AC 2011-536: INVESTIGATING BEST PRACTICES IN THE RESEARCH MENTORING OF UNDERREPRESENTED MINORITY STUDENTS IN ENGINEERING: THE IMPACT OF INFORMAL INTERACTIONS

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Investigating Best Practices in the Research Mentoring of Underrepresented Minority Students in Engineering: The Impact of Informal Interactions

Abstract

This exploratory study addresses the need to increase the numbers of traditionally underrepresented minority (URM) students in engineering careers through an investigation of the role of research mentoring in recruiting and retaining URM students in engineering. Mentoring students in engineering and science research has long been acknowledged as an effective way to engage undergraduates in engineering majors, and is also an essential component of the doctoral degrees that represent the gateway to careers in engineering research. This study was guided by the following questions: 1) What can we identify as best practices in mentoring and supervising URM students as they conduct engineering research? 2) How is the effectiveness of these practices perceived by URM populations? 3) To what extent are these best practices in research mentoring congruent with commonly accepted guidelines for undergraduate and graduate students from majority groups? In order to answer these questions, data was collected through an online survey of a nationwide sample of URM engineering undergraduate students, graduate students, and recent PhD recipients. Semi-structured follow-up interviews were conducted by telephone with a sub-set of the survey respondents. Through coding and narrative analysis of qualitative data and triangulation with quantitative survey data, several themes emerged regarding the impacts of mentoring and students' perceptions of best practices in research mentoring. In this paper, we focus on one theme which stood out in the data: the role of informal mentoring by research supervisors in retaining undergraduate students in engineering. In this paper we describe what informal mentoring looks like in the context of engineering research experiences and how it has contributed to students' persistence in engineering. We also explore how informal mentoring may be particularly beneficial for URM students. We propose that incorporating more informal types of mentoring into the research mentor-mentee relationship is one effective way for faculty to facilitate the retention of URM undergraduate students in engineering.

Introduction

"My mentor believed in me when I didn't believe in myself. My mentor was great for motivation and perseverance. Because of my mentor, I persisted." — Female post-doctoral associate[i]

The need to increase the numbers of traditionally underrepresented minorities (URMs) in engineering careers and research is well documented. Underrepresented minorities (African Americans, Hispanics or Latinos/as, and American Indians/Alaska Natives) make up approximately 31% of the population[1], but account for just 11.6% of the science and engineering workforce[2]. This disparity is also reflected in the demographics of students earning degrees in engineering. In 2008, just 12.4% of the Bachelor's degrees in engineering were earned by underrepresented minorities[3]. Looking at graduate degrees for the same year, 19% of the Master's degrees and 3.5% of the doctoral degrees granted in engineering fields went to underrepresented minorities. According to Seymour and Hewitt[4], approximately one third of URM students intend to major in science or engineering as college freshmen; however, of that group only 37% graduate with a Bachelor's degree in a STEM field, indicating that retention is at least as critical an issue as recruitment into engineering majors. More equitable representation of minorities in engineering would not only allow these individuals to benefit personally, but would also help advance the field through the unique contributions and perspectives that members of these groups can bring, helping to keep the U.S. competitive globally[5, 6, 7, 8, 9, 10, 11].

This exploratory study addresses these disparities through an exploratory investigation of the role of research mentoring in recruiting and retaining URM college students in engineering. Mentoring students in engineering and science research has long been acknowledged as an effective way to engage and interest undergraduates in earning the baccalaureate degrees that lead to careers or advanced degrees in STEM fields[8, 12, 13, 14, 15, 16]. Research mentoring is also an essential component of the doctoral degrees that represent the gateway to careers in STEM research[17, 18, 19]. However, most of the faculty and research staff who supervise students in research have received little formal training in research mentoring. Although "how-to" guides for being an effective mentor exist, the best practices (i.e., techniques proven to reliably produce a desired result) endorsed by these guides are often not grounded in empirical research, and few focus specifically on URM populations in engineering.

In this paper, we focus on one of the themes that stood out in the data: the role of informal mentoring by research supervisors in retaining undergraduate students in engineering. We describe what informal mentoring looks like in the context of engineering research experiences, examine how this type of mentoring has contributed to students' persistence in engineering, and explore how informal mentoring may be particularly beneficial for URM students. We suggest certain implications for practice related to this particular theme, using the notion of communities of practice[34, 35, 36] as an interpretive framework, with further recommendations based on the full data set to be discussed elsewhere.

