Mentoring Undergraduate Researchers: An Exploratory Study of Students’ and Professors’ Perceptions

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Mentoring is believed to be one of the most influential factors in US efforts to encourage college-aged students to seek careers in science, yet the role that mentoring plays in this process has not been elucidated. The researchers were interested in understanding whether the long-held beliefs about the importance of mentoring would be revealed as what actually occurs in an undergraduate research program. They describe students’ perceptions of the mentoring process and students’ beliefs about how it impacted their experiences as undergraduate researchers and their development as scientists. Also described are professors’ perceptions of their roles and effectiveness as mentors in students’ development as scientists. A multi-case narrative analysis was conducted of two groups, undergraduate science scholars (n=5) and mentoring professors (n=5), who were each interviewed on two occasions at the beginning and end of the first year of a funded research program. As this grounded research study shows, students and professors described student gains as increased technical expertise and communication skills. Professors suggested that they were available to students on a regular and frequent basis. However, students’ experiences suggested a contradiction. They were often mentored by postgraduates, technical assistants, and other students; their meetings with mentoring professors were infrequent and at times distant. With respect to mentoring, this finding highlights the differences between beliefs and the reality of what was delivered. Professors discussed the challenges associated with mentoring including the recruitment of and difficulty of working with students whose first language was not English and concerns about the quality of instruction from graduate students.

Keywords: mentoring, undergraduate research, qualitative methods

Mentoring relationships between faculty and students are considered essential to undergraduate students’ decisions to pursue graduate level science (Plund, Pribbenow, Branchaw, Lauffer, & Handelsman, 2006) but the characteristics...
of these relationships are unclear. Despite the well-documented benefits of mentoring, little is known about how mentors actually work with protégés (Chan, 2008). There has been considerable research about mentoring activities and practices but little research has been conducted to clarify how mentors fulfill some of those functions such as listening (Galbraith & Cohen, 1996; Johnson, 2003), initiating and maintaining regular contact (Boyle & Boice, 1998; Morrison-Beedy, Aronowitz, Dyne, & Mkandawire, 2001), being accessible (Cunningham & Eberle, 1993), providing information, guidance, expertise, and advice (Burlew, 1991; Galbraith & Cohen, 1996; Johnson, 2003), defining clear goals and expectations for the relationship (Johnson, 2002; Morrison-Beedy, Aronowitz, Dyne, & Mkandawire, 2001), creating opportunities for the protégé (Burlew, 1991), and teaching the unwritten rules of the organization/field (Johnson, 2003). Despite the dearth of research in this area, most researchers agree that mentoring provides critical opportunities (Chan, 2008; Dolan & Johnson, 2009; Plund et al., 2006) and is essential to the incitement and succession of new scientists (Downing, Crosby, & Blake-Beard, 2005; National Academy of Sciences, 1997).

Academicians who are striving to foster a cadre of new scientists ask how mentoring can help them best meet those needs. Lacking from the field are insights from qualitative research whose approach has the potential to offer an in-depth description of the roles that mentoring may play. This particular study focused on the mentors’ perceptions of their roles as mentors. The researchers asked: How did the students’ describe being mentored and how did mentoring impact their learning? How did the professors’ describe their mentoring process? How did their beliefs about mentoring influence students’ understanding of science and scientific inquiry? This study reported one component of a larger research initiative that explored the effectiveness of the Howard Hughes Medical Institute (HHMI) program at one institution (Behar-Horenstein & Johnson, 2010).

**Mentoring**

According to Joiner, Bartam and Garreffa (2004), mentors provide support, direction, and resources to the mentees to support them and the organization. Considered to be an essential role for leaders, mentors take interest in the development of the protégé to impart “learning gifts” that they have acquired from their own experience and to provide advice, feedback, focus, and support (Goldsmith, Lyons, & Freas, 2000). According to the National Academy of Sciences (1997) a good mentor helps students: (a) optimize educational experiences, (b) become socialized into a disciplinary culture; and, eventually, (c) find employment.

Jacobi (1991) reported that mentors are experienced discipline-based individuals who frequently provide emotional and psychological support, career advisement, and role modeling in a relationship that is often mutually
beneficial. Similar functions in mentoring of undergraduate women pursuing science degrees have been reported by Downing, Crosby, and Blake-Beard (2005). Bruce Alberts, former President of the National Academy of Sciences (1997), explains:

Youth scientists and engineers need strong, creative mentors to provide them with wise guidance as well as with friendship. The future of science and engineering, so important to the health and prosperity of the world, depends on the skillful mentoring of each new generation by the one that precedes it (p. 1).

Support for mentoring has been shown empirically by Betts and Pepe (2005) who investigated the perceived value of the mentoring/protégé relationship. Findings from their study indicated that success, awareness, and advancement are among the positive results of the relationship.

