and Lerner 1998; Russell 2005; Seymour, Hunter, Laursen, & DeAntoni 2004; Zydney, Bennett, Shahid, and Bauer 2002). Graduate student research mentors of undergraduate students have also been shown to benefit intellectually and professionally from the mentoring relationship (Dolan & Johnson 2009). Student-research advisor interactions and the nature of the scientific work undertaken by undergraduates appear to be critical components of the UR experience (Laursen, Hunter, Seymour, Thiry & Melton 2010; Thiry, Laursen, & Hunter 2010); however, the key elements of the research mentoring relationship have just begun to be explored (Laursen et al. 2010).

This paper seeks to begin to build an empirical research base upon which practitioners and researchers can better understand the ways that experienced scientists guide undergraduate researchers on the path to becoming a scientist. To that end, we describe results from an interview study of 73 students from four UR programs on two research-extensive university campuses. From the students' perspective, we discuss the advising and mentoring processes that they feel contributed to their growth and development as a scientist during the research experience.

Mentoring Practices

Much has been written about the role of mentors in the training of scientific researchers (Committee on Science, Engineering, and Public Policy (COSEPUP) 1997; Guberman, Saks, Shapiro, and Torchia 2006; Handelsman, Pfund, Lauffner, and Pribbenow 2005; Pfund, Pribbenow, Branchaw, Lauffer, and Handelsman 2006; Whiteside et al. 2007), yet few of these papers and reports are based on empirical data or the lived experiences of students and scientists. Mentoring within UR has been touted as vital for the retention and graduate school attendance for STEM students, particularly minorities and women (Barlow and Villarejo 2004; Carter, Mandall, and Maton 2009; Hathaway, Nagda, and Gregerman 2002; Villarejo, Barlow, Kogan, Veazey, and Sweeney 2008). Women's experiences with mentors and role models have been demonstrated to be more important in encouraging them to pursue STEM careers than their own achievement and academic success (Zeldin and Pajares 2000). Pfund, et al. (2006) cited mentoring as one of the most important skills for faculty and "critical in the decisions of undergraduates to pursue graduate education, but the effective elements of those relationships are not clear" (p. 474).

The importance of mentoring is clear, yet the actual roles and responsibilities of the mentor are vaguely defined in the literature. Mentors are often described as advocates, counselors, teachers, coaches, supporters, and friends, among other roles (Anderson and Shannon 1988; Boyle and Boice 1988; COSEPUP 1997; Johnson 2003). In her seminal study of mentoring in the workplace, Kram (1985) identified two essential roles of a mentor: career support (e.g. sponsorship, coaching, providing challenging work) and psychocial support (e.g. role modeling, counseling, friendship, acceptance).

In this study, we veer away from strictly psychosocial definitions of mentoring; these expectations of close emotional support may deter already over-burdened STEM faculty members from fully engaging in a mentoring relationship. Rather, we select a definition of mentoring that focuses on the professional and career benefits of scientific lab interactions among undergraduate students and senior scientists. This does not mean that the nature of the personal relationship between student and research advisor is not important; indeed, our data will demonstrate that it is vital to establish a collegial, trusting relationship in the UR experience. However, we assert that the true value of the mentoring relationship in UR rests on the intellectual and professional benefits that students gain from that relationship. Thus we subscribe to the definition of research mentors (Guberman, et al. 2006) as:

- *"Advisors*: People with career experience willing to share their knowledge.
- *Supporters*: People who give emotional and moral encouragement.
- *Tutors*: People who give specific feedback on one's performance.
- *Masters*: Employers to whom one is apprenticed.
- *Sponsors*: Sources of information about opportunities and aid in obtaining them.
- *Models of identity*: The kind of person one should be to be an academic or professional scientist." (p.99)

Guberman, et al., (2006) continue: "In reality, it is unlikely that any one person can fulfill all of these mentoring roles" (p. 99). Therefore, they broadly define a mentor as an "individual who helps another with one or more aspects of his or her personal or professional development" (p.

100). Likewise, we assert that a research mentor will probably not fulfill all of these roles for an undergraduate; nevertheless, these roles offer a starting point for examining and reflecting on the nature of the UR mentoring relationship in everyday practice.

Becoming a Scientist within a Community of Practice

Undergraduate research provides the opportunity for students to learn through a process that is "situated" within a social and cultural context and that is mediated by experience and practice (Lave and Wenger 1991; Wenger 1998). In situated learning theory, learning and development are deeply embedded in social and cultural practices. Learning involves more than just simply mastering content or technical skills; it also involves gaining mastery of the cultural knowledge, norms, values, and practices within a discipline or profession. Learning occurs through ongoing participation in a "community of practice," or a group of people engaged in collective learning through a joint enterprise, such as a group of scientists working together to solve a research problem (Wenger 1998). Through the process of legitimate peripheral participation, learners, or "newcomers" to the community of practice, gain mastery of the knowledge, skills, and practices of the community. Newcomers enter into "legitimate" communities of practice as "peripheral" members who have limited responsibility for group projects and activities. Through authentic "participation" in the community and with the guidance of "old-timers," newcomers move toward greater responsibility and participation. In this way, newcomers begin to gain a greater understanding of the values, norms, and daily activities of the community. Lave and Wenger (1991) discussed the limited nature of newcomers' participation in a community of practice:

> To be able to participate in a legitimately peripheral way entails that newcomers have broad access to arenas of mature practice. At the same time, productive peripherality

> requires less demands on time, effort, and responsibility for work than for full participants. A newcomer's tasks are short and simple, the costs of errors are small, the apprentice has little responsibility for the activity as a whole. (p. 110).

