PURM

Perspectives on Undergraduate Research & Mentoring

Evaluation of a Physics Research Experience for Undergraduates

Tracy Gastineau-Stevens, M.S., University of Kentucky (tracy.gastineau@uky.edu)
Jennifer Wilhelm, Ph.D., University of Kentucky

Introduction

Research experiences for undergraduates (REU) and undergraduate research experiences (URE) have begun to emerge as co-curricular activities that aid in student learning and achievement. Generally, REUs are outside of the student's home institution and UREs are at the student's home institution, but both have been used interchangeably. The main characteristic of REUs and UREs is research opportunities for students outside of their normal coursework. Studies have shown that students who participate in REUs/UREs are more likely to graduate on time, attend graduate school, and stay in that field (Russell et al., 2007; Youssef et al., 2016). This is particularly evident in science, technology, engineering, and mathematics (STEM) fields. These experiences also promote retention and persistence with generally marginalized groups in these fields, such as women and underrepresented minorities (URMs) (Harsh et al., 2012; Youssef et al., 2016). The present paper discusses the first year of a three-year National Science Foundation (NSF) sponsored REU program in the field of physics and astronomy. Over the course of ten weeks during the summer, individual students were paired with a mentor where they worked on a physics or astronomy related research project. Despite some logistical issues that came up, the students and mentors described the REU program as beneficial to undergraduates in their pursuit of physics and astronomy degrees and future career.

Literature Review

Benefits and Barriers for Students

Research experience can play a major role in an undergraduate's college career in the STEM fields. Many undergraduates partake in research in their respective areas for a multitude of reasons. These include bridging the gap between in-class lecturing and real-world applications, research and STEM-based skill building, and post-graduate preparation (Youssef et al., 2016).

REUs and UREs may be somewhat different, but the overall goal for both types of undergraduate research is to improve the necessary skills for undergraduates to succeed in STEM majors both in school and post-baccalaureate. Some of the major benefits that both students and faculty mentors have stated come from participation in REUs/UREs are the increase in scientific skills, confidence in participating and conducting research, understanding of the graduate experience, and educational aspect of their undergraduate careers (Craney et al., 2016; Follmer et al., 2015; Kardash, 2000; Madan & Teitge, 2013; Russell et al., 2007; Sheng et al., 2014; Wei, 2014; Wilhelm & Fisher, 2016; Youssef et al., 2016).

REUs/UREs also have the benefit of increasing retention, graduation rates, and post-baccalaureate participation in STEM fields among women and underrepresented minorities (URMs) (Craney et al., 2016; Hernandez et al., 2018; Kardash, 2000). Kardash (2000) claimed that when faculty rated students' skills and attainment, females achieved just as well as their male counterparts. This is also seen in other REU/URE results when gender is considered (Blackburn, 2017; Harsh et al., 2012). However, most current research does not consider how UREs/REUs facilitate females' persistence in STEM fields compared to males'. Most current research just examines how REUs/UREs benefit undergraduates in general.

There is less discussion on underrepresented minorities (URMs) and the benefit of UREs/REUs for these students. Hernandez et al. (2018) looked at URMs specifically and what the long-term effects were on these students who participated in UREs. They noticed that participation in a URE benefited their academic performance, scientific baccalaureate attainment, acceptance into graduate school, and scientific-workforce participation (Hernandez et al., 2018). Despite the benefits seen among some of the short-term research, there are fewer longitudinal studies examining how UREs benefit URMs. This could also be said for female STEM students and undergraduate students in general. The long-term effects of UREs or REUs have not been evaluated beyond baccalaureate attainment. However, retainment in STEM post undergraduate and even graduate school is also of importance.

One of the other main issues pertaining to REUs is that undergraduate students do want to participate, or show an interest in participating in REUs, but they do not necessarily know how to obtain a research position (Madan & Teitge, 2013). Either it is a lack of research opportunities within their individual programs or students are not made aware of these opportunities early enough in their careers. There are other studies that state that the benefits of an REU/URE program may be amplified if the undergraduate students were able to begin the research experience earlier in their career (Hanshaw et al., 2015; Hernandez et al., 2018). It appears that the major issue pertaining to REUs/UREs is the awareness of their existence for STEM undergraduate students.

Benefits and Barriers of Faculty Involvement

The benefits for undergraduate students who partake in REUs and UREs are prevalent throughout the literature. Even though the students are the main beneficiaries of the research experiences, the literature has also discussed some of the benefits for participating faculty mentors. Besides the extra research assistance for faculty that partake in REUs/UREs, some faculty mentors have stated that being involved with undergraduate research has given them the personal satisfaction of helping students grow and professionally develop (Buddie & Collins, 2011). Faculty can also benefit from undergraduate research by getting the opportunities to test out new theories or avenues of research that they cannot allocate other resources to, and supervising undergraduates compared to graduate students can also help faculty improve both professionally and intellectually (Buddie & Collins, 2011). Even departments can benefit from undergraduate research experiences by assessing how the department is doing as a whole in terms of research, undergraduate retention, and mentorship (Buddie & Collins, 2011).