Research Design and Methodology

This study was guided by the following research questions:

- What can we identify as best practices in mentoring and supervising URM students as they conduct engineering research?
- How is the effectiveness of these practices perceived by URM populations?
- To what extent are these best practices in research mentoring congruent with commonly accepted guidelines for undergraduate and graduate students from majority groups?

In order to address these questions, quantitative and qualitative data were collected through an online survey and semi-structured follow-up interviews.

Survey: An online survey collected responses from a nationwide sample of 92 URM engineering undergraduate students, graduate students, and recent PhD recipients[ii]. Calls for volunteer participants were sent by email (including professional society listservs) to engineering faculty across the U.S., and faculty were asked to pass the information along to those in their networks who might be interested and eligible for participation. Due to this "snowball" method of recruitment it is unknown exactly how many potential participants received the information; therefore, a response rate is not available.

Survey recruitment materials specified that eligible participants must 1) be current undergraduate students, graduate students, or recent PhD recipients (within the last 10 years); 2) have participated in some form of mentored research in engineering; and 3) belong to one or more of the groups traditionally underrepresented in engineering (African Americans, Hispanics or Latinos/as, or Native Americans). Participants self-reported their eligibility and other demographic information within the survey. Information on participants' home institutions was not collected, due to a concern that this level of detail would make participants too identifiable.

This survey included both qualitative (open-ended narratives) and quantitative (multiple choice and Likert scale) questions about respondents' experiences with mentoring in engineering research. The series of narrative questions asked respondents to first describe one mentoring experience or interaction that was memorable, powerful, or influential in either a positive or negative way. Respondents were then asked to describe how (if at all) this particular mentoring experience had influenced their thinking about their career or academic pathways, and how (if at all) the experience might influence their own mentoring of other students. Respondents were also asked, through a series of Likert scale questions, to characterize their actual mentoring experience, rate their satisfaction with various aspects of that experience, and indicate their preferences for an "ideal" mentoring situation. Demographic information about respondents was also collected through multiple choice questions.

Interviews: Follow-up interviews were conducted by telephone with eight of the survey respondents. Interview subjects were selected from among the pool of survey respondents who agreed to be contacted for this purpose. Efforts were made to include a mix of individuals that reflected the demographics of the overall participant sample. In these semi-structured interviews[20], subjects were asked to clarify or expand on their survey responses, in order to help us better understand their experiences, the mentoring contexts, and the impacts of mentoring.

Study population

The 92 survey respondents represented a wide range of backgrounds and experiences, according to their self-reported demographic information. As mentioned above, the survey was open only to individuals who were undergraduate students, graduate students, or recent PhD recipients; had participated in some form of mentored research in engineering; and belonged to one or more of the groups traditionally underrepresented in engineering. The gender balance of the respondents was 31% female and 69% male. At the time of the survey, 70% of the participants were undergraduate students, 22% were graduate students, 1% were postdoctoral associates, and 7% categorized themselves as "other." Regarding their racial or ethnic background, respondents were asked to check all categories that applied, and several respondents did choose multiple categories. The most common identifications were Hispanic or Latino/a (49%) and Black or African American (40%), with smaller numbers identifying with other racial/ethnic groups (see Figure 1 for details). (It should be noted that all respondents who chose the "white" category chose at least one other racial/ethnic category as well.)

