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Prioritizing Expectations Through Professional Development on Mentorship for Physics Undergraduate Research

Heather McCall, Cameron Richards, Jennifer Wilhelm, & Christopher Crawford

University of Kentucky, United States

Abstract: Research Experiences for Undergraduates (REU) programs in Science, Technology, Engineering, and Mathematics (STEM) aim to improve students' research skills, disciplinary knowledge, and career confidence. However, faculty mentors often lack formal training in effective mentoring practices. This study investigates the impact of professional development (PD) on faculty mentors in a physics REU program, focusing on communication and setting expectations, using a modified “Entering Mentoring” PD curriculum. A mixed-methods design explored three research questions: (1) What expectations do mentors establish, and how might they differ? (2) What realities do mentors experience, and how do expectations evolve? (3) What effect did PD have on mentoring, and how do interview and survey data converge to explain REU participant growth? Data were collected through semi-structured interviews with eight faculty mentors, post-program CIMER mentor surveys, and student surveys measuring their confidence in research abilities. Qualitative data were analyzed using constant comparative methods, while quantitative data were analyzed using descriptive statistics and t-tests to assess growth among two REU cohorts: one with mentor PD and one without. Results revealed that mentors faced challenges such as affording independence to mentees and selecting achievable research projects, regardless of experience. Despite these challenges, mentors focused on the research process, rather than the product, providing students with an authentic research experience. This approach led to significant perceived growth in students' general research skills, as reported by both mentors and mentees. Synthesis of qualitative and quantitative data showed that the PD program positively influenced mentoring practices and student outcomes. The 2024 PD-trained cohort showed statistically significant growth in research independence (Q24: $d=0.86$) and career confidence (Q49: $d=0.62$) compared to the non-PD 2023 cohort. This study emphasizes the importance of PD in improving mentoring practices and enhancing student growth, offering valuable insights for future REU programs.

Keywords: Research Experience for Undergraduates (REU); Professional Development (PD); Mentoring Practices; Mixed-Methods

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Introduction

Research Experiences for Undergraduates (REU) programs supported by the National Science Foundation (NSF) have proven beneficial for student persistence and career aspirations, particularly for students in science, technology, engineering, and mathematics (STEM) (Stephens et al., 2017). The focus of NSF funded REU programs is to conduct authentic research with a faculty mentor at a host university with the goal of building knowledge, developing research skills, and learning about educational and career pathway options in STEM (National Science Foundation, 2024). The quality of a mentoring relationship can significantly impact student perceptions of the REU program and ultimately their persistence in STEM fields (Stephens et al., 2017). As such, a key element of successful REU programs has been the student-faculty mentoring relationship (Limeri et al., 2019). While several studies have identified the characteristics of highly effective mentors (Shanahan et al., 2015; Walkington et al., 2020), others have shown the effects of negative mentoring experiences and suggest ways they can be prevented (Limeri et al., 2019). Formal mentor training is not common in doctoral student education prior to achieving faculty status, thus a prominent suggestion for improving mentoring practices is to incorporate professional development and training for the faculty mentors (Baker et al., 2022). This mixed-methods study provides a unique perspective of faculty mentor experiences as they participated in a mentoring workshop prior to a physics/astronomy REU program at a public, high research university in the southeastern United States.

Background

The benefits of REU programs for undergraduates have been well explored and include improved STEM disciplinary knowledge and practices, research skills and experimental design, confidence in research abilities, and development of a professional identity (Stephens et al., 2017). In addition, mentors can also benefit from participating in the research experience. Studies have shown that mentors gain a sense of personal fulfillment and sharpened leadership skills (Stephens et al., 2017), in addition to strengthened teaching abilities of undergraduate students and courses (Dolan & Johnson, 2010). In evaluating mentor experiences, studies have explored the motivations and barriers for faculty willingness to mentor. Barriers often include time needed to guide a mentee through research, lack of funding from the institution to support undergraduate research, and lack of recognition for the research that is accomplished (Baker et al., 2015; Ferguson, 2023). A case study of mentors for undergraduate researchers also found that mentors experience significant difficulty supervising students who lose motivation over the summer and less experienced faculty were unable to adopt strategies to reengage the intern with research responsibilities (Copenheaver & Shumaker, 2022).

Mentors maintain a central role in REU experiences, taking on the responsibility of assigning a research project, monitoring student progress, teaching relevant concepts and skills, providing access to research labs, and serving as a professional role model within scientific research communities (Stephens et al., 2017). Research has also shown that direct faculty interactions are key in improving undergraduate science self-efficacy, scientific identity, and scholarly productivity (Joshi et al., 2019). Considering the importance of the faculty mentor, it is imperative they have adequate knowledge of how to be an effective mentor and receive institutional support. With a lack of formal training or continuous professional development, mentors may not be equipped with best-practice strategies and rely heavily on experience when navigating challenges with undergraduate researchers. These findings from literature suggest that to have an effective REU program, institutions must provide a supportive culture for faculty to engage in mentoring experiences, leading to positive outcomes for both the mentor and the mentee.