Undergraduate Research Experience (URE) Programs
The National Science Foundation and the HHMI have provided considerable financial support to ensure that students have undergraduate research experiences (URE) with university faculty. Numerous benefits of these programs have been reported for both students and faculty including retention, persistence, and promotion of science careers for underrepresented groups (Adhikari & Nolan, 2002; Barlow & Villarejo, 2004; Bauer & Bennett, 2003; Hathaway, Nagda, & Gregerman, 2002; Lopatto, 2004; Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998; Russell, 2005; Seymour, Hunter, Laursen, & DeAntonio, 2004; Ward, Bennett, & Bauer, 2002; Zydney, Bennett, Shahid, & Bauer, 2002a; Zydney, Bennett, Shahid, & Bauer, 2002b). However, less is known about what skills and activities professors provide in their capacity as mentors, how they perceive their roles as mentors, how they encourage students to seek careers in science, and the challenges that they face while serving as mentors.

Benefits of Undergraduate Research Experience (URE)
In a study regarding student experiences and outcomes from UREs, Seymour and her colleagues (2004) found that students described “research-derived gains” and how UREs impacted their career choices and their future. In a follow-up study, Hunter, Laursen, and Seymour (2007) compared student responses to their faculty mentors and the administrators involved in the URE program. Both groups focused on the same types of benefits but described them differently. While students seemed unaware of how gains from the URE would impact their professional lives, faculty saw these gains as the beginning stages in the progression toward students “becoming scientists” (p. 45). Both groups reported that the URE helped students learn how scientific research is performed and that gains were due to the hands-on aspect of the experience.
Hunter et al. (2007) also report that few students showed a gain in higher-order thinking though descriptive reports claimed it as a benefit of URE. Students' changes in attitude and behavior were seen more as self-development rather than professional development. Students made few gains in relation to defining career goals although the experience helped them confirm their decisions to enter graduate school. Both students and their mentors reported that the URE made students feel more equipped to take on graduate school or careers in science. Faculty discussed wanting students to have a fast learning curve in the lab, exclusive of computer skills. Almost half of the gains in skills mentioned by both groups dealt with communication skills while oral presentation skills were seen as most important. Faculty talked about having students work on presentation skills and defend their research. However, few occurrences existed for working on scholarly writing skills. Others such as Barab and Hay (2001) agreed that it is essential for students of science to learn how to present their work. They explained that learning how to communicate findings publicly “is an important part of scientific activity and is where scientists share and convince their peers of the importance and validity of their findings.” (p. 93)

After comparing data from faculty interviews to student interviews, Hunter et al. (2007) and her colleagues found that both groups agreed that UREs were highly beneficial (90% of faculty and 92% of student observations noted specific gains). Along with funding agencies’ and faculty claims, the researchers believed that their findings supported an assertion that UREs are the best way to learn science while also promoting students’ personal, intellectual, and professional growth.

**Participatory Learning Experiences**

Science UREs emerged to ensure that students receive specialized learning experiences such as field-based encounters with experts or more knowledgeable peers (Barab & Hay, 2001). In comparison to the traditional lecture-format, apprenticeships or UREs foster immersive experiences for students by placing them within the lab to conduct experiments and engage in the actual process of science. However, findings concerning the degree that UREs produce beneficial outcomes is mixed. Bell, Blair, Crawford, and Lederman (2003) found very few changes in students’ understanding of the nature of science following participation in a science apprenticeship program. Even though the students were introduced to a range of scientific investigations, they did not “come to understand science by doing science” as the mentors had assumed (Bell et al., 2003, p. 502). Instead, there was little change in participants’ understanding of the nature of science and scientific inquiry. Although they learned new skills related to their investigations and participated in more descriptive studies, most participants never strayed from their certainty that the scientific method is the only means for research. “Epistemic demand alone may not be enough to change
students’ views of science and inquiry because it appears that many students can focus on the task at hand without considering the larger context and implication of what they do.” (Bell et al., 2003, p. 504) The authors emphasized that doing science is not enough; systematic reflection about the experience is necessary for the student to connect what they learn to the larger scientific context. Despite a lack of clear evidence about URE outcomes, researchers such as Hodson (1993) tend to agree that “the only effective way to learn to do science is by doing science, alongside a skilled and experienced practitioner who can provide on-the-job support, criticism, and advice.” (p. 120)

Methods

Participants

Students and professors were recruited from the HHMI undergraduate research program at a large research university located in the Southeast United States for participation in this study. Potential student participants came from a pool of 84 undergraduates who had each received a research award. As a part of the program these students were required to identify a professor with whom they would work to complete an undergraduate research project. Students sought out and interviewed with professors whose research they were interested in after hearing about it during a course taken early in the program. Ultimately it was the professor’s prerogative to invite particular students to join their labs.