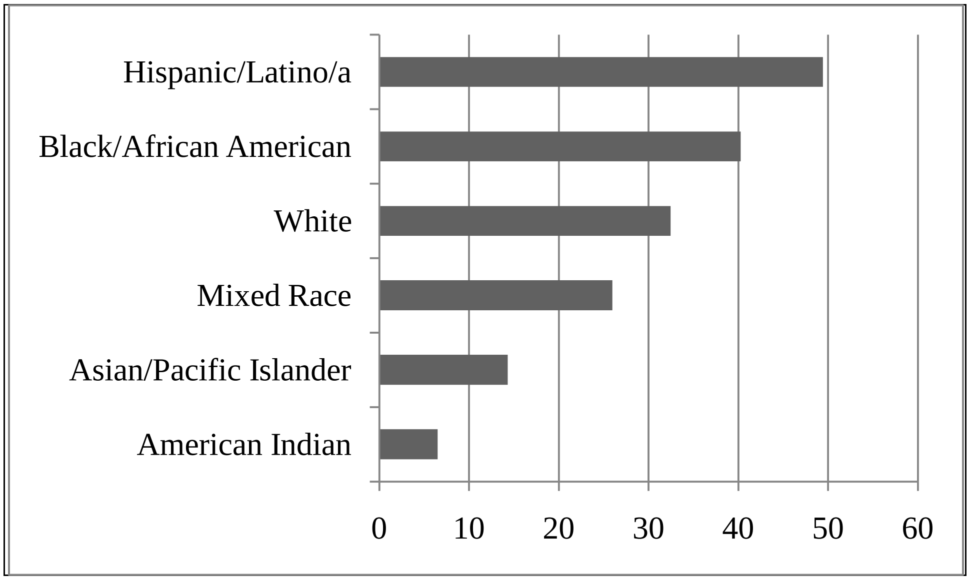

Figure 1. Race/Ethnicity of Survey Respondents (% of respondents who checked these boxes)

Respondents also represented numerous disciplines, reporting 15 different undergraduate majors within engineering and 7 majors outside of engineering. (Eligibility for participation did not require an engineering major, but merely experience doing engineering research.) The most frequently reported undergraduate majors were computer science/computer engineering (17 respondents), biomedical engineering (10 respondents), and civil engineering (10 respondents). The 19 respondents who reported a graduate school major came from 8 different engineering disciplines and 3 non-engineering disciplines, most frequently reporting industrial engineering (4 respondents), biomedical engineering (3 respondents), and engineering management (3 respondents).

Analysis

Qualitative analysis: The open-ended survey responses (i.e., the critical incident narratives) were uploaded to an electronic qualitative data analysis program (Atlas.ti) as they were received. All interviews were transcribed, and transcripts were uploaded to Atlas.ti. Preliminary coding of qualitative data (both interviews and survey narratives) was done during the first six months of data collection, in order to develop and test the coding scheme[21, 22]. Full coding of all data and identification of emergent themes using the constant comparison method was conducted after all data collection was completed[21, 22, 23].

Quantitative analysis: Data from the multiple choice and Likert scale survey questions were analyzed quantitatively, using descriptive analyses to understand the breadth of characteristics of respondents. Quantitative findings were also triangulated with emergent themes from the narrative analysis.

The findings presented in this paper draw primarily on the analysis of narratives (from both surveys and interviews) with triangulation from quantitative survey data. A more thorough analysis of the quantitative survey data will be discussed in future publications.

The critical incident technique (CIT)[24, 25] is a form of narrative analysis in which a person is asked first to reflect about broader phenomena or themes in their personal or professional lives and then identify and describe a specific situation or episode that was memorable, powerful, difficult, challenging, influential, or disturbing. Narratives may be written, or may be spoken and then later transcribed for analysis. The incidents described through narratives are then categorized and characterized in order to identify themes, develop responses to similar situations, and evaluate these responses so that best practices for a given situation may be determined[26]. There is precedent for using the CIT in engineering education research; for example, it has been shown to be an effective method for eliciting narratives in studies of engineering educator decisions about teaching[27, 28, 29, 30].

Narratives represent a means by which humans gain perspective and make sense of events and actions which occur in their personal and professional lives over time[26]. These narratives, or stories of personal and professional experiences, describe specific events and actions, connect these events and actions with other experiences, and occur within a temporal framework[26]. Narratives provide an extremely rich source of data because they describe specific events within the highly contextual framework of how people's lives and career pathways evolve over time.

Because narrative data is so dense, narrative analyses, along with other qualitative data analysis methods, typically focus on far smaller sample sizes than large-sample quantitative studies. These small-sample narrative studies can provide insight into complex situations, such as identifying specific mentoring episodes that participants felt were highly effective in influencing them to pursue careers in engineering and engineering research, unlike large-sample survey data, in which the perspectives of marginalized groups may be lost[17]. These narratives also helped identify research mentoring practices that participants perceived as less effective, or as challenges or obstacles that had to be overcome.