Within a community of practice, more advanced members guide novices' activities to help them enter the "zone of proximal development," or the area in between the novice's independent capabilities and his or her capabilities under the guidance of experts or more knowledgeable peers (Vygotsky 1978).In a process known as "scaffolding," the expert utilizes support structures to help the learner move toward greater independence and mastery of new abilities.

Identity formation is also a critical aspect of learning in a community of practice. According to Lave and Wenger (1991), "Moving toward full participation in practice involves not just a greater commitment of time, intensified effort, more and broader responsibilities within the community, and more difficult and risky tasks, but, more significantly, an increasing sense of identity as a master practitioner" (p.111). Therefore, the developing perception of oneself as a scientist-in-training is essential to STEM students' learning from UR experiences.

In this paper, we use situated learning theory to explore the ways in which student-advisor interactions within local contexts shape researcher identities and understandings of scientific practice. Like any human enterprise, individual research mentoring relationships fall on a continuum, encompassing everything from comprehensive support of many aspects of students' scientific development to a complete lack of support and guidance. We distinguish one end of the continuum as research "supervisors," or those who have the job of supervising UR students but may not provide the level of support needed for students to advance as scientists, and the other end of the continuum as research "mentors," or those who enact successful practices to foster students' scientific development. We will examine both ends of this continuum, including students' reports of research mentor practices that helped to shape their science identity as well as those practices that did not contribute to their professional development. We describe research advising practices within three realms of support: *professional socialization, intellectual support, and personal/emotional support.*

Research Design

This qualitative study was designed to explore the ways that UR students perceive their advisors and research groups supported them intellectually, professionally, socially, and personally during their research experience and contributed to their developing identity as a scientist. This comparative study also explored the outcomes associated with different types of guidance and support from the vantage points of both novice and experienced UR students.

The study was undertaken at two research-extensive universities, one in the South and one in the Rocky Mountains. Research students in the study were sampled from four different UR programs: three of these programs were housed in the western university and one of the programs was housed at the southern university. Two of the programs—one located at each university—were designed to increase diversity in the sciences and served large numbers of students from groups underrepresented in the sciences. Both of these diversity-oriented programs offered multi-year research experiences with the hopes of recruiting minority students into research early in their undergraduate careers. In addition to research placements, these two programs also provided extensive academic and social support to students, including a journal club and laboratory techniques course on one campus, and a summer bridge program, academic tutoring and counseling, and career and educational guidance on the other campus. The other two programs at the western university largely served Caucasian students, who were the majority in the student body there. These two programs were divided according to students' prior research experience—one of the programs served novice or first-year researchers, and the other program served advanced research students. In addition to the research experience itself, the novice program offered training in laboratory techniques and scientific communication skills, and the advanced program offered training in scientific poster preparation. Students in three of the programs, with the exception of the program for novice students, presented at a poster session at the end of the research session. Finally, all four programs provided stipends and offered both academic year and summer research experiences. This paper describes results from interviews with 73 research students from these four UR programs at two universities.

Research Methodology

Our methods of data collection and analysis are qualitative, based on in-depth, semi-structured interviews with participants. Such interviews seek to understand complex behaviors, interactions, and social processes that are relatively uninvestigated (Fontana and Frey 2000). Semi-structured interviews enable researchers to explore specific themes identified in research questions, yet also allow interviewers to spontaneously follow up on interviewees' comments. In this way, emergent issues invariably arise from the interview sessions. In this study, we sought to uncover how students perceived they had developed essential scientific traits, habits, and identities through their everyday interactions within research communities of practice—concepts that cannot be tested through quantitative means but must be explored using descriptive, qualitative methods. Additionally, these constructs of interest cannot adequately be addressed through external measures but must be explored through students' own perceptions of their identity development and personal growth from the research experience.

The interview protocol was designed to be exploratory in nature and elicit rich, detailed information about students' perceived gains from research; their lab interactions with their research advisors, principal investigators (P.I.), and research group members; and the influence of the research experience on the development of their scientific temperament and identity. The interview protocol also addressed the nature of students' scientific work.

All students in the four programs (110 students) were invited to participate in an interview during the academic years 2007-2008 and 2008-2009. Students were only interviewed once. Seventy-three students participated in individual interviews, yielding a participation rate of sixty-six percent. Interviews were conducted both in-person and by telephone. Interviews lasted approximately 40-80 minutes. All interviews were recorded and transcribed verbatim, then submitted to *N'Vivo 7,* a qualitative software program.