An email invitation was sent to every student in the undergraduate research program explaining the purpose of the study and the interview process, along with copies of the letter of consent for students and parents. Students were selected on the basis of availability and willingness to participate in the interviews. Five students—three females and two males—were chosen to participate. The females were both second year students and the males, although third year, were classified as seniors. Three students were Caucasian, one was Vietnamese, and one was Middle Eastern. Their majors included Biology, Neuroscience, Chemistry, Biochemistry, and unclarified. This was the first time that these study participants had ever been given an award to work specifically under the mentorship of a professor.

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<th>Table 1</th>
<th>Undergraduate Science Scholars’ Interview Questions</th>
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<td>First Interview</td>
<td>Second Interview</td>
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<td>1. What skills are you hoping to develop while working with a mentor?</td>
<td>1. What skills were developed or enhanced through the mentoring process?</td>
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<td>2. What do you hope to learn during your mentoring experiences?</td>
<td>2. What did you gain from the mentoring process?</td>
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<td>3. What are your expectations of the mentor?</td>
<td>3. What characteristics make a good mentor?</td>
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Professors were recruited from those who were designated as mentors for the undergraduate research program. Over 250 professors were emailed an invitation to participate in the study. Five professors were chosen on a first-come, first-served basis and their willingness to be interviewed. The participants included four males and one female, two assistant professors, two associate professors, and one professor. Their discipline-expertise included Chemistry, Entomology and Nematology, Materials Science and Engineering, Medicine (Pathology and Immunology), and Zoology. Participating students and professors were unmatched pairs due to difficulties associated with recruitment and the available pool of professors in comparison to students. Both groups were interviewed twice, near the beginning of the program and approximately eight months later. (See the interview protocols in Tables 1 and 2). Approval to conduct this study was granted the university’s institutional review board. Pseudonyms are used throughout the manuscript.

Data Analysis

As described by Roswell (1998) this study used a constructivist approach and grounded theory research design to analyze data that included the basic unitizing, coding, and categorizing (Strauss & Corbin, 1998). Through this analysis a story situated in the participants’ experiences emerged. While the analysis relied heavily on grounded theory, it emerged from an interpretive stance not the positivist tradition (Charmaz, 2006). Unlike the objectivism that ignores the social context, narrative findings, the product of final data reduction, and interpretation
within the constructivist grounded theory that provides the storytelling framework are told. The narrative, as part of this case study, relates the participants’ stories and provided the rich descriptions required of qualitative research.

The inductive analysis utilized in this study began with a deconstruction of the data (Lincoln & Guba, 1985; Rodwell, 1998) through the use of open coding within the transcripts (Patten, 2005). Using the constant comparative method (Lincoln & Guba, 1985; Strauss & Corbin, 1998) each identified unit of data was compared to the labels of existing nodes and the previously coded units of text within those nodes. The placement of data units within nodes and the categorizing of nodes under themes were fluid processes. Ely (1991) stated:

Making categories means reading, thinking, trying out tentative categories, changing them when others do a better job, checking them until the very last piece of meaningful information is categorized and, even at that point, being open to revising the categories (p. 145).

After coding, data units within each node were reread. Units that did not completely fit the definition of the node were moved to better-fitting nodes. Some nodes were combined to create new themes, and some nodes were moved to more logical themes. Data from the first student interviews were analyzed as a distinct and separate set before proceeding with the second interviews. The process was repeated for the professors and data from the first and second interviews were also analyzed as a distinct and separate set of data. This approach was justified because it was anticipated that the two groups would have inherently different perspectives and to preserve the potential of comparing perspectives.

As described by Rodwell (1998), “the primary goal of the case study is to create understanding.” (p. 173) He described case studies as narratives because “the inquirer is telling a story, not objectifying the situation.” (p. 174) Because of the study’s narrative nature and the multiple cases involved, the presentation format is referred to as a “multiple-case study narrative.” The findings are bounded by the themes and categories that emerged during the last stages of data analysis. The framework of the story was created by these major categories and their relationships. The stories of the students are presented first, followed by the stories of the mentors.

**Results**

**Student Interviews**

Five themes emerged across the student dataset including: expectations, mentoring styles, skill sets, good mentors and collaboration (See Table 3).

**First Interviews**

**Expectations.** Kevin remarked that he hoped to advance his skills in the laboratory setting, to learn new procedures and techniques and to learn more
of the jargon. Cindy reported wanting to increase her understanding of laboratory results and do more experiments. Jeff stated that he hoped “to juggle time better [and] learn to juggle two projects at once.”

Mentoring styles. Cindy reported that her mentor supported her learning by knowing “what I should do when I come and how confused I am when I get into the lab” and by giving her “a whole bunch of papers about the experiment that we are doing.” Kevin explained that “both of my PIs have been really great. They’ve been able to direct me towards new projects and literally on the cutting edge of research right now.” Other students shared that they worked without direction from a supervising professor. For example, Jeff actually described his work as more of an “independent study.”