The main barrier that faculty have expressed in terms of participating in undergraduate research is time commitment (Buddie & Collins, 2011). Although research is time-consuming in the first place, many undergraduate students come into research ill-equipped, so the professors must spend time bringing them up to speed. Some faculty in the literature have stated that this influences their own research commitments and other responsibilities, such as teaching.

Limitations of Previous Research

Although the benefits of REUs/UREs are quite evident, there are some limitations of previous work that future studies could learn from and improve. In the Translational Application of Nanoscale Multiferroic Systems (TANMS) program, students stated their desire for more opportunities to interact with industry both in quality and quantity (Youssef et al., 2016). Sometimes the exposure students have to other post-baccalaureate opportunities within the REU programs is limited because the focus of the REU/URE is academic research.

As mentioned earlier, the long-term effects of participation in REUs/UREs have not been well researched. Although most of the benefits of participation pertain to retaining students in STEM in college and into graduate school, there is little research on the effects of research experiences and continued involvement in STEM post-graduate school. Further studies could look at these long-term effects of REU/URE participations and continuance in STEM. A few studies on the long-term effect of REUs/UREs have showed the benefits of participating continue on post-baccalaureate (Hernandez et al., 2018; Wilhelm & Fisher, 2016).

Our study examined a first year REU program in physics to evaluate the effect of a REU on undergraduate students and their mentors. This research was conducted with a convergent parallel mixed-methods approach. There were three main research questions in the study.

1. How well did the REU project enhance student interest in physics?
2. How well did participants become trained with relevant research skills?
3. How successful was the REU program according to mentors and fellows?

Methods

Location and Participants

The NSF-funded REU took place at a Research 1 (R1) institution located in the southeastern United States during the summer of 2021. The overall NSF grant is for three years; this article assesses the first year of the REU to help the researchers improve on the REU for the two remaining years of the project. Although funded a year prior, the program was delayed due to COVID-19. The ten-week program involved physics and astronomy (P&A) based research with faculty. It also included weekly group meetings where the participants discussed their current research work. Classes and optional workshops were also part of the REU, allowing students to become more familiar with certain aspects of P&A research. For instance, classes on coding software and graduate school information were provided for the students. Along with P&A-focused and research-focused classes and workshops, some social activities were included to help foster student involvement into research and university community. Some of these activities included trips to hiking trails, lake trips, and trips to an observatory.

There were six students during the first summer who were funded by the NSF grant. There were eleven other students who participated in the summer REU program whose funding was through other sources. All participants were allowed to participate in any REU activity. According to the American Physics Society (APS, 2018b, 2018a), women earned 22% and URMs earned 14% of all physics bachelor's degrees. Compared to the latest data, women and URMs in the REU program represented a higher proportion among the NSF-funded students (Table 1). Although not as high as when all the REU participants were included, the percentages of women and URMs was still larger than the most recent bachelor's degree attainment according to the APS (APS, 2018a, 2018b).

Although the REU focused mostly on the undergraduate students and their participation in REU, information on the faculty mentors was also collected. A total of eleven faculty members from the research institution participated as mentors in the REU program. The six NSF-funded students were mentored by six faculty members (two females and four males). Some participants were co-mentored by faculty members at the R1 institution and faculty members from other institutions as part of the REU program, but all six NSF-funded students were mentored by faculty members at the R1 institution.

Table 1. *Demographic Information of REU Participants*

	Number	Percent Female	Percent URM	Percent Limited Research Institution
NSF-Funded Participants	6	50	33	66
All Participants	17	41	17	N/A

Assessment Methods

The research data were collected using a convergent parallel mixed-methods approach (Creswell & Creswell, 2018). A convergent parallel mixed-methods approach allows for both quantitative and qualitative data to be collected at the same time. The two types of data provide different information that yields similar results (Creswell & Creswell, 2018). Pre- and post-REU surveys modified from Kardash (2000) were conducted anonymously via the Qualtrics. The surveys were administered in the first and the last week of the summer program. Participants were asked to include a non-identifying indicator (i.e., pet's name) for both surveys so that paired data could be evaluated. The survey consisted of 54 five-point Likert-scale questions related to the student's perceptions of themselves as learners and researchers (specifically in P&A) before and after the summer program. The pre- and post-survey responses were evaluated using paired and un-paired t-tests to assess the perceptions of the students' gains before and after the REU program. The first set of 24 questions mainly covered students' perceptions of how they are as researchers and started with the prompt: "To what extent do you feel you can…". The second set of 24 questions specifically related to how the internship was viewed to help them in their research efforts and started with the prompt: "To what extent do you feel the internship will/did…". The last six questions touched on students' perceptions about a career in research and research in general and had the prompt: "Indicate the extent to which you believe the following statements are true for yourself."