Findings

In analyzing the data, several themes emerged regarding the impacts of mentoring and students' perceptions of best practices in research mentoring. In this paper, we focus on one theme that stood out in the data: the role of informal mentoring by research mentors or supervisors in retaining undergraduate URM students in engineering. 85% of the survey respondents chose to write narratives about research mentoring experiences that took place during their undergraduate years. Of these respondents, 48% indicated that the mentoring experience described in the narrative had contributed significantly to their persistence in engineering, including decisions to major in engineering, go on to graduate school, and/or pursue a career in engineering. In looking closely at the types of mentoring experiences described in these narratives, "informal" mentoring emerged as being particularly influential in regard to persistence in engineering.

What does "informal" mentoring look like?

By "informal" mentoring we refer to interactions during a student's research experience that involve the student's research mentor, but are not explicitly related to the procedures or content of the research project at hand. These interactions may occur either inside or outside of the formal research setting, but are consistent with the "anywhere, anytime" learning that tends to take place in settings defined as "informal" by the National Science Foundation[31], such as "a home, a museum, a street, a virtual or augmented reality game."[31] The episodes discussed here are typically one-on-one interactions and may include conversations about career or academic pathways, discussions about the field of engineering, or support during academic or personal struggles. Within these parameters, the mentoring interactions can take various forms. For example, as one undergraduate respondent recalled,

> "I remember riding with [my research mentor] to a site. … I was expressing concern about how I have all these ideas and interests that I want to pursue, but…I was unsure if I should actually go into graduate school because I was starting to feel burned out with school work. … He promised me that the research and the work that lies ahead in grad school would be a lot more fun than undergrad. He especially stressed that since I have the capacity for it and some desire for it, I should definitely go for it."

Another undergraduate wrote,

> "I was experiencing some personal issues at home and they were greatly affecting my academics. My mentor noticed the slip in my studies and inquired about the source. I confided in her and she sympathized with me and helped me work through the personal issues and regain focus."

At first glance, interactions or conversations like these may appear to be unrelated to research mentoring, as they are not specifically focused on the research in which the student and mentor are engaged. However, they do take place within the broader context of the research mentoring relationship, and likely would not occur if the students were not involved in a mentored research experience. What we are calling informal mentoring can look like incidental conversations that simply fill the gaps in the actual work of research. However, the impact of these interactions on students can be quite far-reaching, as evidenced by the number of our respondents' stories that trace important life decisions to brief conversations with mentors, many of which took place years ago and still stand out as critical incidents. The depth of feeling conveyed and the evident connection to persistence in so many of our respondents' stories about informal mentoring led us to take a closer look at these interactions.

How does informal mentoring impact student persistence in engineering?

Respondents who reported that informal mentoring played a significant role in their persistence in engineering (including choosing a major, completing a Bachelor's degree, and/or pursuing a graduate degree in engineering) talked about two types of support: academic pathway support and personal support.

Academic pathway support

Some respondents reported that their most powerful mentoring experiences centered around mapping their pathways through undergraduate and/or graduate studies. Some respondents described critical incidents in which a mentor provided essential information or encouragement that helped the student navigate through an undergraduate major or see more clearly the pathway into and through graduate school. For other respondents, the critical support came in the form of significantly increasing the student's awareness of the possibilities that exist in engineering, such as planting the first seed of the idea that graduate school was a viable option.

Stories about receiving information or encouragement typically came from students who were already fairly familiar with what a major or career in engineering entailed, but needed some additional guidance or persuasion to continue along the path they were considering. For example, a male undergraduate wrote:

> "[My mentor] explained to me while at the same time provided an example in his own life allowing for me to understand that college can be difficult for people in multiple ways, but everyone has some hardship that they will experience while here. … It helped me push through my undergraduate classes."

Similarly, a female graduate student wrote about her struggles at the undergraduate level, citing what she felt was a key turning point in her journey toward graduate school:

> "I was ambivalent about staying in my chosen major as I was struggling with the abstract concepts within a particular class. [My mentor] was very patient in helping me to understand that struggling to grasp difficult concepts was not a reason to quit but to work hard and ask for help. He gave me the tools to better analyze my decision to change course and the time to work through my ambivalence."