Skill sets. Students described their: (a) skill levels in conducting background research, (b) abilities to apply procedural techniques, and (c) abilities to use lab skills. Cindy, who lacked previous laboratory experience reported that she was learning how to minimize errors, and that the professor and others who worked in the lab were “slowly teach[ing] me how to do the data”. Jeff confessed that his “problem [was] getting organized with background research” and how a lack of organizational skills impacted his work. “I do get things done but I waste a lot of time just jumping around …not using the correct search terms, using too many results.” Heather reported that she was learning how to analyze data:

[I] …kept physical records of it in a notebook …enter it into Excel, and I look at it to see trends that we’re looking for and trends that could be caused by confounding variables we are unaware of.

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<th>Table 3</th>
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<td><strong>First Interview</strong></td>
<td><strong>Second Interview</strong></td>
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<tr>
<td><strong>Theme/Definition</strong></td>
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<tr>
<td><strong>Expectations:</strong> Descriptions of what students hoped to gain during the mentored learning.</td>
<td><strong>Good mentors:</strong> Attributes or, characteristics of a mentor.</td>
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<td><strong>Mentoring styles:</strong> Experiences while working under the tutelage of a professor or a graduate student, or working without direction from a supervising professor and the frequency of meetings.</td>
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<td><strong>Skill sets:</strong> Descriptions of abilities in science research, and written and oral communication.</td>
<td><strong>Skill sets:</strong> Scientific research abilities and abilities to present data and results in written and oral communication.</td>
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<td><strong>Collaboration:</strong> Student working with someone besides the mentor.</td>
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Kevin shared that he was having to read a lot of current literature and that “my PI gives me...a stack of ...literature that I am able to compare, where the research is going to and what has already been established.” As a result of doing summer research, Nadia stated that her skills had gotten better because she had to locate articles from different databases and “read a lot of scientific journal articles.” Heather characterized her skills as equal to that of others and that she had hoped to become more involved in planning because she wanted to conduct her own research. However, she also admitted that her ability to learn particular techniques was limited by her course schedule. When asked to describe his skill level in the lab setting, Jeff reported that “I do pretty well.” Kevin described his inexperience and progress as follows:

At this point, [my skills] are undeveloped. I am making incredible progress. I walked in the first day without...knowing how to use a pipette and now I [am] able...to do pretty much every step and like, something like purification.

Students described the particular laboratory techniques that they were learning, including one individual who had to learn about computers, different computer languages, and various programs. Jeff described his work as very “hands-on.” He became licensed to conduct rat surgery by the Institutional Animal Care and Use Committee (IACUC) to perform what he described as “injecting a tracer into the rat brain and seeing where it goes afterwards.”

Students also described the importance of acquiring proficiency with written and oral communication. They discussed the importance of talking with one another, making presentations, or publishing their work. Cindy “[loved] ...working with other people...to exchange ideas.” She also pointed out how others reinforced her learning: “Yeah, you’re right!...You understand the research better.” Jeff shared that he had already published a paper.

**Second Interviews**

**Good mentors.** Cindy and Nadia characterized a good mentor as someone that “[has] time for the mentee.” A few students commented on the helpfulness of the mentor. Nadia stated: “he talked with me a lot about different programs I can present [at] in the future.” Kevin summed up the attributes of a good mentor as someone who “definitely listens to the students,” and provides any kind of “guidance as it pertains to their career or their academic status.” Heather agreed that mentors should have good listening skills.

**Mentoring styles.** Cindy stated: “Because I shadow him a lot, I know what he’s doing and what step I need to do to approach, [and] do a professional career like him.” Kevin described his interactions while working with his professor as “mainly to report data and present my PowerPoints.... All my questions basically went to him and he’d make sure I was getting everything taken care of.”
Nadia and Jeff reported that they were “working pretty much on [their] own.” Jeff elaborated, explaining that he wrote the methods paper because “the professor didn’t know much about it.” Kevin reported that he did not have an opportunity to formulate his own research questions while Jeff was able to design his own experiments. Perhaps owing to his independent work, Jeff also questioned the professor’s protocols and read previous studies to look for anything that would support or call into question the existing protocol.

**Skill sets.** Cindy said: “I have to read a lot of paper(s)” while Nadia explained: “I just had this huge output file and lots and lots of data and I had to go through and figure out how to cluster it and pretty much how I was allowed to interpret it.” Some students described the communication skills gained, such as presenting their research and data through writing papers and making poster and paper presentations. Cindy’s excitement was palpable when she stated: “We’re going to get published soon.” Students also described informal communication opportunities such as presenting at weekly lab meetings. Cindy explained: “We meet every Monday morning…to tell everybody what we’ve been working on.” Matt stated: “I’ve been reporting back to my principal investigators on a regular basis giving PowerPoint presentations.”