Semi-structured interviews were also conducted with the student participants at the beginning and end of the program. Post-interviews were conducted with research mentors. All interviews were done within the first or last two weeks of the summer. Pre-REU interview questions touched on the students' previous research experience, if any, their anticipated mentor-mentee relationship, new skills they might obtain, and potential benefits and barriers of research for themselves and mentors, among other topics. Post-REU interview topics touched on their experiences during the program, their relationship with their mentor, skills they obtained, if the REU had influenced their participation in research in the future, and general recommendations to improve the REU program. The post-REU interviews with the mentors included their perceptions of how the REU program went, their mentor/mentee relationship, and how the program affected them as researchers and professors, among other topics. All the interviews took roughly 30 minutes and were primarily recorded using the Otter.ai application that also transcribed in real-time. Transcriptions were evaluated and manually edited when the application did not transcribe the interview correctly. Survey questions and interview prompts are included in Appendix A. Institutional Review Board approval was obtained before any data collection. All participants were given consent forms to sign.

Results and Discussions

Surveys

Both the pre- and post-surveys conducted were anonymous besides non-identifying indicator (i.e., pet's name) to allow for paired data to be analyzed. There were a total of twelve participants for the pre-survey and thirteen participants for the post-survey. Since the surveys were anonymous, we do not know the distribution of NSF-funded REU participants or other demographic information (i.e., gender, underrepresented minorities, etc.). We compared the pre- and post-survey responses instead of comparing the individual participants' responses. There were ten surveys that were paired, so a paired t-test was used to evaluate the average pre-survey responses to the average post-survey responses. For the unpaired data, we used a t-test with means assuming equal variance. A few students, at least in the paired data, did not answer any questions. The corresponding question in the other (pre- or post-) set was also set to not applicable to keep the average consistent. One student only answered six of the second set of 24 questions in the post-survey, so all their corresponding answers in the pre-survey were set to not applicable. We decided to do this because the surveys were assessing the students' own perceptions of their gains or losses over the program. If a student did not answer certain questions, then the data can become skewed in overall gains or losses. Even with the removal of some questions, all the paired t-tests were significant (see Table 2 for corresponding p-values). The overall unpaired data showed similar results to the paired data. However, while the last unpaired six questions followed a similar trend to the paired data, the unpaired were not statistically significant.

Table 2. *p-values for Pre- and Post-survey Differences for Paired and Unpaired Data*

	Questions 1-24			Questions 25-48			Questions 49-54		
	t-stat	p-value	df	t-stat	p-value	df	t-stat	p-value	df
Paired	- 4.273	<0.001	23	3.289	0.003	23	3.081	0.027	5
Unpaired	- 4.589	<0.001	46	3.990	<0.001	46	0.400	0.698	10

The average Likert values for the paired data for questions 1-24, 25-48, and 49-54 are reported in Figures 1, 2, and 3, respectively. The adapted Kardash (2000) survey can be found in Appendix A. The first 24 questions asked about students' perceptions on their ability to do research. Theoretically, if the students had little to no prior research experience, the scores at the beginning would be lower, and after the program, their perceptions in their abilities would improve. Our research findings support this hypothesis. The first 24 questions showed a statistically significant increase between pre- and post-surveys, indicating an increase in student confidence. In contrast, both the second 24 and the last six questions had a significant decrease between the pre- and post-surveys. Although the overall unpaired figures are not shown, they followed a similar pattern. Questions 25-48 discussed how the internship was going to aid in building their research skills. The scores in this section of the survey decreased because there was potentially high expectation for what the REU program was going to help them accomplish in terms of research skills. However, in the end, some of the research was not applicable to certain questions or the reality of the program did not meet the students' expectations. The last six questions asked more about their careers in research and overall ability to do research. During the post-interviews, it appeared that although the REU program was helpful in increasing students' overall interest in physics and research skills, it did not necessarily increase their interest in pursuing physics research as a career. The surveys will be conducted again in the next two summers and hopefully the increased sample size will add more clarification to the trends observed in this first year of the program. Overall, students seemed to feel that their skills as researchers improved from the beginning to the end of the program, as seen in their responses to the first 24 questions.

Student Interviews

Students were interviewed in the first and the last week of the program. Interviews lasted about 30 minutes and were recorded via the Otter.ai application. The topics covered their perceptions of how the REU program aided in their research skills, mentor/mentee relationship, and general topics on how the program could be improved for future years. The three research questions were touched on throughout the interviews.

1. How well did the REU project enhance student interest in physics?
2. How well did participants become trained with relevant research skills?

