Lessons Learned from a Chemical Engineering REU: The Importance of Training Graduate Students Who are Supervising REU Students

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Abstract

Research Experiences for Undergraduates (REU) programs have been shown to promote positive outcomes such as increased interest in graduate school and STEM careers for their participants. Research has also shown how graduate students benefit from mentoring undergraduate researchers—namely they receive instrumental research support, improve teaching skills, and develop socioemotionally. Less research, however, has investigated the ways in which graduate students mentor undergraduate REU participants, and how the mentoring role may impact the graduate students. To address this gap in the literature, the current study examines the way in which graduate students mentor, and the impact of the mentor role on graduate students participating in a chemical engineering REU program. The research questions were explored using a mixed-methods approach. REU students and mentors were asked to complete pre- and post-surveys, as well as participate in a brief interview at the end of the REU experience. Mentor pre- and post-surveys included measures of their interest in serving as a mentor, their previous experience as an REU student or mentor, their mentorship style, their confidence in their ability to mentor others, and their beliefs about the value of mentoring others. Interview questions further explored the approaches that mentors used as well as the perceived impact on the graduate student of the mentor role. Overall, the results indicate that training of graduate student mentors in mentorship approaches may help them to more effectively work with REU students. Findings, suggestions for future research, and implications are discussed.

Introduction and Background

Research Experiences for Undergraduates (REU) programs provide participants with valuable experience that supplements their traditional engineering course work. The programs provide students opportunities to get real-world, hands-on experiences working in labs with other researchers. REU programs can be incredibly impactful, particularly towards the encouragement of students to attend graduate school or otherwise further pursue STEM fields (Landis, 2005; Youssef et al., 2016). Indeed, undergraduate research experiences have been promoted in recent years as a method of creating a sustainable pipeline to graduate school (Youssef et al., 2016).

Many positive student outcomes have been associated with REU experiences, including increased interest in research (Alexander, Foertsch, & Daffinrud, 1998; Foertsch, Alexander, & Penberthy, 1997; Humphreys, 1997; Kitto, 1998; Russell, Hancock, McCullough, Roessner, & Storey, 2005; Youssef et al., 2016), increased determination and grit in pursuing post-secondary degrees (Alexander et al., 1998; Chaplin, Manske, & Cruise, 1998; Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998), improved research skills (Alexander et al., 1998; Foertsch et al., 1997; Gates, Teller, Bernat, Delgado, & Della-Piana, 1998; Mabrouk & Peters, 2000), and an increased likelihood to attend graduate school (Alexander et al., 1998; Foertsch et al., 1997; Gates et al., 1998; Mabrouk & Peters, 2000; Russell et al., 2005). Further, students in REU and other similar programs make gains in a plethora of research-related skills such as thinking

logically about complex materials, data analysis, understanding chemical analysis, working independently, and project and time management skills (Porter, 2017; Williams, Hussain, Manojkumar, & Thapa, 2016; Zydney, Bennett, Shahid, & Bauer, 2002).

While the literature abounds with papers evaluating the impact on student participants of various REU programs, less attention has been placed on the experiences of and impacts on the mentors with whom the students work. Although REU students work with faculty members at the host university, they typically work most closely on a day-to-day basis with graduate student or postdoctoral mentors who work in the faculty member's laboratory. The majority of the engineering mentorship literature is focused on faculty as mentors, not graduate student mentors or postdoctoral researchers.

Generally, much of the existing literature relating to mentorship in engineering explores the mentor's experience (typically focusing on faculty as mentors) (Dolan & Johnson, 2009; Mena & Schmitz, 2013; Revelo & Loui, 2016; Tsai, Kotys-Schwartz, Louie, Ferguson, & Berg, 2012, 2013) rather than the mentee's experience (Ahn, 2014; Ahn, Cox, Diefes-Dux, & Capobianco, 2013; Faurot, Doe, Jacobs, Lederman, & Brey, 2013). Those studies that investigate mentors' experiences generally focus on outcomes such as immediate benefits to their research, their perceptions about their roles as mentors, and benefits to their future careers. Dolan and Johnson (2009) found that graduate student mentors benefitted in such areas as improved qualifications and work readiness, enhanced cognitive growth and "socioemotional" growth, and a greater appreciation of their own particular "apprenticeship" experiences. There is a notable dearth of studies investigating the complex relationships between mentors and students; furthermore, studies investigating mentors' approaches to mentoring and teaching are also scarce.

Ahn's doctoral dissertation (2014) provides an extensive analysis of the practices that engineering mentors or postdoctoral researchers use when mentoring undergraduate students participating in an engineering or science undergraduate research experience. The purpose of Ahn's study was to identify mentors who were effective instructors and to develop a survey to assess mentoring abilities in an undergraduate research setting. Based on results of an exploratory factor analysis of the survey data, four main effective mentoring strategies were identified: 1) the mentor's willingness to work with the mentee in a research setting; 2) the mentor's ability to identify the mentee's research knowledge and skills, and provide individualized support; 3) the mentor being attentive to the daily tasks performed by the mentee; and 4) the mentor building a personal relationship with the mentee (outside the research setting).