Previous research has primarily focused on the student or mentee experience during an REU program while few studies have examined faculty experiences (Copenheaver & Shumaker, 2022). And despite recommendations for access to professional development (PD) on mentorship, few studies have examined the effects of a PD on REU program outcomes for both the mentor and mentee. “Even though faculty are the cornerstone of a successful UR experience, the contributions and the benefits to this demographic have often been overlooked” (Baker et al., 2022). To contribute to the gaps in literature, this study aimed to explore the REU mentor experience after participating in a professional development on mentoring physics undergraduate research with a mixed methodology to gain an in-depth perspective of the effects of trained mentors on the overall mentorship experience.

For this project, a training session for mentors was adapted from "Entering Mentoring", a well-studied and well-known mentorship education curriculum (Byars-Winston & Dahlberg, 2019) accessed through the Center for the Improvement of Mentored Experiences in Research (CIMER) mentor/mentee training resources specifically for physics and astronomy research. The curriculum has been used at several CIMER partner institutions, and through quasi-experimental methods has shown that participation in "Entering Mentoring" PD improves mentoring competence (Limeri et al., 2019). The modified session provided at our REU site focused on four aspects that would be most relevant to mentors based on feedback from faculty on challenges with undergraduate researchers in previous years of the program. When considering best-practices of faculty research mentors that could be emphasized in the training session, Walkington et al. (2020) observed that effective mentors maintain high standards and communicate clear expectations to provide an appropriate challenge with a 'safety net' environment for students. Thus, the main training focus, which became the subject of this research, was the establishment of expectations and maintaining effective communication. Findings from this study can inform other REU or undergraduate research program directors and stakeholders in further improving similar programs and use of Professional Development for faculty mentors.

Literature Theoretical Framework

Mentorship in educational settings is often seen as a traditional apprenticeship model where an experienced mentor guides a less experienced protégé through discipline-specific tasks (Kardash, 2000). Mentoring undergraduate students has expanded this view to include all the support faculty mentors provide to young adult mentees. Beyond intellectual support in teaching and learning, mentors offer social and personal support, developing unique relationships in the research training context (Byars-Winston & Dahlberg, 2019). Our operational definition of mentoring, from the National Academy of Sciences consensus study (Byars-Winston & Dahlberg, 2019), establishes a framework for this study. Mentoring is defined as a "collaborative learning relationship that proceeds through stages over time with the primary goal of helping a less experienced person acquire the competencies needed for success in their chosen career" (Byars-Winston & Dahlberg, 2019, p. 130). This relationship is mutually beneficial for both mentors and mentees as a social engagement in contextualized physics/astronomy research, furthering career opportunities.

In line with developmental and learning theories related to mentorship, adult education theory provides a framework for mentor growth throughout the mentorship experience. Adult learning theory views the adult learner as self-directed, reflective, and critical of past experiences (Dominguez & Hager, 2013), which applies to both mentors and undergraduate mentees as emerging adults. This framework aligns with Continuous Professional Development (CPD) practices, emphasizing impactful methods and faculty engagement in teacher professional development (Njenga, 2023). CPD typically includes all forms of learning aimed at enhancing professional competence by gaining new knowledge and skills beyond initial education or training. Faculty as professionals can participate in mentor CPD with the aim of improving mentorship best-practices, extending competencies they have acquired in previous training or experiences (Njenga, 2023). Recognizing mentors as adult learners with unique characteristics, the framework suggests that mentors should receive contextualized and self-directed professional development to encourage independence and reflective practices among themselves and their mentees.

Research shows mentors vary in their approach to mentoring, balancing control and independence for their mentee. An autocratic style involves mentors driving all decision-making, while laissez-faire provides little direction (Houser et al., 2013). Houser et al. (2013) found that the democratic style, between autocratic and laissez-faire, received the most positive feedback from students. The democratic style involves consulting with students, considering their research ideas, and positioning the mentor as a facilitator, aligned with a constructivist view of learning. In this model, mentors facilitate knowledge, provide active learning experiences, and encourage reflection. Learning is individualized based on the mentee's prior knowledge, and the environment allows for continuous exploration with guidance. Though Houser et al. (2013) noted no "best" mentoring style, they found that democratic mentoring provided a positive experience for REU students, who valued the balance of direction and independence.