3. How successful was the REU program according to mentors and fellows?

Figure 1. *Average Paired Response for Pre- and Post-Survey for Question 1-24*

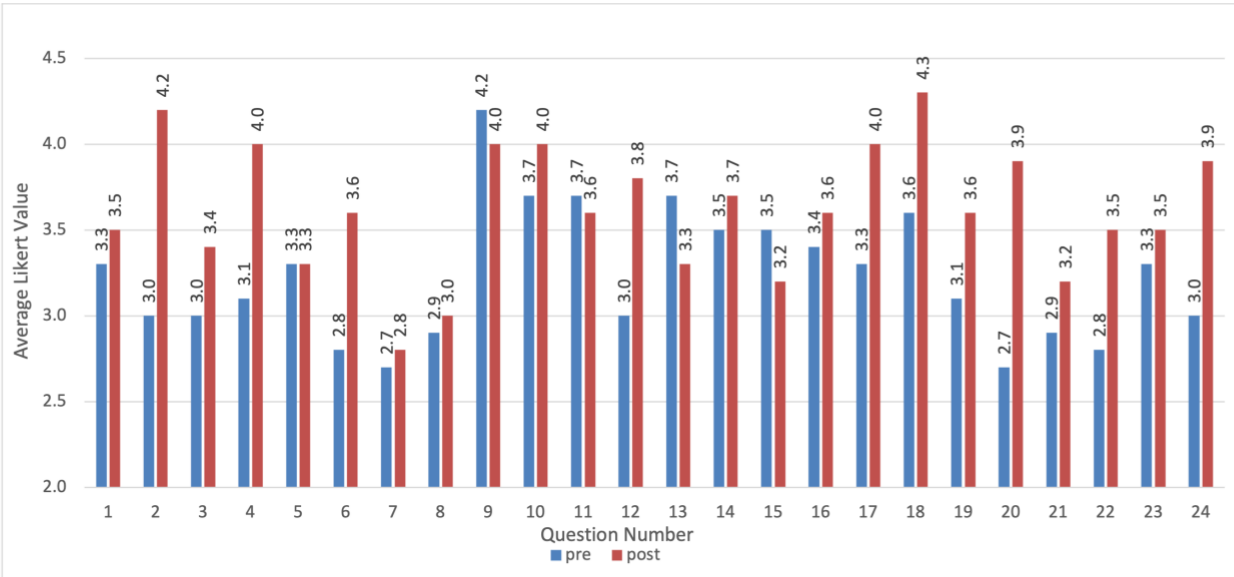


Figure 2. *Average Paired Response for Pre- and Post-Survey for Question 25-48*

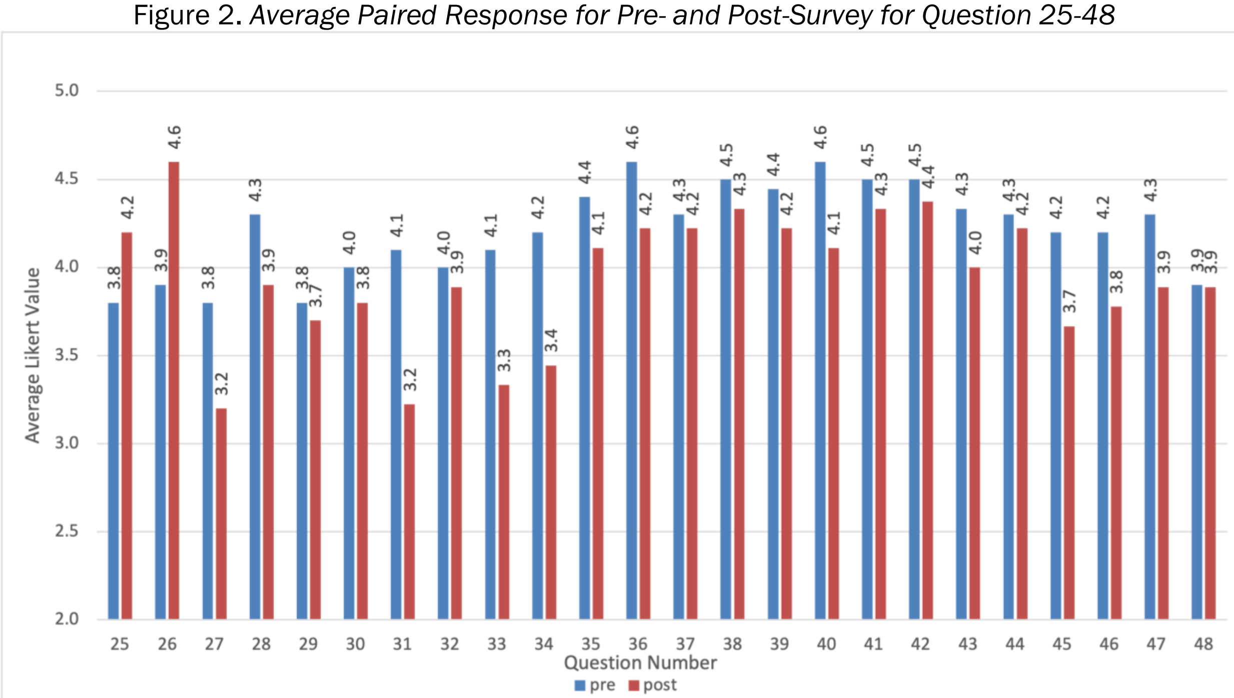
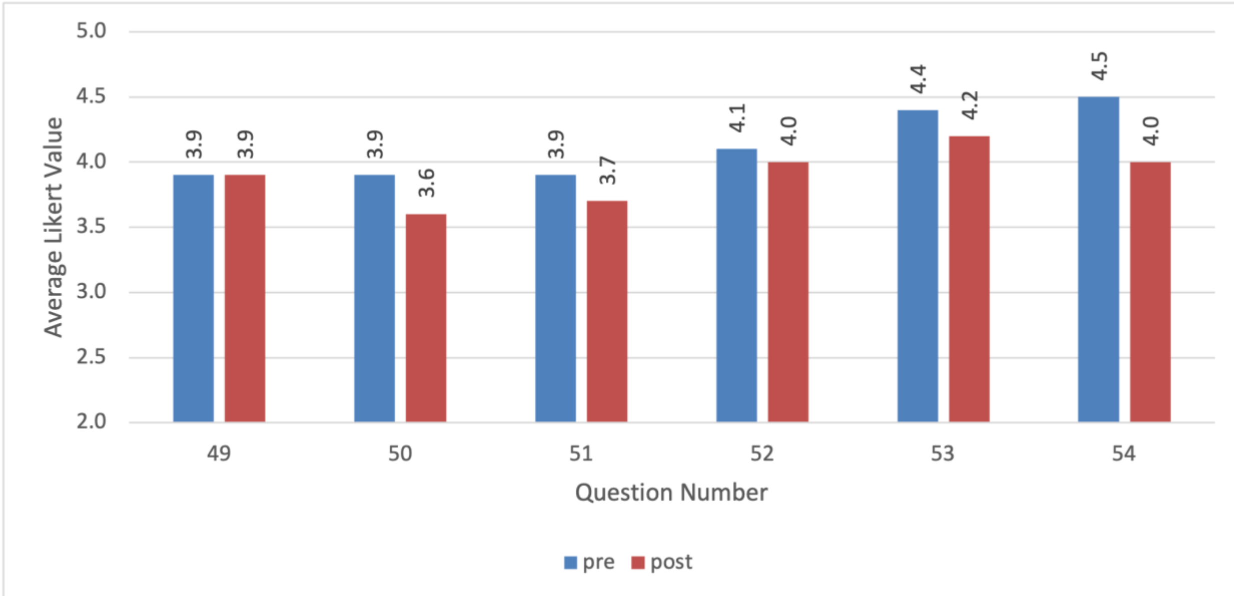