Ahn, Cox, Diefes-Dux, and Capobianco (2013) also investigated the best practices employed by effective mentors of an undergraduate research experience. In their study, undergraduate research participants were given the opportunity to nominate their mentors for an outstanding mentor award. The students were instructed to rate their mentors on a variety of factors, including technical and instructional competence, supervision and guidance, passion and enthusiasm for research, and motivation. Additionally, students wrote up to 500 words describing why their mentor deserved the award. Results from their analyses indicated five best practices that nominated mentors tended to engage in: 1) mentors assisted their students in comprehending their research project; 2) mentors helped undergraduates with their research work/process; 3) mentors answered students' research-related questions; 4) mentors suggested that undergraduates communicate their research findings; and 5) mentors engaged in other

highly-appreciated actions, for example, giving the student space and time to independently explore their interests, being highly available to meet with their students, and spending time with the student outside of the research program to discuss future career options.

Graduate students continue to serve as mentors for undergraduates in a variety of contexts, including REU programs. REU programs are unique in that they typically last no more than about 10 weeks. Thus, the mentor's relationship with their student may serve as a particularly important influence on the undergraduate student's experience with research, which may be relatively short compared to other undergraduate research experiences. As discussed earlier, much of the engineering mentorship literature investigates outcomes pertinent to the mentor, such as their research productivity, socioemotional development, and their readiness for the workforce. However, research that investigates *how* mentors approach mentoring, especially within REU programs, is not as prevalent. Succinctly, more work surrounding REU mentors' relationships with students, their approaches to teaching, and approaches to mentoring needs to be done. Thus, the current study endeavors to add to the REU literature by investigating how graduate student mentors approach mentoring undergraduate REU participants.

Current Study

Mentor-mentee relationships can influence student outcomes in the contexts of REU experiences (Ahn et al., 2013; Laursen, Hunter, Seymour, Thiry, & Melton, 2010). Thus, the quality of relationship and experience may impact a student or mentor's decision to participate in future REUs, continue to pursue STEM fields, or the quantity or quality of positive outcomes related to the experience. With this in mind, the purpose of the current study was two-fold: 1) to explore the ways in which mentors approach mentoring REU students, and 2) to study the impact of the mentorship experience on the graduate student and postdoctoral mentors.

The specific research questions explored included the following: 1) How did participation as a mentor impact mentors' self-efficacy in research, leadership, or mentorship?; 2) Did working with an REU student increase the mentors' perceived research productivity, teaching skills, or communication skills?; 3) What types of approaches did the mentors utilize to supervise and mentor the REU students?; and 4) What challenges related to mentoring and/or the REU program did mentors report?

Methods

The study took place at a large mid-Atlantic research university. The REU program, funded by the National Science Foundation (NSF), was in its fourth year of existence in the Chemical Engineering department. Briefly, the REU program sought to offer hands-on research experiences to a diverse group of undergraduate students with research projects focused on topics at the interface of biology and materials including biomimetics, bioinspiration, bioderivation, and biosourcing. More specifically, the program had five main objectives: 1) Enhance the diversity of students involved in interdisciplinary research; 2) Provide an overview of career opportunities and prepare students for future careers; 3) Provide a solid grounding in a wide range of analytical skills that will serve as a set of transferable laboratory and/or simulation research skills to participating students; 4) Teach collaborative skills and enhance student writing and presentation skills; and 5) Evaluate the effect of collaborative research on undergraduate student outcomes and on mentors. The current study aims to address objective five.

In previous years of the REU, no formal training regarding mentorship approaches was provided to mentors involved in the program. In 2017, when this study was conducted, the graduate student mentors participated in a brief mentorship training led by a member of the College's teaching and learning center. The goals of the training were to help mentors understand: 1) that REU participants were likely novices regarding research; 2) various types of mentorship styles (i.e. supervisory versus coaching); and 3) best practices with mentorship.

Participants

Participants include 16 graduate-student mentors who ranged in experience from those entering their first year to those entering their sixth year of graduate school. Seven mentors had previous experience as a teaching assistant. Four had participated in an REU program previously as a student, and 12 had mentored an undergraduate REU student before. Further demographic information is presented below, in Table 1.

Table 1. *Demographic information for graduate student mentors*

Number of Participants*	Female	URM	% 1/2/3/ 4/5/6/*
15	53%	13%	13/20/20/ 13/13/13/7

Note. URM = Under-Represented Minority; 1 = First-year; 2 = Second-year; 3 = Third-year; 4 = Fourth-year; 5 = Fifth-year; 6 = Sixth-year
*one missing response. 100% from host institution

Measures

The research questions were explored using a mixed-methods approach. REU students and graduate student mentors were asked to complete pre- and post-surveys, as well as participate in a brief interview at the end of the REU experience.