To develop the coding framework, each transcript was searched for information bearing upon the research questions. In this type of analysis, text segments referencing issues of different types were tagged by code names. Groups of codes that cluster around particular themes are grouped within "domains," such as *professional socialization* or *intellectual support* (Spradley 1980). A taxonomic analysis revealed sub-categories within the larger domains. Finally, componential analysis allowed for non-statistical group comparison, including gender, race or ethnicity, amount of research experience, program, or institution. Ongoing discussions among researchers about the types of observations arising from the data sets helped to assess and refine category definitions and to assure content validity and inter-rater reliability.

To evaluate the extent to which students felt they received support in critical areas for developing scientists, we report the frequency of student observations, or comments, in each domain. These frequencies represent the number of students' coded statements within a particular category, rather than the number of people who made a certain comment. These frequencies thus describe the relative weighting of issues in participants' collective report. Occasionally, we also report the number of students who made a particular assertion. As these quantitative measures are drawn from targeted, intentional samples, rather than from random samples, these frequencies are not subjected to statistical tests.

Demographic Characteristics of Interview Participants

Because two of the programs emphasized broadening participation in STEM fields, the interview sample represented greater gender and ethnic diversity than is generally found in STEM disciplines. Women comprised 48% of the sample and students from underrepresented minority groups comprised 36%. Specifically, 23% were African-American, 12% were Hispanic, and 1% were multi-racial; the remaining students were Caucasian (47%) and Asian or Asian-American (17%). Students also represented a variety of disciplines, though the biosciences were somewhat overrepresented because the UR programs at the western university emphasized the life sciences. The greater proportion of women in the sample may be related to the high proportion of biosciences majors. Fifty-four percent of students were biological sciences or bioengineering majors, 19% were studying chemistry or chemical engineering, 7% mechanical or civil engineering, 6% computer science/engineering, 5% physics, and 3% mathematics.

We divided students into two groups, novice and experienced, based on their prior UR experience. Students classified as novice had completed two semesters or less of UR at the time of the interview. Students classified as experienced had completed at least three semesters and one summer of UR. Forty-four percent of interviewees were novice researchers while 56% were experienced.

Results

Our prior research has indicated that the authenticity of scientific tasks and the quality of research mentoring are integral components of a well-designed UR experience (Laursen, et al. 2010; Thiry, Laursen, & Hunter 2010). These studies have demonstrated that student outcomes, particularly in terms of intellectual and professional gains, are strongly tied to their opportunities to engage in "real" science within a community of practice headed by a more experienced scientist.

To explore students' intellectual and professional needs from their research advisors, we asked students about the behaviors and practices of their research advisors that contributed (or not) to their development as scientists. As noted, we analyzed the interviews by student group to explore differences in the ways that women or students from underrepresented groups perceived the support provided by their advisor. To our surprise, there were few differences in our findings according to gender, race/ethnicity, UR program, or institution. Instead, the variable that consistently mattered most was the extent of students' prior research experience. Therefore, we frame our findings by comparing statements made by novice and experienced student researchers. At the end of the findings section, we address differences for students from groups underrepresented in STEM fields.

Advisor Career Stage and Frequency of Student-Advisor Interaction

Undergraduate research at large research universities typically occurs within research groups that may include faculty, postdoctoral scientists, and graduate students. These research groups often incorporate a networked model of mentoring where faculty supervise graduate students and postdoctoral researchers (Bettencourt, Bol and Fraser 1994; Whiteside et al. 2007) and these senior apprentices themselves supervise undergraduate researchers (Merkel 2003). Because students' research experiences in this study occurred at two research-extensive universities and within larger lab groups, scientists at a variety of career stages served as research advisors for UR students. Undergraduates (42%) were most often advised by graduate students, while 27% of students were advised by the principal investigator, 21% by postdoctoral researchers, 4% by other research faculty, and 4% by more advanced undergraduates. One student did not know the career stage of her research advisor. Generally—with the exception of students who named the P.I. as their research advisor—students had less interaction with the project P.I. than with their everyday research advisor.

Almost all students noted that they interacted regularly with their research advisor; most met with their advisor every time they were in the lab. However, approximately 10% of students reported that they rarely interacted with their research supervisor or other lab group members. The following comment from one of these students is indicative of their isolation from more experienced scientists.

> *Most of the time, at this point [the P.I.] is trying, or she's pursuing several large grants to buy expensive toys. So most of the time I am actually by myself [in the lab].(novice student)*

Though few students in this study reported an "absent advisor," students' quantity of time with their advisors may be as important as quality of time. Prior quantitative evaluation studies have suggested the quantity of time that students spent with their advisors was significantly correlated to students' reported intellectual gains and overall satisfaction with the research experience (Thiry & Hunter 2008; Thiry & Laursen 2009).

Domains of Support

Graduate school has long been considered the locus of professional socialization for an academic career (Austin 2002; Golde 1998; Golde and Dore 2001). Thus the undergraduate research experience may be viewed as playing the same role for graduate school in the sciences. Undergraduate researchers must also answer the same four socialization questions with which Golde (1998) argued graduate students grapple: “Can I do this?” “Do I want to be a graduate student?” “Do I want to do this work?” “and “Do I belong here?.” With the increasing prevalence of research experiences for undergraduates, it can be argued that the undergraduate years are the entry point, and a critical period of professional socialization, for a career in a STEM field. We now address the distinct ways that students reported that their interactions with their research mentors and their larger research group helped to socialize them into the culture, values, and practices of a scientific career.