In addition to persistence in undergraduate majors, some respondents also talked about the role played by information or encouragement from mentors in their decisions to continue on to graduate school. As one female undergraduate (who was also quoted above) recalled:

> "I remember riding with my advisor to a site…. I was expressing concern about how I have all these ideas and interests that I want to pursue, but I also want to have a family and a personal life and it just seems like a lot to try to fit in to a 24 hour day. And I was unsure if I should actually go into graduate school because I was starting to feel burned out with school work. He really impressed upon me the fact that grad school, and research in general, gives you the opportunity to dig deeper into the subject you are most interested in and produce something that can actually have an impact on the world. He promised me that the research and the work that lies ahead in grad school would be a lot more fun that undergrad. He especially stressed that since I have the capacity for it and some desire for it, I should definitely go for it. … It definitely had a positive influence. It was encouraging to know that it's possible to have a full life and a full career without going completely crazy."

In this instance, because the student and her mentor had the opportunity to engage in an informal conversation, the mentor was able to provide some "just in time" information and perspective, which influenced the student's decisions about her academic and career pathways.

Other respondents reported that their mentors influenced their decisions about their academic pathways by making them aware of the existing possibilities in engineering, often for the first time. For example, students made comments such as, "Before conducting research as an undergrad, the possibility of doing research as a career was non-existent or not in my scope of view" (male graduate student) or,

> "Starting college I had no idea what I wanted to do with an engineering degree. After participating in undergraduate research, talking with [my mentor], I realized that not only did I want to stay in the engineering field, I want to continue my education within engineering. My mentor was awesome and helped me find my passion for engineering research. This was not an experience that I would have ever thought I would have loved or even liked." (female graduate student)

One male undergraduate wrote at greater length on this theme, recalling a particular interaction with his research mentor which opened his eyes to the possibility of continuing his studies in engineering:

> "I was pleasantly surprised when my professor approached me after class. We had a short talk in which I asked him what his current research entailed. We agreed to meet at a more convenient time to further discuss research opportunities in the Computer Science department. For the first time in my undergraduate career did I feel my hard work was noticed by a faculty member, and I was very appreciative of this. … This was the first time I ever considered getting involved with research. … The situation described above has had an enormous impact in my decision to pursue undergraduate research. Until I was approached initially by my first professor, I had never considered continuing my education and potentially getting a Master's Degree. However, I am now dedicated to getting into a graduate program for Computer Science, and further pursuing engineering research."

Personal support

For other students, informal mentoring in the form of a personal connection and demonstrated concern for the student's life outside the lab played a significant role in their persistence in engineering. Some of these interactions did take place in the research setting, but the support had more to do with fostering a sense of belonging and connection than with the research itself. For example:

> "It was my first day in the lab and my mentor took time out of his busy schedule to walk me through all the labs and explain a little about each experiment that his students were working on. It made me feel welcomed in the lab and helped me to see the variety of work being done. … The welcoming atmosphere has encouraged me to continue my engineering research in that same lab. … This interaction has shown me the benefits of being a friendly face and offering assistance when needed. I am never too busy to help a fellow researcher." (female undergraduate)

Other interactions occurred in the context of a mentoring relationship that began in the research setting but extended beyond it, and gave the student the necessary confidence and motivation to continue through college and/or on to graduate school. As one female undergraduate recalled (as quoted above):

> "I was experiencing some personal issues at home and they were greatly affecting my academics. My mentor noticed the slip in my studies and inquired about the source. I confided in her and she sympathized with me and helped me work through the personal issues and regain focus. … It has helped give me the confidence and the mental strength to pursue greater opportunities even in times of hardship."

A female graduate student reflected that she had had multiple mentors during her academic career,

> "and they all had different roles as far as being a mentor. But the one important thing was for me to have a personal relationship with them. And that means, in order for them to do any mentoring they had to know who I am as a person. They had to know where I come from, my family, my background, my interests, my goals. That was really important to know that they really had a genuine interest in me and not necessarily, 'I'm

> assigned to be your mentor because that's what I have to do, or that's part of my job responsibility.'"