Mentor pre-surveys included measures of their interest in serving as a mentor, their goals for the REU program, their previous experience as an REU student or mentor, their broad experiences with research (EWRAS; Follmer, Zappe, Gomez, & Kumar, 2015), their confidence in their ability to mentor others, and their beliefs about the value of mentoring others (see Appendix A for the full measures).

In addition to the information collected in the pre-survey, the post-survey also collected information regarding the mentors' perceived impact of the REU student on their research, their style of mentoring, and their perceptions about what they gained from the REU experience (see Appendix A).

The interviews further explored the approaches that mentors used as well as investigated how the relationship between the mentor and REU student was characterized. The interviews consisted of 23 questions addressing a variety of topics (e.g., how the mentor integrated the student into their lab's community, how they approached teaching the student a new task, how they most benefitted from mentoring a student), and is included in Appendix A.

Procedures

Both the pre- and the post-surveys were administered via Qualtrics, a secure, online survey administration software. The pre-survey was distributed during the first week of the REU program and participants were encouraged to complete it by the end of the first week. The post-survey was distributed one week before the end of the program, and participants were encouraged to complete it even after the program had ended.

Interviews took place at the end of the REU program. Interviews were audio recorded, transcribed, and coded using NVivo software. Two graduate students in the College's teaching and learning center completed the interviews.

Analytical procedures

Survey data was analyzed using SPSS and interview data was analyzed using NVivo. Survey data was analyzed primarily using descriptive statistics. Responses to open-ended questions were searched for general themes. Interview data was coded using an iterative process. That is, transcripts were first coded for broad themes related to the research questions. Once all transcripts had been coded initially, they were coded a second time to identify finer themes within the broader themes.

Results

Research Question (RQ) 1: Impact of serving as a mentor on self-efficacy in research, leadership, and mentorship

On the post-surveys, mentors tended to agree that they made gains in areas such as teaching (mean = 4.00, SD = 0.67), communication (mean = 4.11, SD = 0.74), and sharing their expertise (mean = 4.11, SD = 0.81). Generally, mentors reported similar scores on the pre- (mean = 20.27, SD = 2.96) and post-survey (mean = 20.07, SD = 3.24) with regards to their self-efficacy regarding mentoring, being an engineer, and research ($t = 0.45$, $p = 0.66$). Additionally, mentors' pre- and post-survey efficacy ratings were positively correlated with each other ($r = 0.69$, $p < .01$), indicating that those who reported being more efficacious on the pre-survey tended to report in the same way on the post-survey. Their views about how mentoring impacts creativity, research skills, and leadership skills also remained fairly consistent (pre-survey: mean = 30.40, SD = 3.83; post-survey: mean = 29.87, SD = 3.72; $t = 0.65$, $p = 0.53$). Again, the correlation between pre- and post-surveys was strong and positive ($r = 0.76$, $p < .01$). This indicates that individual mentors' views typically did not change. That is, results suggest that the REU experience had little impact on mentors' self-efficacy in research, leadership, or mentorship. However, most mentors ($n = 11$) agreed that they gained enhanced confidence from the REU experience.

RQ 2: Changes in mentors' perceived research productivity, teaching skills, and communication skills

Whether participation as a mentor in the REU program impacted the mentors' perceived research productivity, teaching skills, and communication skills was explored by specific

questions on the pre- and post-surveys as well as the post-REU interview. On the post-survey, many mentors (11 out of 16) reported positive impacts on themselves or their research as a result of having an REU student. For example, seven reported that their work progressed as a result of the student's help. Three noted that they now had a better understanding of the subject after having mentored a student, and one reported having gained insight into future work because of working with the REU student. Further, mentors were asked to rate how much they agreed (on a 5-point Likert-type scale with 1 being strongly disagree and 5 being strongly agree) to various statements about what they had gained as a result of serving as a mentor. Indeed, mentors felt that they had made gains in areas such as their qualifications regarding mentoring (mean = 3.74, SD = 0.93), fulfillment from teaching others (mean = 4.05, SD = 0.62), teaching skills (mean = 4.00, SD = 0.67), and communication skills (mean = 4.11, SD = 0.74). Some (*n*=4) reported that the mentoring process caused delays in their research, mostly due to the REU student's training needs. Despite this finding, most (68.4%) mentors indicated that they would stay in touch with their students.