Through engaging in authentic research work with senior scientists, students’ dynamic interactions with their research mentors and research groups acculturated them to the community of practice and the profession. We have identified three critical areas of support needed by UR students:

- *Professional socialization*, that is, transmitting the values and norms of the profession, along with essential disciplinary knowledge and skills
- *Intellectual support* on their research project, through help with problem-solving or identifying the “next steps” of the experiment, for example
- *Personal/emotional support*, seen in general comments that advisor is supportive, accessible, friendly, takes an interest in me, etc.

We will use the above categories to frame our discussion of students’ reported interactions with their research mentors.

Professional socialization. By socialization we mean the cultural and social process through which individuals join a profession. Through the process of socialization, novices learn the formal policies, rules, and requirements of the community as well as the informal norms, values, and behaviors (Van Maanen & Schein 1979). Additionally, students receive an "anchoring," or mooring in the discipline (DeWelde & Laursen 2008). Thus, these values, behaviors and norms are communicated through social interactions. To communicate the values, standards, and practices of the discipline, research mentors must also model high standards of scientific conduct (COSEPUP 2009).

This domain parallels the category, "becoming a scientist," identified in our analysis of the benefits to students from engaging in UR. In the "becoming a scientist" category, students described developing a scientific temperament, gaining confidence that they can do scientific research, and beginning to "feel like a scientist." Our previous work has articulated the significance of "becoming a scientist" for UR participants (Hunter, Laursen & Seymour 2007), and described the processes through which these gains are achieved from the faculty perspective (Laursen et al. 2010). We now describe the student perspective of the processes through which these important gains are achieved.

Students noted that their research mentors helped to introduce them to scientific norms, values, language, tools, and practices through the following methods:

- *Setting expectations and guidelines*: for the research project and professional behavior
- *Disciplinary anchoring*: Explaining important conceptual or theoretical ideas in the discipline; introducing students to data collection and analysis techniques; helping with posters or scientific writing; providing advice about educational or career paths
- *Modeling and guiding scientific behavior and norms:* Guiding students toward greater independence and responsibility in the lab; helping students to accept that setbacks and

failure are a part of the research process; portraying by example the professional practice of scientists

The most common category discussed by students was disciplinary "anchoring," or educating students about key disciplinary concepts, terminology, and research techniques. Other categories were slightly less prominent in student reports and mentioned by experienced rather than novice researchers. Table 1 illustrates the proportion of coded statements within each category from experienced and novice researchers.

Table 1. Proportion of novice and experienced students' comments about professional socialization

Method of Socialization	% of *novice* student comments	% of *experienced* student comments
Setting expectations	13%	6%
Disciplinary anchoring	63%	42%
Guiding/modeling behavior	24%	52%
TOTAL	*100%*	*100%*

We now describe each of these categories in greater detail.

Setting expectations and guidelines. To understand their role and responsibilities within the community of practice, students, particularly novice researchers, needed clear guidelines from senior scientists. Some research mentors defined projects with achievable goals, set clear objectives, and met regularly with students to assess progress and solve problems. A student recounted the ways in which his P.I. helped to establish expectations at the start of his research experience. This type of orientation helped to socialize students into the research group and the practice of scientific research.

> *He lays it out directly, "These are your responsibilities. These are the trainings that you need to get done." And then he puts you on a project with clear-cut goals on what we're doing on a weekly basis, and over the semester what we're trying to get done. We have weekly meetings so we're always keeping up on who's doing what, and what I'm a part of, and what my goals are, and what their goals are. (experienced student)*

In contrast, eight students (11%) noted that they received no guidelines or any orientation from their research supervisors. For example, a student described the lack of direction in his first research lab—prompting him to find another lab at the end of the semester.

> *[In the beginning] You just sign on to some sort of project… And as your first research project, you don't know what's the first step. You don't know what [the research supervisor] expects from you. I constantly had to ask questions, "Well, do you want me to do this?" And he was very dismissive. I didn't really feel like I was excelling, which just made me feel like I was waving in the ocean and he didn't care where I floated off to. (experienced student)*

Disciplinary anchoring. Besides needing clear expectations and guidelines, many novice students initially didn't understand the concepts underlying their project, nor were they were familiar with the language or tools of their discipline. Senior scientists often introduced novices to the big picture of their project, the major theories and concepts in their field, and the key terms and research techniques utilized in their project. Novice students described these types of interactions more often than experienced students, who may have already developed greater mastery of the concepts, language, and tools of their field.

Discussions in lab group meetings, where colleagues shared their research progress and received feedback on questions and problems, helped students to develop their understanding of the conceptual underpinnings of their project. These interactive discussions also helped students to situate their new understandings within the broader discipline.

> *At lab meetings, listening to everybody talk about how this might be related to everything else. Especially [the P.I.], he's really good at backing out and taking a look at how [the project]is related to everything else. (novice student)*

Because graduate students were themselves being mentored into the profession by faculty, many UR students noted differing socialization practices by their graduate student advisors and project P.I. For instance, a student contrasted the teaching roles of his research mentor and P.I.; while the graduate student provided instruction in lab procedures and equipment, the P.I. helped orient the student to the "big picture" of the project.