Since mentorship is a symbiotic relationship, integrating a social theoretical framework is valuable. Social interactions between mentors and mentees influence situated learning in discipline-specific research contexts. Engaging in social learning experiences establishes a community of practice. This theory fits well with mentoring as undergraduates are socialized into the scientific research profession, and mentors aid in building social networks for information sharing (Dominguez & Hager, 2013). Within their communities, mentees contribute fresh ideas while building knowledge through established networks. Mentors, as part of a community of practice, build relationships with other faculty, exchange information, and improve networking. Research shows that continuous professional development should also nurture a community of practice among mentors, contextualized within physics research (Njenga, 2023).

Research Questions

By offering structured professional development and guided discussion among mentors about setting and communicating expectations, our research aimed to investigate the potential effects of the PD on the mentoring experience and how faculty develop effective mentoring practices. The framework of adult education and communities of practice provides a lens on the relationships that are established and how both mentors and mentees grow throughout the course of the REU program. This study will primarily focus on faculty perspectives to provide crucial insight into the experiences of mentors, which has been limited in empirical research (Ferguson, 2023).

This mixed-methods parallel convergent study is guided by the following research questions:

1) What expectations do mentors establish? How might they differ among faculty?
2) What realities do mentors experience? How might have expectations changed throughout the program?
3) What effect did the professional development have on the mentoring experience and how might the interview data converge with survey data to explain REU participant gains?

Methods

Research Design

A parallel convergent design will be used to collect quantitative data and qualitative data at the same time, analyzed separately, then merged (Creswell & Plano Clark, 2017). In this study, qualitative interview data will explore faculty experiences mentoring and their perceptions of the mentorship professional development. The quantitative survey data from both faculty mentors and undergraduate mentees in two cohorts will further illustrate growth of the mentee due to the REU program and provide a comparison cohort group of non-trained mentors. The two forms of data will bring greater insight into the effects of faculty mentorship training than would be obtained by either type separately.

Study Context

The REU program at our research site is a 10-week program from May through July and is in its fourth year of operation partially funded through NSF grants. The REU research site goals are to a) Enhance interest in physics, astronomy, and technology of undergraduate participants from rural areas where there are limited research opportunities, b) Train participants with skills relevant to graduate research in contemporary fields of physics and enhance the STEM workforce, and c) Strengthen research ties between the participating university and other undergraduate post-secondary institutions (with limited resources) to provide technical expertise and research and educational opportunities.

Throughout the program, morning workshop sessions were offered to the undergraduates which focused on building scientific skills and computer programming using Python in various physics contexts. Information sessions were also provided periodically on writing scientific research reports and graduate school opportunities. A program expectation of students is completion of a mid-term and final scientific report on their summer research project along with a final poster presentation.

A PD experience was provided for all faculty mentors at the onset of the 2024 program, with a focus on emphasizing and reiterating best-practice guidance when engaging with undergraduates in a mentorship capacity. This mentoring PD lasted approximately 70 minutes with eight mentors, one graduate student assistant, and one instructor in attendance. The PD focused on best practices for engaging with undergraduate mentees, with particular attention given to areas identified as most relevant based on previous feedback from mentors. These key aspects included establishing clear expectations and maintaining effective communication, being a positive role model while promoting a sense of belonging in STEM, addressing diversity, and identifying elements of effective mentoring. The session incorporated situation case studies to help faculty reflect on real-world scenarios and consider how they might navigate specific mentoring challenges. Mentors were also asked to reflect on whether they have a core mentoring philosophy, encouraging them to define their personal approach to mentoring. Additionally, the PD emphasized the importance of providing both academic and emotional support to mentees. Finally, ample open discussion time was provided for mentors to pose questions, share insights, and engage in meaningful dialogue about their experiences, helping to foster a supportive mentoring community within the program.

Participants

In this 2024 cohort of the Physics and Astronomy REU, 28 undergraduate students participated in the program from five different regional universities. Most faculty participants were from the main research site while three were from physics departments in other regional colleges within the state. Program participants were each assigned to work with a mentor on a specific research project with most participants being the sole undergraduate paired with a faculty member. The faculty mentors had a wide range of experience, some mentoring for the first time, while others had 10 or more years of experience mentoring undergraduates with research.

The 2023 cohort of Physics and Astronomy REU included 21 undergraduate students from nine different institutions where four were regional colleges within the state. Similar to the 2024 cohort, program participants were assigned to work with a mentor where some of the faculty mentors were mentoring for their first time. All other aspects of the program were the same, with workshops for the undergraduate students and required completion of a midterm and final scientific research report with a poster presentation.