Figure 3. *Average Paired Response for Pre- and Post-Survey for Question 49-54*



All NSF-funded students (*n*=6) participated in the pre- and post-interviews and five additional students also participated in both the pre- and post- interviews (total=11). Additional two students participated in the pre-program interviews.

Question 1: How well did the REU project enhance student interest in physics?
All of the students in the post-interviews expressed either an increased interest in physics, astronomy, and technology, or that the REU helped them solidify the post-undergraduate plans they have already had in the area. As one female URM student said,

> "I plan on pursuing engineering. I mean it [REU program] just showed me more that physics is really interesting, but I knew that already; but learning about quantum materials, and the things that they can do is pretty exciting and cool."

Another student, although planning a different career path, said that the research they did in the REU could "somehow merge into [their] career." Some students (about 36%) even mentioned that although their future is physics, the REU has given them a "much better insight into what actually happens in the academia branch."

Question 2: How well did participants become trained with relevant research skills?
In the interviews, especially the post-interviews, all of the students stated that they gained valuable skills. Some of the skills were fairly technical, like new coding programs and instrumentation, while other skills encompass research as a whole. These included science writing, setting up an experiment, communicating, data acquisition, and interpersonal skills. Six students in the whole REU program had partners in their labs working on the same project as a team. Three of those six students spoke in the post-interviews and really appreciated working in a pair and suggested that it would be beneficial for students to be paired in the future. As noted by one female student,

> "If possible for going forward, students are to be paired with another undergrad. That was a really positive experience for me, I don't know if I would have had as good of an experience working alone for 8-10 weeks. And I'm sure there's a lot of helpful graduate students as well.

> But it was just nice to have someone who was sort of at the same level of physics and mechanics to talk through things."

Question 3: How successful was the REU program according to mentors and fellows and what makes a program successful?
Although this question was not directly asked to the students, students alluded to whether the program was successful or not. One comment that appeared frequently was on the research skills they gained throughout the program. The students alluded that the attainment of these research skills made the REU successful. Because this was the first year for the REU program, there were some issues that arose, most of which were logistical in nature. For example, over half of the students did not receive necessary resources like lab access, meal cards, or even funding until near the end of the program. Most of the recommendations were based on these issues. There were some discussions on how lectures, workshops, and scheduling in general could have been streamlined. A couple of students mentioned how some workshops were not applicable to their summer research or how the timing made it difficult to vet out a proper research schedule.

Other Themes
Other themes emerged from the interviews. All of the students interviewed stated that they had an overall positive experience participating in the REU. None of them brought up any issues with their mentors. At least half explicitly stated their pleasure at working with their mentors, and that they had pleasant experiences with them. One female URM student noted,

> "I think it was very open, like, communicative and very understanding. He never assumed what I knew and I like, but he was never condescending to me. ...he would explain [concepts] in a way that didn't make me feel like silly; it was good."