In the interviews, seven mentors said that their research productivity was positively impacted by having an REU student to mentor. Indeed, REU students did not simply provide menial support for the projects; they contributed meaningful ideas as well. One mentor noted that having a new perspective on the team helped spawn interesting, fresh questions. Another mentor reported that helping an REU student to overcome obstacles and problems allowed the mentor to learn more about their research. One mentor also commented that mentoring an REU student gave them a sense of responsibility, which motivated them to be more disciplined in their own work. The three codes used to answer RQ 2 are presented below in Table 2, with example quotes provided. Beyond instrumental support for their research, mentors developed in other areas as well.

The most common area that mentors reported making gains in was their teaching skills. Thirteen of the mentors reported that the REU experience helped them gain valuable teaching experience and that it impacted their teaching style. Some mentors gained valuable insight into the practice of teaching and even into their own understanding (and shortcomings therein) of the subject that they were researching. An illustrative quote is provided, below.

> "It's so easy to experience for me because it helps realize my own shortcomings and you tell the student what we're doing and you've got a good job of explaining it and then realized that they don't fully understand why we're doing it or what purpose it serves and so it helps to kind of revisit the explanation and learning how to really get the point across and I guess, the core principles, the underlying purpose of it."

Communication skills were also positively impacted by the REU experience, according to interview results. Seven REU mentors said that they gained communication skills through the mentoring experience. Most of these mentors' responses centered around being able to communicate complex scientific ideas to the "lay person" or to someone with relatively low background knowledge. For example, one mentor said the following to illustrate this point:

> "So this experience has taught me how to explain my research to the common people, like people who doesn't have a background in x-ray techniques."

Table 2. *Codes and example quotes regarding changes in mentors' perceived research productivity, teaching skills, and communication skills*

Code	Example
Research productivity	"So that sense of responsibility kind of makes you a little more disciplined, I would say. A little more focused. So that kind of helped me in my research, and my work in general."
Teaching skills	"So I really don't have much teaching experience, and through this I definitely would say it's easier to teach yourself than it is to teach another person. So, I think it really helped me become better at showing how to do something for others."
Communication skills	"I think that it definitely taught me how to effectively communicate these ideas, these projects that we're working on to someone who is just starting now. So starting out with the basics. Someone who doesn't really have a background in this."

RQ 3: Approaches to mentoring the REU students

Graduate student mentors were asked whether they engaged in certain activities related to mentoring an REU student, and all mentors indicated that they: were available for the student if they had questions, considered how proficient their student will be at a task before assigning it, observed the student to ensure that they are on task, had the student work independently, and worked side-by-side with the student. Other activities that most mentors engaged in throughout the REU include: assigning tasks to the student that were directly related to their own research (79%) and allowing the student to explore what interested them (79%).

Further, mentors were asked to indicate behaviors that they engaged in while mentoring the REU students that they worked with in lab. Table 3 displays the results in order of which behaviors were most common. Note that this table includes all participants who participated in the post-survey, regardless of whether they chose to participate in an interview or not. This was done to uncover a more comprehensive picture regarding mentors' behaviors while mentoring, and because no comparison to the pre-survey was being drawn. The four most common behaviors include "sharing the big picture" and goals of the project with the REU student, organizing the research activities for the REU student, modifying the research plan/schedule based on the student's progress, and helping the REU student prepare a presentation.

Table 3. *Number of mentors reporting engaging in various behaviors*

Behavior	**N***	**%**
Shared the "big picture" project goals with your student	19	100
Organized the research activities for your student	16	84

Modified the research plan or schedule based on your student's progress	16	84
Helped your student prepare a presentation	16	84
Assessed your student's research progress	15	79
Helped your student perform data analyses	15	79
Accepted a student's suggestion for the project	13	68
Helped your student to perform a literature review	13	68
Contacted your student at least daily during the workweek to check in with them	13	68
Held daily in person meetings with your student during the workweek	12	63
Organized the student's tasks from simple to complex	11	58
Constantly evaluated your student's knowledge	11	58
Created a project schedule that lists tasks that the student needs to complete	10	53
Helped your student prepare a written report	8	42
Met with your student outside of the research work environment	7	37

**Note:* All participants who completed the post-survey (regardless of whether they participated in the interview) were included in this table.

Several themes were identified in the interview transcripts during the coding process that identify the ways in which mentors approached supervising and mentoring the REU students. All of the mentors reported that they shared the "big picture" project goals with the REU students, and 84% reported organizing the research activities for the REU students. Additionally, mentors displayed *adaptability* regarding their expectations and tasks for the REU students. Adaptations typically came in response to informal *assessments* of the students' abilities. When asked about a specific time in which they taught their student something, mentors recounted a few different *approaches to teaching.* Further, some mentors made explicit efforts to *foster a sense of belonging* to the lab team in their students, while others perceived that the REU students already felt like they belonged because they had worked in the lab prior to the REU experience. The efforts made to help REU students feel welcome may depend on whether or not the REU student

had previously worked in the lab. Some of the REU students started their experiences during the academic semester (n=2) and were not brand new. However, other students were from external colleges and universities and were new to the lab (n=10). There were a couple of different approaches that mentors took when *introducing the student to the project.* Finally, mentors engaged in various forms of *goal setting* for their students and their projects. Each of these will be discussed in turn, next.