Data Sources

Qualitative data came from mentor interviews conducted using a protocol and semi-structured format to discuss when each mentor joined the REU program; how their approaches to research, teaching, and mentoring have changed by being an REU faculty mentor; how they viewed success for their REU participant(s); their views on how to improve the REU program in the future; and how, if in any way, the "Entering Mentorship" professional development presentation helped them with best practices for mentoring an undergraduate research student, as well as ideas for future professional development in mentorship best practices. The final post-interview protocols are provided in Appendices.

Quantitative data came from two survey metrics. To measure mentor perceptions of the fellows' growth due to the program, all NSF-funded mentors were invited to participate in a CIMER survey, administered through the CIMER portal. The survey included questions regarding the perceived growth of the intern in three areas: thinking and working like a scientist (e.g., analyzing data for patterns), personal mindset towards research (e.g., confidence in ability to do research), and general scientific research skills (e.g., writing scientific reports or papers). The survey began with the question, "How much did your mentee GAIN in the following areas as a result of his or her most recent research experience?", followed by several observable skills in each category. Mentors responded along a 5-point Likert scale (1: no gains, 5: great gain) with a sixth option for "Not Applicable" for each skill.

To quantitatively measure the interns' perception of growth due to the program, all undergraduate students were invited to participate in a survey measuring perceptions of their ability and confidence doing physics/astronomy scientific research. The survey used modified questions from a study evaluating undergraduate research experiences (Kardash, 2000), which established the validity of the survey metric with an internal consistency of 0.90.

Undergraduates responded to questions along a 5-point Likert scale (1: not at all, 5: great deal). The modified survey question items are provided in Appendices.

Procedure

Figure 1

Mixed-Methods Parallel Convergent Design Procedure Flow Chart

For the study, a pre-survey was provided to only the undergraduate researchers at the beginning of the program, but most of the data collection was performed at the end of the 10-week program. The post-survey was provided to the undergraduate researchers as was the CIMER survey for the mentors in the final week of the program. At the same time as the quantitative post-survey data was collected, qualitative interviews were conducted with the mentors immediately following the conclusion of the program. Both the quantitative data and qualitative data were analyzed separately, then merged for final analysis and integration of results. Refer to Figure 1 for a diagram illustrating the methodological process.

Data Analysis

The qualitative data collected from the eight (N=8) mentor interviews were analyzed using the constant comparative method, a technique commonly employed in grounded theory research. This approach involves systematically comparing data segments, codes, and categories throughout the research process to identify patterns and develop emerging themes (Charmaz & Smit, 2007). Initially, graduate researchers independently coded and analyzed the data, identifying key themes as they emerged. These themes were cross-checked by an experienced researcher to ensure consistency and rigor in the analysis. This iterative process facilitated the refinement of the themes and the development of a deeper understanding of the data.

For the quantitative analysis, a descriptive statistical analysis was conducted on the CIMER survey due to the low sample size of mentors (N=7). An inferential statistical approach was employed for the modified Kardash (2000) survey provided to the fellows. There were approximately the same number of responses from participants in both the pre-and post- survey and from 2023 (N= 16) to 2024 (N=17). To assess significant changes in the participants' responses, a two-sample t-test was first performed using the Excel software analysis tool-pack to compare pre- and post-test results for the 2023 and 2024 cohorts of REU participants (Bandalos, 2018). The analysis determined whether there was statistically significant growth for either cohort analyzed separately. Additionally, an independent t-test was conducted to explore potential differences in growth between the two cohorts, examining specific subsections of the survey to assess statistical significance.

In this mixed-methods approach, the integration of the qualitative and quantitative results allowed for a comprehensive analysis of the data, providing a more nuanced understanding of the research outcomes, and validation of the qualitative themes with quantitative trends. The final analysis involved synthesizing the themes and statistical results, highlighting areas where qualitative and quantitative data aligned, and exploring potential discrepancies that could offer further insights into the research questions.

Results

Research Question 1: Mentor Expectations

To answer the first research question, what expectations do mentors establish and how might they differ among faculty, the analysis of faculty interviews produced emergent themes that described the mentor experience. Themes aligned within two categories that help illustrate not only how mentors set expectations for their mentees, identified by (1) struggles mentoring undergraduate students, but also the mentor expectations of themselves and program outcomes, identified by (2) personal priorities to be an effective mentor.

Struggles mentoring undergraduate students

All eight of the faculty interviewed mentioned a challenge or struggle faced when mentoring an undergraduate student in research, regardless of their years of experience. The following quotes illustrate the different struggles faced by faculty mentors when establishing expectations.