> *[My research mentor] is teaching less on the level that she is, and more on the level of lab procedure-type things. Like pouring gels, and setting up different procedures, and stuff like that… and [the P.I.] is more of a vision-type lady. (novice student)*

Students needed to learn the language and terminology of their field in order to participate in the community of practice and research mentors helped them by sharing prior research related to their project—for example, helping them to understand journal articles by discussing key terms and explaining important ideas in lay language.

> *We talked about [the journal article]. I read through some of it, but there was just a lot of terminology, I had no idea what it meant. And I tried looking it up, but it got really confusing. And so she would re-interpret it into more English, so that I'd understand it better. (experienced student)*

Seven students, however, mentioned that they had not received help of this type. Some of these students engaged in menial tasks rather than authentic, hands-on research. The nature of the work, therefore, did not generate higher-level intellectual discussions about the discipline. For instance, a student mentioned that though his supervisor had provided some orientation to the research project, he never quite understood the big picture.

> *I'm pretty sure my advisor did [explain the concepts underlying my project], and I got disconnected from it, 'cause I couldn't see what I was doing, and how that contributed to the big project basically. So I mean they told me what the overall goal was, but, making the connectivity between that and what I'm doing [didn't happen]. (experienced student)*

Another important component of "anchoring in the discipline" is information and advice about coursework, graduate school, and scientific career options. Students from underrepresented groups, in particular, may lack knowledge about the steps needed to select and apply to graduate school or the scientific career options available after graduation (Villarejo et al. 2008). Research mentors served as vital sources of information about career and educational possibilities within the field and, through their encouragement, helped students to see the possibility that they could become scientists. Experienced students more often referenced this benefit, perhaps because they tended to be farther along in their undergraduate careers and were actively considering post-graduation options.

Students gained a greater understanding of the life and work of graduate students from observing and interacting with graduate students in their community of practice.

I work with grad students and they tell me about their classes sometimes or they tell me how their undergraduate school was and how grad school is different. They've given me an idea of what it will be like. They show you that it's a lot more research because they have their own office and stuff like that. (experienced student)

Lab P.I.s, on the other hand, had more extensive professional networks than students' daily research mentors that helped students broaden their options for graduate school.

I'm talking with [my P.I.] about options for graduate school. So he has a lot of contacts in research in [this field], so pretty much I'll be going on with this. (experienced student)

Modeling and guiding scientific behavior. Senior personnel supported students in developing the behaviors and temperament that are necessary to become scientific researchers. Research mentors helped students to accept that setbacks and failures are inherent to the research process. Senior scientists shared their own experiences with failure in the lab and encouraged their protégés to develop perseverance in the face of setbacks.

A couple times [it] was kinda discouraging. [The P.I.] and both the grad students, they're really encouraging and they're reminding me, "This is science, don't take it personally, just keep trying," and they've been giving me different tips to see if I can make it work. (experienced student)

For UR students, moving toward greater participation in a community of practice requires assuming more responsibility within the research group and developing an identity as a scientist-in-training. Working side-by-side with more senior practitioners, newcomers gained confidence in their skills and abilities and began to see themselves as scientists.

> *I got really lucky because my lab is so small, I get to interact. I know a lot of other undergraduate researchers, their P.I. is kind of this scary, ominous person they don't ever actually see, and working with [my P.I.] one-on-one gave me confidence to pursue my interests, and to actively say, "Okay, I know I can do research, I know I have something to offer," and present myself in a more positive light as a researcher. (experienced student)*

Highlighting the importance of this role modeling, five students described its absence and how this inhibited their understanding of scientific practice and development of scientific temperament. For instance, the opportunity to work independently, and even make mistakes, while being supported by the community of practice was critical to students' scientific development. One student mentioned that her research supervisor was so "hands-on" that she never had the opportunity to work independently or advance as a scientist. She was also not allowed to fail, a critical step in developing persistence and perseverance.

> *I feel like my mentor, she doesn't just be like, "Okay, here's what you're doing, I'm leaving." She's always there supervising. But I feel like sometimes in order for me to understand things better, or to really make sure I know what I'm doing, I need to be given the chance to do things on my own. Like I'd had a few times I felt like I've screwed up, and she's like, "I can't, you know, let you do this by yourself again." I just wish I was given more of an opportunity to try to do the procedures by myself. (novice student)*

In conclusion, students received important professional socialization benefits from their everyday interactions with senior scientists within the research group community of practice that helped them to "become scientists" (Hunter, Laursen & Seymour 2007). Research mentors educated students about the theoretical foundations of the discipline, taught research skills, and served as models of professional practice.

Intellectual support on project. UR students also needed intellectual support on their research project. Students' comments about research mentoring demonstrate the progression of intellectual guidance and support that is needed as students move from the periphery to a more central role in their community of practice. Novice undergraduates needed to gain a basic understanding of the project and its procedures, while more advanced students developed problem-solving skills and the ability to plan the next steps of an experiment, and even more advanced students needed support in generating research questions or experimental design—though these latter activities were rare for undergraduates. While we discussed students' conceptual understanding in the "professional socialization" category, the nature of those comments differed from those offered in the "intellectual support" category. Professional socialization referred to the "big picture" concepts, theories, and language of the discipline as a whole, while intellectual support refers to what is needed to accomplish the specific research project—thus the latter category is narrower in scope.