One student mentioned having a similar relationship with their graduate student mentor that helped them during the summer. Another positive theme that students described was the cohort building during the summer. Even though it was not explicitly asked or discussed, the students mentioned that the social activities and seeing others' work were helpful in building that cohort experience.

There were, however, one or two students who had complaints about how long it took for their projects to start. One male student stated in their post-interview,

> "I was mostly working with articles and trying to find the connection between them. It felt like I wasn't doing anything for most of my time here. I only started working in a lab in the last two weeks of the program. So, I kind of struggled with and felt useless."

Although a couple other students had similar issues like this one, they all generally had a good experience during the REU.

Faculty Interviews
Although the faculty interviews were only conducted during the final week, similar questions were asked. Although there were more faculty that participated, to be conscientious of their time, we only interviewed those that mentored the NSF-funded students (n = 6). These interviews lasted about 30 minutes and were also recorded and transcribed via Otter.ai application with an evaluator double checking the transcriptions after the interviews. There were a couple faculty who mentored more than one student (through both NSF- and other funding), and they discussed their students overall in the interviews. The interviews were coded first based on the three main goals of the NSF REU program. Then they were coded for other emerged themes.

Question 1: How well did the REU project enhance student interest in physics?
All of the faculty expressed some type of pleasure with their students and indicated that they saw a growth over the summer, especially in students that had very limited research experience and opportunities. As one mentor said,

> “My student…has absolutely no experience in a lab. She's from [a community college] in far western part of the state. And she…has aspirations to be in biomedical engineering. [In order to do that,] you have to have nonzero lab experience and … she's keeping a lab notebook, she has [been] getting her hands dirty, and making measurements and she's never done any of that before and so I think that's actually quite, quite good.”

Another mentor mentioned that their student had for the first time “real hands-on experience,” and the student found the research “quite interesting” just by “simply watching what’s going on.”

Question 2: How well did participants become trained with relevant research skills?
In terms of training participants, all of the interviewed mentors mentioned that the REU program was successful in giving the students new research skills. One mentor mentioned that their student “didn’t know much about physics or any relevant topics” at the beginning of the summer, but near the end showed great improvement and even knows “some [details] better than me.” Other mentors mentioned how well students grew in their research skills and understanding of the associated physic concepts. One mentor mentioned,

> “I've been really impressed. I'm mentoring two students… They've been doing a lot of computer programming for me and actually it's been very enlightening that they have been able to catch on so quickly. I actually didn't expect that… So that has been a rewarding experience for me. … I got them going. I wrote some codes myself and handed it off, but they really caught on quickly.”

Question 3: How successful was the REU program according to mentors and fellows and what makes a program successful?
The faculty mentors varied on what they considered a successful research program. Some identified that actual products, such as papers, are good markers of success. However, others mentioned other markers of success. For example, one professor stated that the measure of success was more on the experience than the actual physical products that could come from research. Another marker of success that a few mentors mentioned was the ability to communicate. They saw that many of the students “understood what was going on” based on their communication skills.

> “You know the way in which I judge success and failure is… If the work done by the student outlives the student, then I think that's successful. If the work that the student has done just dies there when they leave, then that's probably a failure.”

All of the faculty thought that the program overall was successful for its main purpose. However, like the students, they expressed some general comments about the logistical issues that occurred. These issues, however, did not impede the students’ ability to do research. Another recommendation on how to improve the program from mentors included determining a schedule beforehand. Similar to the students’ comments, faculty mentioned that the times of some classes and workshops were not conducive to allowing a large amount of the day to be devoted to research. Many faculty stated their lack of awareness of when these classes and workshops were held and whether they were mandatory.

Other Themes
Other themes emerged from faculty interviews. One of these was how the mentors would approach mentoring undergraduate researchers in the future. Mentors claimed they would "not underestimate what [the students] can achieve and how quickly they can [catch on]."

Conclusion
The first summer of the REU program provided a positive experience for the involved undergraduate students. The NSF-funded students recruited included proportionally more women and underrepresented minorities than those that have received a bachelor's degree in physics (APS, 2018b, 2018a). A major goal of many REUs, especially in the STEM fields, is to increase accessibility and retainment of those marginalized in these fields. This includes women and URMs. It was not asked in the interviews, but none of the students expressed to the interviewers any discomfort in the program in terms of their reception as a woman or URM. None of the faculty discussed their students in terms of these factors, either. They discussed how well students did and how their student exceeded their expectations for the summer.

Most of the student interview participants (90%) expressed that they would still pursue research in P&A or may pursue similar research but in a different area of STEM. Especially for the women and URMs, this is a great start to bringing these marginalized students into the STEM fields and keeping them in the field. Based on the surveys and some of the interviews, all of the students felt that their research skills, both technical and more general, improved over the summer. Although some of the research skills mentioned in the surveys saw a decrease over the summer, this could be due to the lack of application of some of those skills in their research area (e.g., the use of controls may not have been utilized or applicable to their project). Since the surveys were done anonymously, we could not look at the trends in terms of demographics. Therefore, in the future, we may include demographic questions to see how these answers correlate to gender and race/ethnicity.