**Collaboration.** Students often described working with graduate students and fellow undergraduates, and working in collaborative teams. Jeff clarified by saying: “I worked a lot with that graduate student, a lot on a daily basis” and he also acknowledged working with a laboratory technician. Cindy said: “I work with a fellow…most of the time.” She also said: “…We were working together like a really collaborative team” and added that they had recently presented at a conference. All of the participants reported having had an opportunity to present their research at the site-sponsored HHMI poster sessions. Cindy described another benefit of working with her mentor: “Had I not got involved with this I would have never gotten to know Dr. ________ and it’s kind of frustrating at a big university and you can’t really make a connection with any of your professors.” The URE offered her “a perfect opportunity to do that.”

Prior to receiving the HHMI scholarship, four of the students reported that they lacked previous laboratory experience. But now, on average, students reported working in the laboratory 15–30 hours per week. During the first interview, overall, students explained that they were primarily learning how to: (a) work with data, (b) improve the accuracy of the laboratory work, (c) maintain precise physical records of their work, and (d) understand the literature. By the second interview, students shared that they were reporting and interpreting findings, communicating their results through writing and presentations, seeking advice about graduate programs, and recognizing their increased
skills. While students tended to agree about the characteristics of an effective mentor, most reported meeting with their mentors infrequently. Heather and Cindy noted that it was the laboratory manager who mentored them and meetings with their mentors were few. Kevin reported that he met with his mentor once a month. Nadia explained that her mentor expected her to ask questions frequently. Two students reported specific examples of how their skills had changes, while others did not. Cindy shared that at the beginning she was “scared to pipette...what happens to the experiment...[if] I ruin it and now I [am] so calm and don’t even think about those problems any more.” Heather explained that as a result of the program that she was able to “plan an investigation into alternative pathways that might occur when certain receptors are stimulated.” Nadia and Jeff reported that they had gained some autonomy in selecting their research project. Jeff reported that he was working without the benefit of his mentor’s input, while Nadia stated that the project was driven completely by her own questions and that she was allowed to interpret the “huge output file.”

Cindy, Kevin, and Matt did not share that type of experience. As Cindy explained: “I have no clue what’s coming on...my ideas are a [small] contribution to the project because I’m not that far yet.”

Table 4
Professor Themes by Interviews

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<th>First Interview</th>
<th>Second Interview</th>
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<tr>
<td>Theme/ Definition</td>
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<tr>
<td>Expectations of students:</td>
<td>Collaboration: Student working with someone besides the mentor.</td>
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<tr>
<td>What students should learn in the short-term.</td>
<td>Mentoring styles: Meeting with students, facilitating their entry into scientific inquiry, and providing academic and career advice.</td>
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<tr>
<td>Mentoring styles:</td>
<td>Skill sets: Developing students’ understanding of science and scientific inquiry, and their abilities to discuss the scientific processes in both written and oral communication.</td>
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<td>Facilitating students’ entry into scientific inquiry (orienting students towards making scientific inquiry, helping students make connections with others, giving advice to students) and areas of mentoring where professors did not feel efficacious.</td>
<td>Challenges: Students’ situational obstacles and skill level encountered by the mentor.</td>
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<tr>
<td>Skill sets: Helping students make connections between the conceptual and application of new knowledge and promoting their ability to share their findings orally.</td>
<td>Accessibility: Frequency and location of communication and/or meetings.</td>
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<tr>
<td>Challenges: Students’ situational obstacles and skill level encountered by the mentor.</td>
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Professor Interviews

Six themes emerged across the professors’ dataset including expectations of students, mentoring styles, skill sets, challenges, accessibility, and collaboration (see Table 4).

First Interviews

Expectations of students. While expecting students to be energetic and independent, Dr. Wilcox reported that “if I say go learn about this …they will go learn about it and come back. That’s actually an expectation for most of my students, but I think it’s even higher here.” She also expected students to work with her and develop their own projects.

Drs. Nettles and Zamboni wanted their science scholars to maintain their grades. Specifically, Dr. Zamboni explained: “My expectations …[are] that whatever they do here does not interfere with their academics.” Dr. Nettles stated that he expected students to demonstrate consistent efforts. Reflecting a similar concern Dr. Held noted that his expectation was “that he or she take it serious and they actually put some work in.” Dr. Wilcox also expected that students persist in the face of failure. She believed that the most valuable experience a student could have was a failed experiment. “If you don’t have that resilience, you can’t do research.” Dr. Zamboni reported that he identified the brightest minds based on academic achievements and expected that by providing challenging opportunities, perhaps they might chose science careers. He went on to explain that the URE formed a “unique educational opportunity and experience” that might pull them in.

Mentoring styles. While mentoring students for whom English was not their first language, Dr. Wilcox reported that she gave students written and oral instructions. She explained that this process helped to make sure there was no miscommunication because, as she pointed out, “often no one wants to say they don’t understand.” In addition, two professors reported having had a very active mentoring relationship with their students, while Dr. Zamboni had mentored his student from a distance using the Internet. Dr. Birnbaum described characteristics of effective mentors as those who: (a) spent time with the students, (b) tried to develop their critical thinking skills and ability to ask questions, (c) helped them identify interesting and important questions, and (d) taught them “how to run through the scientific process”. He also shared that his approach with females, males and students of different racial backgrounds was to treat them as individuals.