A female post-doctoral associate reflected that she and her mentor

> "established a relationship outside of my research, which made it easy to build rapport and trust. Without this rapport, I would not have opened up about research, personal life, etc. … My mentor believed in me when I didn't believe in myself. My mentor was great for motivation and perseverance. Because of my mentor, I persisted."

The theme of increased confidence and motivation due to a mentor's support appeared in several other narratives as well. For example:

> "This experience has encouraged me to go to graduate studies. It has made me believe that I can accomplish graduate school even as a single mother. It has given me confidence in my abilities. This experience has taught me to network and be a self-starter. This experience has really shaped the future of my engineering career. Potentially it has given me the confidence to go into research and development when I graduate." (female undergraduate)

As demonstrated by these narratives, research mentors can have significant and long-lasting impacts on students' persistence in engineering. Not only is guidance in the research itself crucial, but it is also important to value interactions that allow the mentor to fill potential gaps in a student's "toolbox," including knowledge about engineering pathways or personal confidence. Even interactions that seem small and insignificant can have unexpectedly far-reaching results. For example, although the narrative below refers to a fairly formal research mentoring interaction, as opposed to the informal mentoring that we have been discussing in this paper, it provides an illustration of the strength of the impact that even brief mentoring interactions can have on a student's academic decisions:

> "In my lab, during a summer research program, I spent a while drawing up a design for a new part that I wanted to build for my experiment. Once I completed my drawings, I brought them to my research advisor, who commended my efforts. The situation was short and simple, but it was important because it let me know that I have an advisor who appreciated my work. … Situations like the above are what help to encourage people like me to stay in the field of engineering; it is through situations like those that we students realize that our work is worth something. Knowing that my work is valuable makes me want to stay in the field of engineering. … An experience like this would be a powerful motivator… that says 'Hey, you are worth something as an engineer!' People tend to stay where they are wanted." (male undergraduate)

Are these findings unique to URM students?

The question of whether the findings discussed here are unique to URM students remains open. It is likely that the types of mentoring and support discussed above can be helpful for all students, regardless of their backgrounds. We are currently conducting a comparative study of majority group engineering students in order to better answer this question in future publications. At the time of this writing, we can report that several of our URM study subjects felt that informal mentoring is especially important for minority students, for various reasons, suggesting that these types of mentoring interactions merit closer examination by those working to broaden participation in engineering.

Some subjects observed that the mentoring experiences of majority students seemed to be more formal than their own mentoring experiences. For example, as one female graduate student reflected in her interview:

> "I do believe that mentoring is different for minorities than the majority of the population. I'm not sure why. … I believe there is a difference. And I definitely believe there is a difference just because …my colleagues that may not be minorities or women, their role of mentorship is very different. It's very formal. … I mean, they usually are paired up with someone. 'Oh, my mentor was assigned to me.' … I was assigned a person to mentor me too, but we didn't have anything in common to talk about, so it just didn't work out. So I think sometimes the mentoring is different."

Even though this student could not describe exactly how or why mentoring might be different for URM students, she did have a sense that URM and majority students experienced or utilized mentoring differently, and she clearly felt that she had personally benefited from mentoring that was less formal than that of her majority peers.

Other subjects talked about the importance of mentoring for URM students in a broad sense, suggesting that URM students might benefit from different types of mentoring or support in different areas than their majority group peers. One male undergraduate, in response to an interview question about whether mentoring makes a difference for URM students, replied:

> "Yes it does. It *does* make a difference, it does. … For instance, like when I was a mentee, I learned a lot from my mentor. My first mentor was, she was a white lady. She pretty much, like, taught me *so much,* you know, about just interacting with white America, you know, in terms of a business culture. … It's a lot more than engineering. It's a lot more politics. And she taught me *so much,* and I'm really thankful for that."

Still others pointed out that the potential benefits of mentoring for URM students may be very context-dependent. The ways in which students benefit from or respond to support like research mentoring may vary from individual to individual, depending on how a particular student's background intersects with a particular institution's context and culture. One male graduate student discussed this idea at length in his interview, drawing on his own experience as well as his peers'. First he compared the experiences of minorities in more-diverse and less-diverse contexts:

> "I think it depends on the minority student's actual specific background. ... It depends on the city. Because coming from [a city] where Caucasians are the minority, and Hispanics or Blacks or Haitians or anything else…it's like, why would anyone care about what you are? And it's like sort of a moot point. But I had a friend who, when we graduated undergrad, he went out to the Midwest. He was Hispanic. And…he looks very Hispanic. … And people would give him these really weird looks, like, what are you doing here?"