Affording levels of independence and recognizing the individuality of mentees:

> I think this student in particular really needed me as a mentor to try to make him think on his own more. And he was, he's really gung-ho, and he'll really do things, but, but the second anything came up, he would, you know, want my hand… So I think this summer, I really attempted to not, I purposely didn't give answers as easily. I made him look things up… I really wanted him to go read, you know, do some search and bring it to me and say, 'Look, I read this paper, this paper, and they did this, and they did...' and that didn't really happen the way I wished. (Mentor, 10+ years)

Selection of an achievable project and relevant connection to research:

> I initially thought this would be a project that, you know, the student could get significant results in, like, during the program. I think what I learned afterwards was that, like, maybe that was a little too ambitious, because, and again, I think it depends a lot on, like, the student who's coming in, you know, how much experience that they have, like programming, for example, and so in the end, my own expectations for what we were gonna, how far we would get in the project had to change. (Mentor, 1 yrs)

Frequency of meetings to gauge comprehension:

> If I typically meet with them once a week, with the REU student, I quickly learned that, you know, she would get stuck on things, and a lot of them, like, she couldn't get past until we met again and talked about it, and so that over the first couple weeks, I learned that it was better to have short meetings like almost every day, so that if she was, you know, running into something, we could talk about it more frequently, and that could really help, like, move things along. (Mentor, 1 yrs)

> But I do try to be a little bit more hands off... And sometimes it's really good, and sometimes I have to be more hands on. So I try to start with a little bit more hands on then brake, come off the brakes, and then I see that they need more than- more and go and more. But you know, it's going to be a give and take between both. (Mentor, 2 yrs)

Research Question 2: Realities for Mentors

To answer the second research question, what realities do mentors experience, in addition to the struggles mentors faced when establishing expectations, the second theme of personal priorities to be an effective mentor further illustrated their experience and expectations of themselves as a mentor.

Personal Priorities to be an effective mentor

Faculty articulated personal values in their interpretation of how to be an effective mentor learned through their experiences mentoring. Variations existed based on the type of research being done by the faculty mentor and years of experience.

Providing tangibility of research through lab/observational experiences:

> In my lab, we make crystals, and then we do experiments on them. And so my students these summers have spent most of their time working on crystal growth projects. And so I think it is, I think it's quite I do enjoy it when the students do end up making a crystal at something, right? We start from, like, raw elements, and then we do a little bit of solid-state chemistry, and then all of a sudden, like, a week later, there's something completely different that's on there, you know, that's standing in front of them. (Mentor, 4 yrs)

Establishment of background knowledge:

> I picked her from among other candidates, because she has mathematical background, So I knew that I could give her some problem right away and teach her a bit of coding. I always find that if you let the students code and they get some intermediate results that sort of reinforce their confidence that they they're actually reproducing something rather than just keep reading papers… and when she arrived here, just spot on, perfect. She knows all the fundamentals. (Mentor, 1 yrs)

Focus on the process, not the product:

> Don't expect them to advance your research agenda. Maybe I think that's the first thing, just like, just give them a good experience and they learn something. They, more importantly, they sort of see what should they choose to go for PhD, this is what they're going to experience. (Mentor, 1 yrs)

> The most recent experience, it ended so abruptly. The student...wanted to do the poster and finish the program. I do not know; there was some cut off with the program. And once the program ended, he didn't get in touch. So I don't even know if he answered. There was a very concrete...research question, which I thought he could answer, and I wanted him to answer it, and I wanted to know the answer. Once we understood there was a question, I wanted to know the answer. I don't even know if he answered it. So that's sort of a challenge, [he had a] slightly different mindset. (Mentor, 1 yrs)

Quantitative Analysis of CIMER mentor survey

Findings from the CIMER survey provided further insight into the realities of faculty experiences with post-program measures of faculty perceptions of student growth due to the program. Results from the CIMER post-program mentor survey indicate overall perceived improvements for REU fellows in their ability to think and work like a scientist, conduct research, and attitudes and behavior. Seven mentors completed the survey out of 11 invited to participate. Overall, a majority of mentors believed the research experience was good or excellent. Survey results organized by average perceived growth for each element can be seen in Table 1. The areas where mentors saw the most growth were gains in general skills, in particular working with a computer (M=4.286) and preparing a scientific poster (M=4.286). High gains were also witnessed in conducting observations in the lab or field (M=4.750), although several mentors (3 out of 7) provided “not applicable” as a response. In addition, growth was also seen in the mindset towards research, specifically understanding what everyday research work is like (M=4.286) and confidence in research ability (M=4.143).

The areas where mentors saw the lowest growth were in students’ ability to think and work like a scientist, including understanding connections among scientific disciplines (M=2.857) and formulating a research question that could be answered with data (M=3.143). A notable area of moderate growth in students’ mindset towards research was the ability to work independently (*M*=3.571). In addition, the attitude and behavior with the lowest frequency was trying out new ideas or procedures on his or her own (*M*=3.429).