When it came to introducing the project to the REU student for the first time, several mentors provided relevant literature to read that would get the student up to speed. Some mentors even provided guides on how to read the articles or pointed out key areas to pay attention to when reading. Others introduced the student to the project in their first meeting by giving an overview of it and explaining goals associated with the project.

Fourteen mentors reported informally assessing their students, and they accomplished this in a variety of ways. Some mentors simply made wholistic assessments based presumably on an aggregate of many interaction with the student, while others had specific methods to assess the student's ability. Two illustrative quotes are produced below.

> "I ask her a lot of questions. So for example, she made a poster, then I go through, and then asked her, "What does this mean? What does this mean? Explain to me what basic principle of this." So I ask her a lot of questions. And anything she doesn't know or if she's not really clear in her knowledge, then I asked her to study more and come back to me and explain."
>
> *Interviewer:* "Did you gauge or assess your student's knowledge and skills?"
>
> *Respondent:* "Yes, so overall I thought my student did a good job with following protocols, but sometimes I did feel that some of the knowledge was relied a little bit on written text and not so much thinking. . ."

In response to mentors' assessments of their students' abilities, mentors altered the tasks given to the students, and sometimes altered how they interacted with the students. For example, one mentor reported using the information gleaned from informal assessments as a basis to determine how to explain things to the student. Another mentor described how he or she would adapt to the student's level of proficiency as to foster the greatest benefit for the student, while still another mentor reported having to learn things that he or she did not already know, as well as having to teach the student more than what was initially anticipated. Finally, mentors displayed the ability to adapt to time constraints imposed by the REU program itself. Students were only there for about 10 weeks and needed to produce a final poster presentation of their work. Thus, some of the students' work had to be cut back to account for this.

Mentors approached their teaching in many different ways. When attempting to teach their student a new procedure, the majority of mentors focused on *fostering understanding* of the underlying concepts and reasons for doing the procedure, and also *modeled the procedure first followed by guiding the students* as they practiced the procedure. Nine mentors utilized one of these two approaches. Other mentors approached teaching by simply *modeling the procedure only*, or by providing the student with a *detailed protocol* to follow. Another mentor utilized analogical reasoning for his or her more knowledgeable mentee and utilized multiple representations for his or her less knowledgeable mentee. This mentor's excerpt is reproduced below.

"Well, I guess with [one REU student], it was a bit easier in that sense because I could use some analogies from the course work. He was pretty much done with his coursework and classes and everything. So we had some analogies that we could use to introduce him to this new test or whatever we were doing in the lab or this phenomenon. With [another REU student], I couldn't use those analogies, but we tried to figure maybe doing some sketches, looking for videos on the internet, looking at some sketches on paper, some literature that we use to introduce her to."

Table 4, below, provides the coding system used to assess mentors' teaching styles, and example quotes for each code are also provided.

Table 4. Codes and example quotes about mentors' approaches to teaching their student something new

Code	Example Quote
Foster understanding	"the idea was that before we started anything, we would go to the literature and make sure he had an understanding of what we're doing, what the goals were, why we do things a certain way. The reactions had to be run in a very specific way with [inaudible] added at a certain rate, things like that. So we made sure he had an understanding of why we were doing all of the steps and then move on to actually having him set up the equipment so that it worked out the right way and things like that."
Model with guided practice	"I performed the experiments the first week myself and they, basically, took notes of what I was doing. Then, I will have the students do the experiments under my supervision and try to tell them what they were doing wrong, or don't forget to do this, don't forget to do that until they were fully independent, and they were working on their own, and they will just bring the data to me."
Modeling only	"I would try to explain him first of what we are trying to do, how we are trying to do, maybe show him once, and then would hope that he has learned it. And if he has not, I think he's free enough. And we both are free with each other that he can come and ask me then, "This is the problem and how do I rectify it?" I mean, usually, that's how we do things."
Used detailed protocol	"The student was using an instruction sheet with the set of instructions, basically how to start and perform some simple tasks with

	following the guidelines provided on the instruction sheets with me verbal on the side. And when the students had questions, I was there to answer the questions and obviously when learning a complex program, they asked a number of-- the students had a lot of questions. So it was learning the instruction sheet-- the instruction sheet was helpful in that I provide instruction on what to learn first and slowly build up and my presence there was important to provide clarity on exactly how to do some of the tasks that were not straightforward."