He then discussed how, for minorities in less-diverse academic contexts, mentors can play crucial roles in giving students the confidence or motivation to persist:

> "I think if you're Hispanic and you went to a non-diverse undergraduate university, professors might be less inclined to expect things from you, and that can affect you. And having a mentor in that sense to tell you, 'No, he's not,' and so forth, that could be really

> beneficial. … It's like you'd feel like quitting…but if you had someone to talk you out of it, you probably wouldn't. … But I think it has more to do with your background…and the university, like how diverse that university is, and how much emphasis they put on diversity."

This student's insights also suggest that to fully understand the impacts of mentoring on URM students, we must take into consideration the larger, institutional contexts in which students and their mentors interact. While we cannot definitively conclude from our data exactly how or why informal mentoring is particularly beneficial for URM students, we argue that our subjects' stories do offer important insights into what effective mentoring looks like from the perspective of URM students themselves.

Many students (both majority and minority) come to college with background experiences, resources, and knowledge (or social capital[32, 33]) that can help them navigate academic pathways and participate successfully in the academic (and/or engineering) culture. They rely on their research mentors for guidance on research, but have their other needs met elsewhere. A male graduate student gave one example of how this might work for URM students:

> "I'd say if you're a minority but you came from a relatively affluent background, you probably already know how to deal with any sort of prejudice and can work around it, and it won't affect you because you already know, some people would expect less of you, but some people would tell you to go around it. And you've already had that practice."

However, for students who do not have the same types of experiences or resources to draw upon (as is the case for many URM students), a research mentor can make a significant difference, particularly if the type of mentoring and support provided matches the needs of the student. For many URM students, that means informal mentoring.

Discussion

Research mentoring does appear to be an important means of increasing the participation of underrepresented minority students in engineering, but perhaps for more reasons than anticipated. As asserted in many studies[8, 12, 13, 14, 15, 16], participating in a research experience is particularly important for undergraduate students in science and engineering, and these experiences often lead to students' making decisions to stay in the field. This is supported in our data by the number of respondents who were currently graduate students or beyond, yet chose to write about a mentoring experience that occurred during their undergraduate studies. Clearly, undergraduate research experiences in engineering can impact students' decisions to continue along an engineering pathway.

Our data also supports the idea that research mentors or supervisors play an important role in whether a student's research experience is a good one. What might be called "formal" mentoring, or explicit guidance on research methods or content, is essential for the success of the research project. If a student does not feel sufficiently supported in this way, the experience will likely not be as positive.

However, our participants' stories strongly suggested that a broader, more lasting influence comes from guidance and support from the research mentor that is more "informal" and extends beyond the research itself. What we have heard from our participants is that when students feel supported by an engineering professor, not only in terms of a specific research project, but also in broader "life" areas, they gain confidence, motivation, and a sense of connection to the field. As a result, they are more likely to persist in engineering, which can mean choosing an undergraduate major, pursuing a graduate degree, or following a career path.

Mentoring as facilitating entry into the engineering community of practice

Our findings can be interpreted using the notion of communities of practice[34, 35, 36]. As Lave and Wenger[34] define it, a community of practice is:

> "a group of people who share an interest, a craft, and/or a profession. The group can evolve naturally because of the members' common interest in a particular domain or area, or it can be created specifically with the goal of gaining knowledge related to their field. It is through the process of sharing information and experiences with the group that the members learn from each other, and have an opportunity to develop themselves personally and professionally."

In addition, a community of practice must consist of a domain of knowledge, the community itself in which members interact and share ideas, and a shared practice[34, 35, 36].