Table 1

CIMER Mentor Survey Results

CIMER observable skill	Average perceived growth (*M*)	Gains area
Conducting observations in the lab or field[a]	4.750	Skills
Preparing a scientific poster	4.286	Skills
Working with computers	4.286	Skills
Understanding what everyday research work is like	4.286	Research mindset
Confidence in his or her ability to do research	4.143	Research mindset
Analyzing data for patterns	4.000	Thinking like scientist
Identifying limitations of research methods and designs	3.714	Thinking like scientist
Understanding the relevance of research to his or her coursework	3.714	Thinking like scientist
Ability to work independently	3.571	Research mindset
Comfort in working collaboratively with others	3.500	Research mindset
Using statistics to analyze data	3.333	Skills
Understanding journal articles	3.286	Skills
Conducting database or internet searches	3.286	Skills
Managing his or her time	3.286	Skills
Formulating a research question that could be answered with data	3.143	Thinking like scientist
Defending an argument when asked questions	3.143	Skills
Understanding the connections among scientific disciplines	2.857	Thinking like scientist

Note: *N=7*

[a] Several N/A responses from mentors

Research Question 3: Effects of PD on Mentoring Experience

To examine the direct effects of the professional development on faculty, a thematic analysis revealed several mentioned benefits for faculty. Interviewed faculty that attended the "Entering Mentoring" session noted the most beneficial aspect was the camaraderie achieved through discussion of personal mentoring techniques.

> What I found really beneficial about that was the other REU faculty mentors.… People just shared their past experiences or, like, what they found worked or didn't work. And I found that really helpful just to, like, hear, hear their experiences.…Just general, thinking about some of the things that [was] presented, I mean, like, one of the things was, like, discussing expectations with your mentee, and so hearing that in that session, like at the beginning of the program, I had it on mind, my mind that, like, okay, like, I should, you

know, talk to her about this and make it clear, or thinking about, like, her future goals and, you know, trying to make the program most useful for that… (Mentor, 0 yrs)

Even experienced mentors were able to find benefits from attending the PD session.

It's sort of reinforced. It did reinforce a few things. Like, you know, trying to make sure that the students are not, you know, students struggling is one thing, but a student struggling and floundering, yeah, yeah, floundering and then just left to flounder. (Mentor, 4 yrs)

I mean, it's good to hear other people and recognize what they're doing and then think, Am I doing enough? Maybe I should do a little more. Maybe I should so it keeps you conscious. (Mentor, 10+ yrs)

Quantitative analysis of REU survey

To examine possible indirect effects of the professional development on student outcomes, a statistical analysis comparing the 2024 mentor-trained cohort with the 2023 non-trained cohort was performed. Cronbach's alpha was calculated to assess the internal consistency of the survey instrument. The resulting value of α=0.968 for the 2024 cohort data and a value of α=0.964 for the 2023 cohort data indicates excellent reliability for both sets of survey data ($\alpha > 0.90$). The means for the pre-, post-, and gains (difference post from pre) for each cohort can be seen in Table 2, divided by survey question group. For the initial analysis comparing pre- to post-test means for the 2024 and 2023 cohorts, there was statistically significant differences for questions 1-24 indicating positive growth in "confidence in research and scientific skills (in general)" for both cohorts ($p<0.001$ for both).

Table 2

Pre-, Post-, and Gain means for 2024 PD-trained cohort and 2023 cohort

Variable	Q1-24 *M*	Q25-48 *M*	Q49-54 *M*
2024			
Pre-	3.103	4.451	4.039
Post-	3.939	4.102	4.377
Gains	0.836*	-0.348*	0.337
2023			
Pre-	3.365	4.326	4.471
Post-	4.029	3.776	4.348
Gains	0.627*	-0.534*	-0.122

*p<.05

For questions 25-48 there was statistically significant differences in pre- to post-test means indicating negative growth or losses in “confidence in research and scientific skills as a result of the program” for both cohorts ($p<0.001$ for both). In comparing only pre- and post- test differences, both cohorts experienced gains in confidence in research and scientific skills and a decrease in perception of the program’s contribution to the improvement of those skills. For questions 49-54 measuring confidence in a future career path as a physicist/astronomer and researcher, there was no statistically significant difference in pre- to post-test means for either cohort, but it is worth noting that the mean pre-test for the 2023 cohort was very high (M=4.47) in comparison with the 2024 cohort (M=4.039) and thus may have experienced a ceiling effect (Bandalos, 2018). Because the average for the 2023 cohort was at the highest end of the scale, there likely was little room for improvement and difficult to detect changes or differences from pre- to post survey results.