While some students already had a sense of community within their labs according to mentors — chiefly due to their involvement with the lab in the prior academic year — other mentors made more explicit efforts to foster a sense of community and belonging in their students. A common method of accomplishing this goal was to include students in weekly lab meetings, in an attempt to introduce the student to all other people working in the lab. Another indicator that the REU student felt like they were part of the lab was that the student provided input into lab decisions.

Finally, mentors typically set regular goals for the student, themselves, or both the student and themselves. These goals would vary by day, week, or two-week period. Sometimes the goals would simply be updated when a particular phase of the project had been completed.

RQ 4: Challenges and recommendations related to mentoring and/or the REU program

On the post-survey, mentors were asked if they had any recommendations for future iterations of the REU program. Six mentors reported data for this question. Recommendations from mentors on how to improve the REU program included giving the mentees general lab skills training (n=1), providing orientation and training for graduate student mentors (n=1), clearly stating to the REU students and mentors what is expected of them (n=1), disseminating information about the REU program earlier and giving feedback to the mentors about their performance (n=1), suggesting more REU programs be created (n=1), and finally, one graduate student mentor noted that the program was good as is.

From the post-REU interviews, a myriad of challenges that mentors faced during the REU experience were identified. Challenges included things such as how to properly guide and mentor students, intrapersonal challenges such as trusting the student and time-management, the student's lack of experience with research or key skills, lack of student training and knowledge, and other miscellaneous challenges. Table 5 provides the codes that identify these challenges and sample, illustrative quotes.

Table 5. Challenges that mentors faced during the REU

Student training	"That's a drawback of our group is we have to use equipment in the other department and

	they require the training which takes really long to schedule."
Student's prior knowledge	"So for example, she did not have much experience with linear algebra. And linear algebra is something you can explain in layman's terms, but you can only do so much. At some point of time, you have to really sit down and go through some of the very basic tenets of linear algebra and that kind of-- that was kind of a little bit challenging…"
How to guide students	
Having patience with student	"I think is the giving of patience to a lot of them to learn and understand the concept and experiments. And sometimes is a lot more time for the mistakes. Which also had happened."
Motivating students	"But I expected her to figure out [the problem] first because that is really, really research. If she was [inaudible] and she will have a lot of research tasks and problems but [she?] needs to figure out by herself. So I tried to motivate her but sometimes it was hard because it was too difficult for her because she's never had experienced."
Balancing student's workload	"I would say the greatest challenge would be to give the students not more than what they can handle, so that it's not too overwhelming for them, and breaking down the whole project into small bits that the students can handle…"
Mentor's internal challenges	
Managing own workload	"Like I said, it's a time management and having to work with multiple students at once. That required being able to manage my own time pretty well."
Trusting the student	"The biggest challenge for me was trusting someone else to do the work initially. Because I have always done it, I know exactly how I do it, and so just letting some of that control go and trusting that they're doing it right. They were taught hopefully well [laughter]."

Other challenges encountered by mentors included: the *mentor did not know much about the student's project*, *differential goals* between the mentor and student, *different preferences for work time* (early vs late in the day), *communication*, and *having enough of a "heads-up"* about getting an REU student. This last challenge may be a factor of lack of communication between

the mentor and the supervising faculty member, as all faculty members were provided with information about their REU student prior to the start of the program.

Discussion

The purpose of the current study was two-fold: 1) to explore the ways in which graduate student mentors approach mentoring REU students; and 2) to study the impact of the mentorship experience on the mentors. In pursuit of these purposes, four specific research questions were explored: 1) How did participation as a mentor impact mentors' self-efficacy in research, leadership, or mentorship?; 2) Did working with an REU student increase the mentors' perceived research productivity, teaching skills, or communication skills?; 3) What types of approaches did the mentors utilize to supervise and mentor the REU students?; and 4) What challenges related to mentoring and/or the REU program did mentors report?

Results from the surveys and the post-REU interviews indicated that the REU did not have a perceived impact on the mentors' self-efficacy regarding research skills, leadership, or mentorship capabilities. One potential reason for this finding is that on average, mentors reported on the pre-survey that they were "mostly confident" (5 out of 6 on the Likert scale) in each of these areas. Thus, if the mentors start the REU program being highly self-efficacious, it would be difficult for the program to raise their self-efficacy. Arguably, the REU experience may have reinforced the mentors' already relatively high self-efficacy regarding their research skills, leadership, and mentoring capabilities.

Interestingly, most (n = 11) mentors did report that they gained confidence as a result of mentoring a student in the REU program. Given that this is a relatively open-ended question, mentors may have been thinking about a myriad of different contexts in which they gained confidence. Some may have gained confidence in their ability to act as an authority figure, while others may have gained confidence in their communication skills. Exactly what each mentor was thinking about when they responded to this particular question remains unknown and could be further explored in future research.