The community of scholars engaged in engineering research can be seen as this type of community of practice. Membership in this community requires discipline-specific knowledge, engagement in practices that define the community (i.e., engineering research), and acknowledgement by community members of legitimate membership (defined, for example, in terms of degrees earned, positions held, and work in the field). Members must also develop a sense of identification with the community of practice. As Wenger[35] argues:

> "There is a profound connection between identity and practice. Developing a practice requires the formation of a community whose members can engage with one another and thus acknowledge each other as participants. As a consequence, practice entails the negotiation of ways of being a person in that context. … In this sense, the formation of a community of practice is also the negotiation of identities."[35]

Along these lines, the retention of students in engineering can be viewed as moving students toward full membership in the engineering community of practice, including facilitating their personal identification with engineering.

The question then becomes, how can the entry into the engineering community of practice be facilitated? One method might be to provide opportunities for what Lave and Wenger[34,35] call "legitimate peripheral participation." As Wenger[35] describes:

> "Communities of practice can connect with the rest of the world by providing peripheral experiences – of the kind I argued newcomers need – to people who are not on a trajectory to become full members. The idea is to offer them various forms of casual but legitimate access to a practice without subjecting them to the demands of full membership. This kind of peripherality can include observation, but it can also go beyond mere observation and involve actual forms of engagement."[35]

Mentored research experiences are one way of providing this type of legitimate access to and engagement in the practice of engineering research for students who are not (yet) full members of the community.

As noted above, participants in experiences like these are "not on a trajectory to become full members" of the community of practice. However, opportunities for legitimate peripheral participation may function as an early step toward such a trajectory. For some students, transitioning from legitimate peripheral participation to full participation in the community is relatively straightforward. They are familiar with the trajectory and have resources to keep them on it. However, for students who do not have the necessary resources to draw upon (e.g., knowledge of engineering, knowledge of academic pathways, confidence and support), that transition can be difficult or does not happen at all. Unfortunately, many URM students fall into the latter category. We argue that mentoring – and informal mentoring in particular – can be an effective way of guiding URM students onto the trajectory toward full membership and lasting participation in the engineering community of practice.

It should also be noted that it matters *who* is doing the informal mentoring discussed here. It is significant that the mentoring interactions discussed in the students' narratives took place with the students' research mentors, rather than with another type of academic advisor. Mentors in engineering research are typically engineering faculty and/or researchers, and therefore represent successful, full participation in the engineering research community. An advisor from an undergraduate advising office, for example, could certainly provide helpful support. However, this type of advisor would not have the prestige or engineering-specific credentials of an engineering professor. Encouragement in one's engineering studies or being perceived as a real (or future) engineer by a core member of the engineering community carries important weight with these students, and helps foster their sense of identification with the community of practice (i.e., believing that "I am – or can be – an engineer.").

Implications for best practices in research mentoring

Based on this particular set of findings from our study, one recommendation for those who mentor URM students in engineering research is to value and make time and space for informal interactions in mentoring relationships. We acknowledge that many faculty already do this successfully; however, this type of mentoring is still not the norm. To draw on examples from our participants' narratives, these interactions could include casual conversations on the way to a research site, periodic check-ins about how things are going in a student's life outside of the lab, or encouraging words about a student's work or future possibilities. As our participants have demonstrated, even brief interactions can be powerful.

Building in informal mentoring is not always easy to do, given the time constraints in academia, as well as the fact that these sorts of interactions do not typically fit into the faculty reward system, and informal mentoring may still not be widely perceived as part of the research mentor's job description. Based on our data, we argue that informal mentoring is important enough to reconsider as a legitimate element of research mentoring. In fact, it might make sense to re-conceptualize research mentoring itself in a way that encompasses informal as well as formal interactions, perhaps drawing again on the community of practice model. Rather than thinking of research mentoring as simply guiding students through the procedures of an isolated research project, we might think of it more broadly as facilitating students' entry into the engineering community of practice. By seeing the mentor's role in this way, it may become easier to build in and value the informal types of interactions that our data show are so influential for students in the long run. If more research mentors were to consciously think of themselves as facilitators of students' entry into the engineering research community of practice, informal mentoring might be viewed more broadly as a central part of the research mentor's role.

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[i] All participant quotes are identified only by the participant's gender and academic level. Due to the relatively small size of the URM population in engineering, there is a concern that including further information, such as race/ethnicity, could make participants too easily identifiable.

[ii] This paper is based on data from 92 initial participants. A second phase of recruitment has been completed since that point, yielding an additional 76 participants. A full analysis of data from all participants will be reported in future publications.