The range of students' reported intellectual needs to support their research work can be mapped onto Bloom's Taxonomy of Learning (Bloom 1956). The taxonomy divides knowledge into six categories of increasingly demanding cognitive tasks, from factual recall through conceptual comprehension and real-world application, and analysis, synthesis, and evaluation. Table 2 illustrates the proportion of novice and experienced students' comments that fell within Bloom's Taxonomy.

Table 2. Students' intellectual needs for support from research mentors

Method of intellectual support	% of *novice* student comments	% of *experienced* student comments
Knowledge & Comprehension	54%	34%
Application & Analysis	43%	60%
Synthesis & Evaluation	3%	6%
TOTAL	*100%*	*100%*

As might be expected, the majority of novice students' comments fell within knowledge and comprehension, although experienced students also made a fair number of comments within application and analysis.

Knowledge and comprehension. Novice researchers, in particular, needed to learn and understand the specific components of their research projects and laboratory techniques. Developing basic knowledge and comprehension of the research project and procedures is a necessary first step in researchers' progression toward advanced intellectual activities, such as data analysis and interpretation, or scientific critique.

Senior scientists answered students' questions and shared facts and information. Answering questions and providing information was particularly beneficial at the beginning of the research project when students were inundated with information about the project, lab procedures and research protocols.

> *She did a great job of explaining anything that we were doing, going into detail, and explaining exactly what it meant. And if I didn't understand, I felt comfortable asking her questions, and if it didn't make sense when we would talk about it, she would draw*

pictures. So she wouldn't just try and say the same things over and over, and hope I get it the next time. But she'd go about it in a different way. (novice student)

Senior scientists helped to advance novice students' understanding of their research projects by providing explanations of techniques, methods, and research findings.

Application and analysis. Undergraduate researchers also learned to apply their prior knowledge and understanding to a new experiment, technique, or problem. UR students needed support from senior scientists to apply their new knowledge and understanding to their research. Engaging in collegial discussions was integral in helping students to apply their prior learning to research problems.

At the beginning, I was always getting standardized recipes. [My research mentor]would tell me how much to put in. 'Cause I was just learning—I didn't question it, because I was barely absorbing everything. But now I'm understanding. And when I run into problems, I'm asking, "How did you know this was the optimal time or optimal amount?" I'm asking a lot of questions to prepare myself for grad school. I'm watching the grad students and seeing how they become independent and run their own experiment. (experienced student)

Senior scientists facilitated students' scientific thinking by teaching basic data analysis techniques, and even more importantly, by explaining why certain techniques were used in specific situations. A novice student described the process through which she gained independence in conducting basic lab procedures, as senior scientists within the community of practice helped her to move from observation, to guided work, to independence.

…the graduate student was teaching me how to use the graphing program. And he would teach me with one set of data, and then I would try to do it, while he was sitting there,

with another set, to make sure I understood. And then we would look at the graphs that we made, and try to explain why that was happening. (novice student)

Very few comments related to a lack of intellectual support from research supervisors, but they all fell within the realms of "application" and "analysis." Some students recounted a lack of support in trouble-shooting problems or setbacks, or a lack of opportunity to discuss their research progress with others. For example, a student described a lack of opportunity to advance to data analysis and interpretation within her research experience:

I've entered data, but I haven't actually made the graphs. I kind of know how to, just because I've taken a statistics class, and then in our biology class we're expected to do that. But, [my research supervisor], I think she uses a different program than I do anyway, so she does it, and I don't. It's on her computer. (experienced student)

Therefore, "application" and "analysis" can be stumbling blocks for students' intellectual advancement when senior scientists do not adequately support students in their advancement to tasks at these more challenging cognitive levels.

Synthesis and evaluation. Unlike "application," in which prior knowledge is used to *understand* a new situation or solve a problem, synthesis involves the *production* of something new and unique, such as the development of research ideas or questions, interpretation and use of findings, and developing research designs. Evaluation involves judging the merit, worth, or value of ideas, information, or research methodology and design.

Very few experienced students had the opportunity to practice these higher cognitive levels within the course of an undergraduate research project. These few students learned to modify experiments, test hypotheses, and interpret findings from their everyday interactions within the community of practice.