Participating as a mentor in the REU program did appear to positively impact mentors' perceptions regarding things such as their teaching skills, communication skills, and their research productivity. Seven mentors reported that their work progressed because of the REU student's help, and better yet, three mentors reported that their own understanding of their project was positively affected because of the REU experience. Further, on average, mentors perceived that they made gains in their teaching skills (mean = 4.00, SD = 0.67), and communication skills (mean = 4.11, SD = 0.74) as a result of the REU program. These findings were generally corroborated in the post-REU interview. In fact, thirteen of the mentors reported that the REU experience helped them gain valuable teaching experience and that it impacted their teaching style. Further, results indicated that REU students made meaningful contributions to the mentors' research.

However, some mentors (n = 4) noted that having an REU student actually hindered progress on their research projects, due mostly to needing to train the student or the student's lack of prior knowledge related to the research content. Although training REU students prior to attending the program is not realistic, perhaps assigning readings to students ahead of time can help the transition in the lab. This strategy could help ameliorate any potential delays in the research process and may also help to further benefit the student and the mentor.

Limitations

Some limitations to the current study should be noted. First, though the response rate was relatively high for the surveys and the interview, the overall sample size is still a limitation to this study. Fewer than 20 mentors participated in the surveys and interview, and all of these mentors came from the same (host) institution and participated in the same REU. Thus, factors such as the institutional or departmental culture, and individual mentor differences could influence the experiences that students and mentors had. It would be difficult to generalize the findings from this study to all REU mentors at all institutions—especially institutions that differ in terms of size, research intensity, and other factors.

Second, not all mentors (n=4) chose to participate in the post-survey and/or the interview. This is important to note because those mentors may be qualitatively different from the mentors who did choose to participate. It could be argued that mentors who decided not to participate did so because they were less interested in the REU, mentoring, or research in general. Thus, it is possible that those mentors would have reported different results if they had participated. Conversely, those who decided to participate may be more interested in mentorship, more efficacious, and better prepared to mentor than those who did not choose to participate. This could be a possible explanation for why the average mentor reported being "mostly confident" in terms of research, mentorship, and leadership.

Finally, the study's findings are based on self-report data such as surveys and interviews. It is possible that mentors were subject to the social desirability bias when answering survey questions and interview questions. Many of the constructs that were examined in this study rely on self-report data (e.g., self-efficacy), and efforts should be made in future research to use multiple data collection techniques to triangulate findings. Employing multiple methods such as diary entries and multiple self-report surveys could prove useful in helping to ameliorate common criticisms of using a single self-report measure. Further, future studies should consider observational methods to address mentors' actual change in research productivity, teaching skills, and communication skills. Observational methods could reduce social-desirability biases among respondents.

Implications

The study's findings result in some implications for REU programs and REU-related research. First, REU programs should consider enacting comprehensive training for mentors prior to REU student arrival. Based on the results from this study, the training should focus on teaching mentors how to motivate students, balance the students' workload, and manage the mentor's own time. Further, some mentors noted that they would have liked more time to prepare for the REU student prior to arrival, so it may be beneficial to graduate student mentors and REU students to communicate in advance of the start of the program to make sure that the project is set for a quick start. Further, REU students and mentors alike should be told clearly what the expectation are of them, and what — if any — outcomes are expected of them.

It is also clear from the results related to RQ 1 that mentors perceive that they are highly efficacious in general even before the REU program begins. It is interesting that this may be the case, since there was minimal mentor training provided. While the mentors may be accurate in their efficacy judgements, it is possible that they are not. That is, the mentors may erroneously

perceive their efficacy to be high because they may not know what being a good mentor truly entails. Consequently, mentorship training prior to the start of the REU program will likely benefit the graduate student mentor and the REU students.

Future research

There are many avenues of future research to be explored in this area. One of these avenues could be longitudinal studies that investigate the long-term impact of being an REU mentor. Is there any impact on mentors after they graduate? Or after they move on to the next phase in their career? Future research should employ longitudinal designs to address these questions. Further, future research should investigate any possible differential effects of mentoring one student versus mentoring two or more. It is possible that there is an upper-limit to the number of students that mentors can handle without sacrificing productivity or other positive outcomes.

Next, additional research is required to assess which types of mentoring behaviors correspond to better outcomes, if any. Is it typically better for mentors to plan out their student's time day-by-day, or is it better to allow more freedom in this regard? Additionally, future research could investigate the link between mentors' reported experiences, students' reported experiences, and faculty's reported experiences. Whether or not student, mentor, and/or faculty perceptions align could provide critical insight into the REU program, and further elucidate the experiences of REU participants in all roles.

Finally, future research should investigate the effects of mentors' year in graduate school on their gains in areas such as teaching, communication, and sharing their expertise. This is because more senior students may report highly already on these factors, and thus may not have much room to improve. Further, future research should determine if there are any differences in responses to how efficacious mentors feel towards mentoring, research, or leadership based on gender or URM status. These questions were beyond the scope of the current work, and would likely require a larger sample size than was available in this study.