In further analysis of a difference in gains for the 2024 cohort versus the 2023 cohort, an F-Test was first performed to check the assumption of equal variances between groups. The F-test indicated no significant differences in variances between the 2024 and 2023 cohort gains for all survey questions. The independent t-Tests assuming equal variance results can be seen in Tables 3-5. For questions 1-24, there was a statistically significant difference in gains for the two cohorts ($p<0.0167$) with an average gain of M=0.836 for the 2024 cohort while 2023 had a gain of M=0.627. Comparing individual question gains and differences between the cohorts, the questions with the largest gains for the 2024 cohort were Q4 (“Make use of the primary scientific research literature in the area of research you are working on in this program”) (d=0.95), Q18 (“Relate results to the ‘bigger picture’ in the area of research you are working on in this program”) (d=0.63), and Q24 (“Think independently in the area of research you are working on in this program”) (d=0.86).

For questions 25-48, there also was a statistically significant difference in gains for the two cohorts ($p<0.006$) with an average gain of M= -0.348 for the 2024 cohort and M= -0.534 for the 2023 cohort. Because the gains were negative for both groups indicating losses, the 2024 cohort experienced significant mitigated losses in the perception of the program contribution to the improvement of research and scientific skills compared to the 2023 cohort. Analyzing individual questions again revealed the questions with the largest minimized loss for the 2024 cohort were Q32 (“Design a research study in the area of research you will be working on in this program”) (d=0.45), Q42 (“Relate results to the ‘bigger picture’ in the area of research you will be working on in this program”) (d=0.61), and Q44 (“Orally communicate the results of research projects in the area of research you will be working on in this program”) (d=0.66).

For questions 49-54, there was a statistically significant difference in gains for the two cohorts ($p<0.010$). In addition, the 2024 cohort experienced a positive gain (M=0.337) while the 2023 cohort experienced a loss (M= -0.122) in confidence of future career path as a physicist/astronomer. Comparing individual questions revealed the questions with the largest gains for the 2024 cohort were Q50 (“I have the ability to be a successful researcher in my future career") (d=0.98) and Q49 ("I have the ability to have a successful career as a Physics/Astronomy educator/researcher") (d=0.62).

Table 3

t-Test Comparison of Q1-24 Gains for 2024 & 2023 Cohorts

Parameter	Gains cohort 2024[a]	Gains cohort 2023
Mean	0.8360965	0.6272282
Variance	0.0773721	0.0923911
Observations	24	24
df	46	
t Stat	2.4834556	
P(T<=t) two-tail	0.01672	
t Critical two-tail	2.01289	

Note: Two-sample t-Test assuming equal variances

[a] PD-trained mentors

Table 4

t-Test Comparison of Q25-48 Gains for 2024 & 2023 Cohorts

Parameter	Gains cohort 2024[a]	Gains cohort 2023
Mean	-0.348897	-0.5343137
Variance	0.0476128	0.0541571
Observations	24	24
df	46	
t Stat	2.8473756	
P(T<=t) two-tail	0.00657	
t Critical two-tail	2.01289	

Note: Two-sample t-Test assuming equal variances

[a] PD-trained mentors

Table 5

t-Test Comparison of Q49-54 Gains for 2024 & 2023 Cohorts

Parameter	Gains cohort 2024[a]	Gains cohort 2023
Mean	0.3374510	-0.1221034
Variance	0.0997079	0.02804102
Observations	6	6
df	10	
t Stat	3.1494438	
P(T<=t) two-tail	0.01034	
t Critical two-tail	2.22813	

Note: Two-sample t-Test assuming equal variances

[a] PD-trained mentors

Convergence of Qualitative and Quantitative Data

To examine how the survey data converges with the interview data to explain the REU participant growth, the first question that guided the analysis was: Did the mentors from the 2024 cohort focus on or specifically prioritize any of the areas where there was significant positive growth? The qualitative interviews indicated that mentors prioritized valuing the process, not the product, which relates to participants experiencing a significant level of growth overall in confidence in scientific research skills and abilities for survey items Q1-24. More specifically, participants experienced significant gains in survey items Q18 and Q42, both measuring ability to “Relate results to the ‘bigger picture’ in the area of research you will be working on”. In addition, mentors perceived the largest growth in participant scientific research skills and abilities according to the CIMER survey, which included “conducting observations”, “working with a computer” and “preparing a scientific poster”.