> *I would talk [the interpretation of findings] over with them. I'd try to come up with a couple things on my own, and then I would show them, and talk to them about it. And just bring the results themselves to the lab meeting, and put 'em up on the overhead projector and then we would have a group discussion about what it might mean. (experienced student)*

A common scientific activity is the evaluative process of peer review and scholarly critique. Scientists may critique or find flaws in methodology or experimental design, evaluate competing interpretations of findings, and review others' scholarly works. Some students observed practices within this domain through their participation in lab meetings, while others received feedback or critique on their posters or scientific writing from scientists in their lab, and a few engaged in the peer review process by co-authoring an article. However, students rarely provided critique or evaluation themselves: they were sometimes the recipients of scholarly critique but rarely practiced it themselves. Students' lack of participation in evaluative activities is unsurprising given that these practices involve a very demanding level of scientific thinking, and a broad perspective on the field or research domain as a whole. Undergraduates were simply not ready to offer critique of journal articles or experimental methods. However, research mentors could facilitate students' evaluative thinking by asking for their feedback on methodological debates or competing interpretations of research findings during lab meetings or one-on-one discussions. For students, the very act of trying to formulate hypotheses or evaluating and defending competing ideas—even if their knowledge base is incomplete or their assumptions are incorrect—may facilitate higher-level reflection as they come to understand why their assumptions are correct or incorrect through dialogue with senior scientists.

In sum, intellectual support was integral in how research mentors helped students to develop their scientific knowledge and thinking abilities. Students initially needed basic knowledge about their project so they could *work* independently on lab procedures. Later, students needed support in higher-level analytic and interpretive skills, such as the ability to *think* independently about their project.

Personal/emotional support. Another important source of support during the UR experience was personal and emotional support from research mentors and peers. Productive, collegial relationships were facilitated by research mentor behaviors and attitudes such as being open, accessible, friendly, patient, respectful, and committed to the work of the group. Building a foundation of trust and collegiality with research mentors and peers helped students to feel comfortable in the lab, and in taking the intellectual risks that are necessary to develop and grow as a scientist.

There were several ways by which research mentors and others in the lab built collegial relationships with students and helped them to feel comfortable. P.I.s and research mentors signaled to students that they were available and easily accessible.

> *[The P.I.] tells us, "If you have any questions just e-mail me, or schedule an appointment, or come to my office, I'm always available for you guys." (novice student)*

Research mentors also helped to establish collegial relationships by being receptive to students' ideas. When students felt that their ideas and input were valued, they were more willing to take intellectual risks.

> *She's providing direction for me. But a lot of what we do is worked on together. But she'll allow me to ask questions, or suggest ideas, or changes to the protocol. And she'll be*

really receptive to that. And, sometimes she'll use my ideas, other times she'll give an explanation why she would prefer to do it another way. (novice student)

Eleven students (15%) described senior personnel who were unavailable or inaccessible and the resulting losses to their learning when they were left to engage in meaningless tasks. Students who are not engaged with the research activity or socially and intellectually integrated into a community of practice appear to be at greater risk of leaving the field or choosing against graduate school or a research career (Thiry, Laursen & Hunter, 2010).

It's hard because of how much work [the P.I.] has to do. It's hard because she doesn't spend all that much time in the lab actually working, so most of the duties I have are not horribly 'researchy.' I'm not doing research all that often really, I'm mostly just doing upkeep on things there. (novice researchers)

Besides access, students also required personal support and guidance. Students benefited when they felt their research mentors were committed to their progress and took an interest in their professional development. Students also benefited when they felt they were being taken seriously by senior personnel in the lab. In this way, students felt more socially integrated into the lab group, a necessary prerequisite for intellectual growth and development.

The P.I. never really treated us like we were idiots, which in some ways we are, we just don't know as much as them. And he was very helpful because he would explain things very clearly. I thought they treated the undergraduates really well. They made us feel just as important as everybody else. (experienced student)

Overall, most students reported positive, collegial interactions within their research communities of practice.

Importance of Mentoring Interactions for Students from Underrepresented Groups

The professional socialization benefits of student-research mentor interactions were important elements of students' narratives, particularly those from underrepresented groups, including women, African-Americans, and Hispanics. Minority students typically had less adequate preparation for college-level scientific work and fewer role models in the discipline, and thus particularly emphasized the socialization benefits of their interactions with their research mentors. Some reported entering the research experience with little confidence and limited understanding of scientific career paths. Consequently, they benefited from working side-by-side with senior scientists and observing professional practice. Some students reported that their research mentors motivated and encouraged them which, in turn, increased their confidence in their research abilities. For example, an African-American woman stated:

> *I think that the motivation [from my research mentor] made me feel like I can really do something, and really get something accomplished.*

Students from underrepresented groups gained confidence when their research mentors provided encouragement to continue in scientific careers, modeled persistence in the face of setbacks, and were readily accessible to students. Students from underrepresented groups also noted benefits from the opportunity to have science mentors—even when their research mentors were of a different gender or race—and to feel that someone is "looking out for me and my future as a scientist."

Underrepresented minority students' interactions with their research mentors may also have influenced their career paths. Fully 52% of underrepresented minority students reported that their interactions with their research mentor had changed their career path and increased the likelihood that they would pursue graduate school and a career in scientific research. For instance, an Hispanic male, who initially wanted to be a doctor, became very interested in a research career as discussions with his research mentor had helped him to realize that he could pursue an M.D./Ph.D. Therefore, minority students' interactions with senior scientists often helped to broaden their future possibilities as they became more aware of career and educational options.