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Appendix A

Mentoring Confidence: *At the current time, prior to serving as a mentor for a student participating in the Research Experience for Undergraduates (REU) program, how confident are you in the following areas?* (6 scale points, Not at all confident – Very confident).

1. My qualifications as an engineer
2. My leadership skills
3. My ability to mentor undergraduate researchers
4. My ability to supervise others in my future professional career

Mentorship Beliefs: *At the current time, prior to serving as a mentor for a student participating in the Research Experience for Undergraduates (REU) program, how much do you agree with the following statements?* (5 scale points, Strongly disagree – Strongly agree), adapted from Ragins and Scandura (1999)

1. I have the ability to mentor undergraduate researchers
2. One's creativity increases when mentoring others
3. Mentoring is a catalyst for innovation
4. Th rewards that come from being a mentor compensate for the costs
5. Mentoring others improves one's own research skills
6. Mentoring others improves one's own leadership skills
7. Mentoring others improves one's ability to look at a problem from different points of view

Mentorship Style: *Think about your interactions with the student you worked most closely with during the REU program. Did these interactions change during the REU program?*

Please group the experiences listed to the left below according to when they most often occurred by dragging and dropping each one into one of the four boxes to the right below. (Four groups: Month 1—June; Month 2—July; Roughly equally both months; I did not do this/I don't know).

1. Consider your student's interests when assigning tasks
2. Assign tasks to your student that are directly related to your own research
3. Ensure that tasks are not too boring or complex for your student
4. Allow your student to explore what interests them
5. Make sure not to deviate from the project plan
6. Work side-by-side with your student while they complete tasks
7. Have your student work independently while they complete tasks
8. Allow your student to struggle when they do not know something
9. Make sure to be available if your student has questions

10. Consider your student's research project to be separate from your own research
11. Consider how proficiently your student will be able to perform a task when assigning it
12. Consider yourself to be the lead on the research project
13. Observe your student to ensure that they are on task
14. Consider the work that you need completed when assigning tasks to your student

Perceived Gains from Mentorship: *Think about what you have gained from serving as a mentor for a student participating in the REU program. How much do you agree with the following statements?* (5 scale points; strongly disagree – strongly agree) Adapted from Dolan and Johnson (2009)

1. I have gained improved qualifications
2. I have gained improved research productivity
3. I have gained an improved understanding of my advisor's job
4. I have gained fulfillment from teaching others
5. I have gained improved teaching skills
6. I have gained improved communication skills
7. I have gained improved lab skills
8. I have gained career clarification
9. I have gained enhanced confidence
10. I have gained intellectual growth
11. I have gained a sense that I shared my expertise
12. I have gained knowledge of something new from the student that I mentored

Mentor Interview Protocol:

Time/Date _____:_____A/PM_____2017
Interviewer's name _____
Mentor's name _____

1. Why did you decide to supervise a student this summer in the REU?

2. Briefly tell me about the student that you mentored during the REU.

3. What types of projects did the student that you mentored work on?

4. What types of tasks did you have the student do?

5. How did you introduce students that you mentored to the lab, projects, etc.?

6. Were you able to integrate the student that you mentored into your "lab community?"
    a. N___ Why not?
    b. Y___ Why/how?

7. Describe a time when you taught the student something new. How did you go about doing that?

8. How much independence did you allow the student to explore topics that they were interested in?

9. Describe how you see your relationship with the student. For example, how did you interact with him or her?

10. Did your interactions with the student change during the REU?
    a. N ___ Why not?
    b. Y ___ Why do you think your interactions changed? What do you think this change was related to (e.g., student characteristics, mentor made a conscious decision to change, etc.)?

11. Did you gauge/assess your student's knowledge and skills?
    a. N ___ Why not?
    b. Y ___ Did you make any adjustments when interacting with them based on this information?

12. What did you expect to gain from this experience?

13. Did what you expected to gain change during the summer?

14. How did you most benefit from mentoring a student in the REU?

15. How do you think the student that you mentored most benefited from the experience (e.g., skill level change)?

16. Did you have daily, weekly, monthly priorities for yourself and/or your student?
    a. N ___
    b. Y ___ [Circle: self, student, both] Did these priorities change during the REU?
        i. N ___
        ii. Y ___ Why did these priorities change?

17. What is the biggest change you would make if you could go back in time, to the beginning of the REU?

18. What were the greatest challenges that you encountered while mentoring a student in the REU?

19. How did you address these challenges?

20. Did your experience as a mentor affect how you would approach teaching students in the future?

21. Did your mentorship experience change your planned career trajectory?
    a. N ___ Why not?
    b. Y ___ Why?

22. What type of training would help future mentors to be successful?