Dr. Zamboni stated that he “usually advise[d] students to look at the careers and where previous students in that program ended up” and that students should look at the mentor’s publication records with students. He suggested that they should assess how often students actually spend time with the mentor or if they just had a distant figure with whom they have never interacted.
Others stated that the mentoring process should encourage social interactions and build team projects. Dr. Wilcox expanded on this by explaining how she “[tries] to cultivate a relationship with the student as an individual. ...My goal...is to have a lab that is a happy social group. I think that is really important.” Dr. Nettles noted that he tries to “integrate undergraduate ... into the researching process and...make [them] member[s] of the [research] team.”

**Skill sets.** Professors reported preparing students for laboratory work by giving them something to learn during the first summer. Dr. Birnbaum explained that “by summer two they figure out how they, what they want to do, to follow up and I help them design it.” Dr. Nettles required his students to share, by presenting and interpreting “their data in front of the [research] group, at approximately at two months intervals.” Dr. Held described building students’ skills in developing explanations:

[Students] usually come with their data and ask what they mean...I usually do not give them an answer right away but ask around the bush until hopefully they come up with the right explanations...it’s a complicated process.

By introducing a new technique, and then helping students understand what it is, why it is used, how it works and what it tells you, Dr. Birnbaum then asked students to explain what they expected to see. He also explained that he:

like[s] to do fairly predictive science, before [an] experiment, I sit down and I think about what are all possible outcomes. This is typical... But, I...train them to do that. Particularly...early students just want to hit things with sledge hammers and find out what happens rather than making predictions. ...So, I...instill in them to think about everything that could possibly happen and why it might happen...the upfront work really helps their explanations later.

Dr. Birnbaum tried to ensure that his students learned to be precise about their work, to keep a lab book with appropriate amounts of details for notation, and that they should be “really anal about your data”. He encouraged them to write down everything they saw and did and why they did it including their “observations, potential questions, idea sheets.” Dr. Wilcox stressed that she hoped that her students learn how “to invent their work within the literature.”

**Challenges.** Some professors described their lack of mentoring skills. Dr. Birnbaum talked about his difficulties with getting students to know how to work with data. Dr. Zamboni remarked that he had difficulty recruiting students for whom English was a second language (ESOL). He stated that it took him “two or three times as long to communicate with these individuals in comparison to English speaking students.” Along the same lines, Dr. Held reported that he found that mentoring took so much time, that he could not take on any more students.
Accessibility.  Dr. Nettles noted that he typically met his students three times a week, individually, at a general co-op meeting, and during journal club. Dr. Zamboni explained that he “essentially [has] an open-door policy”. Commenting on the ease and speed of the Internet, he also indicated that he is available via email at all hours and he encouraged his students to use this communication tool.

Second Interviews

Collaboration. Professors described students working with others, besides the mentoring professor, often noting the importance of working with graduate students and fellow undergraduates. Dr. Birnbaum explained that “often …my technician and my graduate students have been able to solve their [students] problems.” Dr. Held reported that his student was working in another professor’s lab, while Dr. Zamboni shared that one of his students who was planning to apply for medical school was shadowing doctors. At times, professors routinely paired the newest students with students who had previously worked in the lab. Dr. Nettles described the need for collaboration because “I don’t find things in my own lab anymore, …so typically they get their lab directions from the graduate students or from each other.”

Mentoring styles. Professors tried to teach their students about the scientific method. Dr. Birnbaum tried to emphasize “setting up your experiments ahead of time…and then thinking about what your experiment says afterwards and how to interpret your data.” Professors also discussed helping students develop their critical thinking skills and problem solving skills. Dr. Birnbaum said: “I mean one of the things I try to push in my students is critical thinking skills.” Dr. Held explained that what he “find[s] most effective is if I ask questions and…try to steer the student to finding his own solutions for the problem that he is working on.” Professors also provided academic and career advice, by discussing their decisions concerning coursework, applying for graduate school, choosing career paths, and being successful. Dr. Zamboni explained that he was “trying to foster their careers into science.” Dr. Nettles said: “Frequently, issues come up which are more general career advising: ‘So I’m thinking about this for graduate school, what do you think?’” He reported that students asked about scholarships and graduate school. He also shared that he tried to help students self-motivate.