> *[My research mentor has] helped me with my career. He is actually an M.D./ Ph.D student and he's been telling me about that and, also just the potential and the possibility for it."*

In contrast, just 30% of majority students reported that their interactions with their research mentor had steered them toward graduate school or a research career. More of these students reported a strong prior interest in scientific career paths and therefore research and lab group interactions had less influence on their current thinking about their future plans. Women reported a slightly stronger influence on their career paths from their interactions with their research mentors than men (46% and 37% respectively, who were influenced toward graduate school), yet less than that reported by underrepresented minority students. Our findings, along with other recent studies, demonstrate the importance of exposure to scientific role models; academic as well as personal and emotional support; and structured opportunities for identity exploration and development for students from groups traditionally underrepresented in STEM fields (Kahveci, Southerland, & Gilmer 2008; see also chapter 6 in Laursen et al 2010).

Discussion and Implications

Widespread investment and engagement in UR signifies belief in the value of research experiences in apprenticing undergraduate STEM students and developing future generations of scientists. While recent research has documented the benefits to students from participating in UR, the literature has only begun to elucidate the actual processes through which student researchers become integrated into communities of practice and begin to develop science identities (Hunter, Laursen & Seymour 2007; Laursen, et al 2010). Yet our findings demonstrate these processes and interactions can shape students' career paths in STEM fields, particularly for underrepresented minority students and, to a lesser extent, women.

Novice researchers articulated three types of support they needed and effective mentoring practices within each of these areas: *professional socialization, intellectual support, and personal support*. Research mentors guided students' professional development, and helped to shape (or not) their identities as scientists-in-training. These research mentors—typically graduate students or postdoctoral researchers—helped to socialize them into a research community of practice by setting clear expectations and guidelines; and introducing them to disciplinary concepts, terminology, and laboratory techniques. Students learned about the broader scientific community by observing their research mentors and research group members as models of professional practice. Some research mentors also encouraged students to continue on a scientific career path and provided advice about how to do that. These everyday interactions were important for women and minority students to enhance their confidence, help them see the possibility that they could enter the scientific community, and broaden their understanding of educational and career options in their field.

Students also described a process by which advisors scaffolded instruction and intellectual support so that they could undertake increasing responsibility within the community of practice. Senior scientists helped students to move from observation, to guided work, to greater independence in their research work. Student researchers demonstrated a progression of needs from their research mentors as they advanced in scientific understanding and expertise. Novice students needed to understand the guidelines and expectations of their advisors, and required support in moving toward conducting lab procedures independently. Experienced students closely watched their research mentors and began to gain a better understanding of professional practice through their observations and interactions.

Students' professional and intellectual gains, they felt, would also not be possible without the personal support of their research mentors. When their research mentors were accessible, friendly, and treated them as legitimate members of the research group, a collegial, trusting relationship was established and students felt comfortable taking the intellectual risks that contributed to their development as scientists.

These advising behaviors and practices occurred on a continuum. Rarely could a single scientist fulfill all roles for students. Nevertheless, the majority of students reported enough support in several areas from their research mentors and research groups that they began to develop an identity as a scientist-in-training and increased their understanding of scientific norms and practice. The nature of support from senior scientists within the community of practice also differed. For instance, graduate student research mentors helped undergraduates with day-to-day work on the research project, such as mastering laboratory procedures, while faculty P.I.s helped undergraduates to step back from the immediate work at-hand and understand the "big picture" and conceptual underpinnings of the research project as a whole.

More rarely—typically only 10-15% of students for any category of support—students experienced gaps in support that inhibited their development as a scientist. These students often described an absent advisor that was not available to help and guide them, or expressed frustration at being stuck in "entry-level" tasks. In these cases, research supervisors did not work with students to identify increasingly responsible, challenging tasks that fit their zone of proximal development. These student accounts provide a cautionary tale of the ways in which research advising can fail to meet undergraduate researchers' intellectual, personal, and professional needs.

Overall, our findings demonstrate that mentoring undergraduate researchers is an educational activity with specific pedagogical practices that are successful and others that are not. Students learned about the nature of scientific research and practice from explicit instruction, and through implicit interactions and observations within their research community of practice. Students' descriptions of these interactions demonstrate their centrality to their developing scientific identities and, for some, their educational and career trajectories. Research advisors do not often recognize their role in UR as educational (Feldman, Divoll, and Rogan-Klyve 2009), but these findings suggest that advisors could be more effective if they became aware of the pedagogical aspects of their advising practices and the importance of scaffolding tasks to advance each student's zone of proximal development.

Undergraduate research at research-extensive universities illustrates a cycle of scientific learning and practice where undergraduate researchers are mentored by graduate students and postdoctoral researchers, who are themselves apprentices to faculty members. As such, undergraduate research advisors should be aware of the dual scientific and educational role of the everyday interactions, work, and dialogue within their research group. These interactions not only advance the scientific work at hand, they also integrate students into a scientific community of practice, foster their identity development, and model professional practice.

Acknowledgements

This research was supported with funding from the National Science Foundation, Howard Hughes Medical Institute, and National Institutes of Health. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We thank the Biological Sciences Initiative, NIH/HHMI Scholars program for Diversity in the Biosciences, and the LA-STEM Research Scholars program for their support. We also thank Anne-Barrie Hunter and Rebecca Crane for their research assistance. An earlier version of this paper was presented at the American Educational Research Association annual meeting in Denver, Colorado in May, 2010.

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