Although the overall experience for students and mentors was beneficial, there were some recommendations for improving the program in the future. One of the main complaints by both students and faculty was the number of classes and workshops and their scheduled times. Although some of the classes and workshops were optional, that was not conveyed to the students or faculty. As a result, some students attended the class that was not applicable to their summer research. The scheduling of the classes and workshops made it difficult to get in a rhythm of research for the students and interfered with other research-related activities, like group meetings. A suggestion to resolve these issues was better communication about the level of compulsory classes and having a more concrete schedule before the start of the program. To address other logistical complaints made by faculty and students, it is helpful start the program preparation process for lab access cards, meal cards, and other logistical items earlier in the spring semester so that they are ready upon students' arrival.

Despite the complaints, the students and faculty mentors thought the summer program went well "for the first year" and hope that it will only improve in the future. There is concern about continuing to recruit students, especially women and URMs, from institutions where research opportunities do not exist or are lacking. Aiming to get marginalized students is of great importance in the future. To date, there are no longitudinal studies prepared, but we are interested in seeing the long-term benefits of the REU program especially as it pertains to females and URMs in STEM persistence.

There is a plethora of research showing that research experiences help keep students in STEM fields, degree attainment, graduate studies, and entrance into the STEM workforce. Although this paper does not discuss these metrics given this is the first year of the program, the findings from the post-survey and the post-interviews indicate that the REU program has helped the students to solidify their path in STEM.

Acknowledgment
This project is funded by National Science Foundation (NSF Award Number: #1950795).

References

American Physics Society (APS). (2018a). Fraction of bachelor's degrees earned by women. *APS Physics. Education & Diversity*. https://www.aps.org/programs/education/statistics/upload/Fraction-of-Women-Physics-vs-STEM-PDF.pdf

American Physics Society (APS). (2018b). Physics degrees earned by underrepresented minorities (URM). APS Physics. Education & Diversity. https://www.aps.org/programs/education/statistics/minorityphysics.cfm

Blackburn, H. (2017). The status of women in STEM in higher education: A review of the literature 2007–2017. *Science and Technology Libraries*, *36*(3), 235–273. https://doi.org/10.1080/0194262X.2017.1371658

Buddie, A. M., & Collins, C. L. (2011). Faculty perceptions of undergraduate research. *Perspectives on Undergraduate Research and Mentoring*, *1*(1), 1–21. https://www.elon.edu/u/academics/undergraduate-research/purm/purm-1-1/

Craney, C., McKay, T., Mazzeo, A., Morris, J., Prigodich, C., & de Groot, R. (2016). Cross-discipline perceptions of the undergraduate research experience. *The Journal of High Education*, *82*(1), 92–113. https://doi.org/10.1080/00221546.2011.11779086

Creswell, J. W., & Creswell, J. D. (2018). Research design: Qualitative, quantitative and mixed methods approaches (5th ed.). Sage Publications, Inc.

Follmer, D. J., Zappe, S. E., Gomez, E. W., & Kumar, M. (2015). *Preliminary evaluation of a research experience for undergraduates (REU) program: A methodology for examining student Outcomes*. Paper presented at the 122nd ASEE Annual Conference and Exposition, Seattle, Washington. https://doi.org/10.18260/p.24580

Hanshaw, S., Dounas-Frazer, D., & Lewandowski, H. (2015, July 29-30). Access to undergraduate research experiences at a large research university. Paper presented at Physics Education Research Conference 2015, College Park, MD. https://doi.org/10.1119/perc.2015.pr.026

Harsh, J. A., Maltese, A. V., & Tai, R. H. (2012). A perspective of gender differences in chemistry and physics undergraduate research experiences. *Journal of Chemical Education*, *89*(11), 1364–1370. https://doi.org/10.1021/ed200581m

Hernandez, P. R., Woodcock, A., Estrada, M., & Schultz, P. W. (2018). Undergraduate research experiences broaden diversity in the scientific workforce. *BioScience*, *68*(3), 204–211. https://doi.org/10.1093/biosci/bix163

Kardash, C. A. M. (2000). Evaluation of an undergraduate research experience: Perceptions of undergraduate interns and their faculty mentors. *Journal of Educational Psychology*, *92*(1), 191–201. https://doi.org/10.1037/0022-0663.92.1.191

Madan, C. R., & Teitge, B. D. (2013). The benefits of undergraduate research: The student's perspective. *The Mentor: An Academic Advising*, *15*, 1–3. https://doi.org/10.26209/MJ1561274

Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research experiences. *Science*, *316*(5824), 548–549. https://doi.org/10.1126/science.1140384

Sheng, H., Landers, R. G., Liu, F., & Nguyen, T. (2014). A longitudinal study on the effectiveness of the research experience for undergraduates (REU) program at Missouri University of Science and Technology. Paper presented at the 121st ASEE Annual Conference and Exposition, Indianapolis, Indiana. https://doi.org/10.18260/1-2--19955

Wei, Z. (2014). Research experience for undergraduate students and its impact on STEM education. *Journal of STEM Education: Innovations & Research*, *15*(1), 32–39. http://hdl.voced.edu.au/10707/319682

Wilhelm, J., & Fisher, M. H. (2016). Creating academic teacher scholars in STEM education by preparing preservice teachers as researchers. In B. Doig, J. Williams, D. Swanson, R. B. Ferri, and P. Drake (Eds.), *Interdisciplinary Mathematics Education: The State of the Art and Beyond* (pp. 281–296). Springer.