The professors also illustrated the outcomes of mentoring. Dr. Birnbaum said he assessed his “own success by seeing progress in the scholar’s work.” He described his success as the student’s progress in work. Additionally, Dr. Nettles explained that he used mentoring experiences to “build and maintain relationships” with his collaborators.
Skill sets. Dr. Birnbaum described the changes he observed in a student, stating: “I definitely saw improvement in his comprehension of...[ability to set] up a question, how to deal with it, some with the data analysis towards the end”. Other professors described teaching students to collect and analyze data, and run experiments. Dr. Zamboni noted that he believed his student gained “knowledge of understanding the whole scientific process”. Students often made presentations to other students and faculty and also used PowerPoint. They also participated in conferences making paper and poster presentations. Dr. Zamboni said: “[The student is] learning how to effectively communicate results of his findings, and communicate those in different settings and vehicles.” Dr. Birnbaum stated: “I’m very proud of my record with students: even though I’ve only been here three years, three of my students have publications in press or out.” Dr. Nettles acknowledged that he had students present at group meetings, on campus, and at a national conference. He discussed the value of each experience and explained: “I tend to think that the group meetings are still the most effective way because it’s the most interactive discussion.”

Challenges. While describing one challenge, Dr. Nettles said: “I always wonder how much they learn from the graduate students.” He also mentioned that the nature of the program and its timeframe posed problems. He explained: “When I was a graduate student or post doc, I never wrote a paper in three months. If they write a paper in a year it will give them the wrong impression of how the whole thing works.” Dr. Zamboni described the challenge of recruiting minority students into the lab because “we just don’t receive that many minority applicants.” He also described the challenge he encountered when working with students whose first language is not English. He stated: “[When] English is not your permanent language [and you] can’t communicate well, it’s tough.”

Accessibility. Professors described how they were accessible to students. They mentioned holding weekly and/or monthly meetings. Professors also described checking in on students daily while walking through the lab or via email. Dr. Birnbaum said: “I meet with my students every week and often...several times a week whenever they come in. ...I make a run through the lab... see them in there and just take a minute or two.” Dr. Zamboni commented on the flexibility allowed by email, stating that this rapid form of communication was a positive aspect of his mentoring style. Dr. Held added that when working on projects with his student, “at some point we exchanged emails almost daily.”

In the first interview, the professors described the type of work habits they expected from students (consistency, seriousness and precision; grounding work in the literature; asking questions and providing explanation; working with others) and the attitudes they hoped that they would develop.
(persistence). They also described how they tried to avert mistakes among ESOL students (providing written and verbal instruction) and the stressors associated with mentoring such as the time commitment and getting students accustomed to analyzing and using data. By the second interview, professors spoke about how teamwork assisted in the development of student problem-solving and the importance of reflection in science research. They explained that mentoring consisted primarily of providing continuous communication and advising students (about graduate school and science careers). Indicators of mentoring effectiveness focused on student progress such as analyzing and interpreting results, making presentations, or getting published. They also described the pressures imposed by the program itself that sought tangible products (annually) such as completed papers or research projects even if the quality of the science did not warrant it, receiving instruction from graduate students, and the difficulties of teaching ESOL students.

Discussion

This study supports previous findings that listening is an essential attribute of mentors (Galbraith & Cohen, 1996, Johnson, 2003). While professors described themselves as available and in touch with students on a regular and continuing basis, students’ experiences contradict earlier findings that initiating and maintaining regular contact (Boyle & Boice, 1998; Morrison-Beedy, Aronowitz, Dyne, & Mkandawire, 2001) and being accessible (Cunningham & Eberle, 1993) takes place between students and mentors. Students and professors agreed that mentors provided information, guidance, expertise, and advice (Burlew, 1991; Galbraith & Cohen, 1996; Johnson, 2003). There is no conclusive evidence to show that clear goals and expectations for the mentor-student relationships were ever established (Johnson, 2002; Morrison-Beedy, Aronowitz, Dyne, & Mkandawire, 2001) or that the students learned the unwritten rules of the organization/field (Johnson, 2003). However, findings from the professors’ interviews suggest that mentors tried to impart the importance of being tenacious, serious, and persisting even in the presence of continuous failures.

Overall, the students described their gains in cognitive skill sets and abilities including interpreting data on their own, making frequent presentations, questioning existing protocol, or getting published. This finding is consistent with the literature and supports the belief that research mentors provide students with presentation and publication experiences (National Research Council [NRC], 2003) as well as opportunities for the development of communication skills including presenting and writing for publication (Mabrouk & Peters, 2000; Nikolova Eddings, Williams, Bushek, Porter, & Kineke, 1997; Ward et al., 2002). Students also mentioned that their technical skills in interpreting the meaningfulness of data and using equipment (Lopatto, 2004; Mabrouk & Peters, 2000; Ward et al., 2002) had improved. Like Nikolova
Eddings et al., (1997), Stevens and Reingold (2000), and Ward et al. (2002), students pointed out that teamwork (collaboration) was central to their undergraduate research experiences. While two students also described acquiring independence to form their own research questions and question existing protocol (Lopatto, 2004; Ward et al., 2002), the remaining three students expressed their desire to have greater autonomy and independence over the research that they conducted.

The professors reported that students’ understanding of the scientific process and scientific inquiry had increased as evidenced by their ability to explain and interpret results (Hunter et al, 2004; Lopatto, 2004; Mabrouk & Peters, 2000; Ward et al., 2002) and to communicate results at group meetings and at on-campus poster sessions (Barab & Hay, 2001; Mabrouk & Peters, 2000; Nikolova Eddings et al., 1997; Ward et al., 2002). Both the students and professors reported that the students were actively presenting and discussing the results of their work during group meetings and in other forums, consistent with what Barab and Hay (2001), Mabrouk and Peters (2000), Nikolova Eddings et al. (1997), Seymour et al. (2004) and Ward et al. (2002) have reported, and supporting the notion that professors created opportunities for students (Burlew, 1991) (See Table 5).

Professors described challenges they experienced in their roles as mentors as the quality of teaching provided by graduate students, their difficulties recruiting minorities and in working with those for whom English was not their first language, and their concerns that scholarly papers were being written too rapidly. These particular issues have not been reported previously. Limitations of mentoring, such as the requisite time to mentor an undergraduate properly, were supported while supply costs (Stevens & Reingold, 2000; Zydney et al., 2002b) were not.

UREs can be a powerful mechanism because they provide students with considerable time and interaction with faculty about research and career trajectories and frequent feedback from mentors and other collaborators (Kuh, 2008). Yet, as these findings show, it is still unclear how mentoring contributed to URE. The specific ways in which mentoring occurred or contributed to students’ development as scientists was not evident during a year of this federally funded program. As this study showed, although students described enhanced skills, they did not allude to how specific aspects of the mentoring process influenced those changes. Professors described how they believed mentoring aided students’ development as scientists, their ways of thinking about science, and the challenges associated with mentoring, but they did not identify how personal attributes, activities or practices influenced their roles as mentors (See Figure 1).

These findings should give the principal investigators pause as they ask what role mentoring plays in this process. If mentoring is perceived as a central component, yet not all students—especially those who self-selected their participation in this study—are experiencing mentoring, what are the
<table>
<thead>
<tr>
<th>Student Themes</th>
<th>Student Categories</th>
<th>Comparable Themes</th>
<th>Professor Categories</th>
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<tbody>
<tr>
<td>Expectations</td>
<td>Juggle time and projects.</td>
<td>Accessibility</td>
<td>Frequency of meetings.</td>
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<td>Lab walk-throughs.</td>
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<td>Good mentors</td>
<td>Listens to students.</td>
<td>Expectations of</td>
<td>Serious work habits.</td>
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<td>Provides time and explanation.</td>
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<td>Provides career and academic guidance.</td>
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<td>Skill sets</td>
<td>Gets organized.</td>
<td>Comparable Categories</td>
<td>Skill sets</td>
<td>Scientific interpretation.</td>
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<td></td>
<td>Communicates and analyzes data.</td>
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<td>Presents findings.</td>
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<td>Reviews literature.</td>
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<td>Requires execution of precise work.</td>
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<td></td>
<td>Time commitment to mentor and related lab activities ranged from 15-30 hours per week.</td>
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<td>Requires documentation of observations, questions and ideas.</td>
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<td>Becomes calmer.</td>
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<td>Develops autonomy.</td>
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<td>Collaboration</td>
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<td>Collaboration</td>
<td>Works with graduate students.</td>
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<td></td>
<td>Exchanged ideas with mentor yearly, weekly and during unscheduled times.</td>
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<td>Team work.</td>
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<td>Mentoring styles</td>
<td>Knows when to question student.</td>
<td>Mentoring styles</td>
<td>Asks questions.</td>
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<td></td>
<td>Shadows mentor.</td>
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<td>Runs through scientific process.</td>
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<td>Asks questions.</td>
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<td>Steer students to figure out solutions.</td>
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<td>Works independently.</td>
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<td>Provides academic and career advice.</td>
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<td>Directs students.</td>
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Table 5 (Continued)

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<th>Comparable Themes</th>
<th>Professor Categories</th>
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implications for student scholars who were not study participants? Perhaps notions of the professor as mentor need to be re-conceptualized as the collective efforts of all those in the professor’s laboratory: postgraduates, technicians and other students, rather than solely the efforts of the primary research professor. The authors suggest that the goals of mentoring are probably more adequately addressed by providing formal training in mentoring and/or explaining to participating mentors in an online presentation the expectations that UREs holds for the mentors. Clearly when a program is so dependent upon the quality of the mentoring relationship, its impact on research productivity and ability to enhance the diversity of under-represented student groups (Plund, Pribbenow, Branchaw, Lauffer, & Handelsman, 2006) there needs to be ongoing assessment of the relationship utilizing concurrent qualitative and quantitative approaches. The themes of mentoring and challenges have not been explicitly discussed in previous studies. The authors suggest that these findings highlight the need for future URE research that is longitudinal and with a larger sample of participants in order to explore the relational aspects of mentoring and to assess the promise of UREs for enhancing students’ development as scientists.

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