Youssef, G., Ainsworth, E. A., Shapiro, C. A., Sayson, H. W., Levis-Fitzgerald, M., & Chang, J. (2016). Comprehensive research experience for undergraduates. Paper presented at the 123rd ASEE Annual Conference and Exposition, New Orleans, Louisiana. https://doi.org/10.18260/p.26547

Appendix A. Survey Questions (adapted from Kardash, 2000)

Question 1-24. To what extent do you feel you can…?
Rate each skill on a 5-point scale ranging from 1 (not at all) to 5 (a great deal).

1. Understand current concepts in the field of Physics/Astronomy.
2. Understand concepts in the area of Physics research you are working on in this program.
3. Make use of primary scientific research literature in the field of Physics/Astronomy.
4. Make use of primary scientific research in the area of research you are working on in this program.
5. Identify a specific question for investigation based on the research in the field of Physics/Astronomy.
6. Identify a specific question for investigation based on the research in the area of research you are working on in this program.
7. Design a research study in the field of Physics/Astronomy.
8. Design a research study in the area of research you are working on in this program.
9. Understand the importance of "controls" in research in the field of education.
10. Understand the importance of "controls" in research in the area of research you are working on in this program.
11. Observe and collect data in the field of Physics.
12. Observe and collect data in the area of research you are working on in this program.
13. Statistically analyze data in the field of Physics/Astronomy.
14. Statistically analyze data in the area of research you are working on in this program.
15. Interpret data and research results in the field of Physics/Astronomy.
16. Interpret data and research results in the area of research you are working on in this program.
17. Relate results to the "bigger picture" in the field of Physics/Astronomy.

18. Relate results to the “bigger picture” in the area of research you are working on in this program.
19. Orally communicate the results of research projects in the field of Physics/Astronomy.
20. Orally communicate the results of research projects in the area of research you are working on in this program.
21. Write a research paper for publication in the field of Physics/Astronomy.
22. Write a research paper for publication in the area of research you are working on in this program.
23. Think independently in the field of Physics/Astronomy.
24. Think independently in the area of research you are working on in this program.

Question 25-48. Indicate the extent to which you believe that the internship can/will help you develop each skill.
Rate each skill on a 5-point scale ranging from 1 (not at all) to 5 (a great deal).

25. Understand current concepts in the field of Physics/Astronomy.
26. Understand concepts in the area of research you worked on in this program.
27. Make use of primary scientific research literature in the field of Physics/Astronomy.
28. Make use of primary scientific research literature in the area of research you worked on in this program.
29. Identify a specific question for investigation based on the research in the field of Physics/Astronomy.
30. Identify a specific question for investigation based on the research in the area of research you worked on in this program.
31. Design a research study in the field of Physics/Astronomy.
32. Design a research study in the area of research you worked on in this program.
33. Understand the importance of “controls” in research in the field of Physics/Astronomy.
34. Understand the importance of “controls” in research in the area of research you worked on in this program.
35. Observe and collect data in the field of Physics/Astronomy.
36. Observe and collect data in the area of research you work on in this program.
37. Statistically analyze data in the field of Physics/Astronomy.
38. Statistically analyze data in the area of research you work on in this program.
39. Interpret data and research results in the field of Physics/Astronomy.
40. Interpret data and research results in the area of research you work on in this program.
41. Relate results to the “bigger picture” in the field of Physics/Astronomy.
42. Relate results to the “bigger picture” in the area of research you work on in this program.
43. Orally communicate the results of research projects in the field of Physics/Astronomy.
44. Orally communicate the results of research projects in the area of research you work on in this program.
45. Write a research paper for publication in the field of Physics/Astronomy.
46. Write a research paper for publication in the area of research you work on in this program.
47. Think independently in the field of Physics/Astronomy.
48. Think independently in the area of research you work on in this program.

Question 49-54. Indicate the extent to which you believe the following statements are true for yourself.
Rate each skill on a 5-point scale ranging from 1 (not at all) to 5 (a great deal).

49. I have the ability to have a successful career as a Physics/Astronomy educator/researcher.
50. I have the ability to be a successful researcher in my future career.
51. I have the ability to conduct successful research.
52. I possess the motivation and persistence required for a career as a Physics/Astronomy

researcher.
53. College faculty have encouraged and promoted my interest in pursuing a career in Physics/Astronomy.
54. College faculty will encourage and promote my interest in pursuing a career in Physics/Astronomy.