From the qualitative interviews, mentors discussed challenges with selecting an achievable and relevant project for students to complete in the relatively short 10-week program. The mentors’ focus on selecting an authentic physics/astronomy research project translated to REU growth in learning what everyday research is like and career options, related to the significant positive growth in survey items Q49-54 measuring their confidence in a future career path as a physicist/astronomer researcher/educator. Participants also perceived a minimized loss for Q32 attributing the program to their ability to “Design a research study in the area of research you will be working on”. In addition, mentors perceived large growth in undergraduate mindset towards research as measured in the CIMER survey, including “understanding what everyday research is like” and “confidence in research ability”.

The qualitative interviews indicated mentor focus on affording levels of independence in research, an area where participants did experience a significant level of growth as measured by large gains in survey item Q24, “Think independently in the area of research you are working on”. While the interns experienced significant growth, the mentors perceived only moderate growth in “ability to work independently” and low frequency of witnessing the intern “trying out new ideas or procedures on his or her own” from the CIMER survey.

Discussions

The aim of this study was to investigate the experiences of physics/astronomy faculty mentors in an REU program after participating in a mentorship professional development focused on improving communication and setting suitable expectations for undergraduate researchers. The use of both qualitative interview data from the mentors and quantitative survey data from mentors and mentees provided rich insight into the positive effects of the PD on the mentorship experience.

The first research question explored what expectations mentors establish and how they may differ among faculty. Post-program interviews showed most mentor-mentee pairings had an informal discussion regarding the expectations of the mentees for the research. Most commonly, mentors set expectations for the workload or working hours that they wanted to see from their undergraduate REU participants and would over time establish patterns for interactions. Mentors shifted more towards an explicitly directive style with undergraduates when setting expectations as they likely required more guidance on selecting and accomplishing a research task or project. Despite valuing the balance of control and independence, mentors were less democratic with overall expectations, with only one mentor mentioning consulting with and listening to the intern about what their expectations and goals were for the program. These findings align with previous studies observing similar challenges of mentors limiting undergraduate student opportunity for autonomy and misaligned expectations (Limeri et al., 2019).

Regardless of the years of experience mentoring, all mentors had some element they considered a challenge when establishing expectations for an undergraduate researcher. The mentors recognized the intern as an individual with a unique set of background knowledge and experience they were arriving to the REU program with, and as such could not treat the intern the same as one they may have had previously. All faculty demonstrated reflective practices, refining their perspectives, reconstructing their knowledge and mentoring strategies based on new knowledge gained from their experiences. They recognize the importance of "Balanc[ing] rigorous expectations with emotional support and appropriate personal interest in students" (Shanahan et al., 2015) as a mentoring best practice yet finding a challenge in how to achieve this balance. All mentors navigated the challenge of affording undergraduates a level of independence balanced with effective guidance and control, but more experienced mentors were able to navigate the challenge more efficiently as revealed through their realities.

The second research question aimed to explore the realities that mentors face throughout the REU program. The qualitative interviews revealed that more experienced faculty held expectations more closely aligned with reality which did not change significantly throughout the program. The project goals and workload for the intern did not shift, nor did their meeting frequencies. Faculty with less experience in mentoring noted larger shifts in expectations, some within the 10-week program, some from one year to the next. Literature suggests mentors improve strategies through years of mentoring (Copenheaver & Shumaker, 2022) and reconstruct their understanding of "good" mentoring through experience, which aligns with our observed results.

Interview feedback and CIMER results indicated an overall positive experience for mentors participating in the program, several noting they would very likely participate as a mentor again. CIMER also indicated mentor perception of very positive growth for interns. In particular, for understanding what everyday research is like and improvement of specific scientific research skills. While the program does provide workshops to work on skill development, by focusing on providing tangible research experiences, students not only witnessed authentic professional research, but also could apply and improve their skills within a specific physics/astronomy context. As observed in a similar study of a summer undergraduate research experiences, faculty aimed to professionally socialize interns into the sciences, emphasizing the process of "becoming a scientist" fostering essential skills (Hunter et al., 2007). Because mentors framed their expectations around valuing the process of research, not simply the product, the students in turn appreciated the development of their research skills, as measured in growth on the intern pre- to post- survey results.

Mentors articulated the importance of establishing the background knowledge of their intern throughout the course of the program, and for some as an essential pre-assessment before starting the summer research project. While faculty expressed the importance of gauging undergraduate student comprehension, the frequency of meetings to do so was consistently a challenge when trying to balance student independence yet maintaining adequate support. Research has found that routine checks for understanding and frequent interactions are vital for effective mentor support of undergraduate students which positively affects their research experience (Dolan & Johnson, 2010). Based on student progress, mentors in our study could adjust or scaffold expectations, and as needed teach necessary content knowledge. The wide range in prior student experience led to challenges for mentors and how they approached working with the participants. By the end of the program, a majority of mentors (4 out of 7 who completed the CIMER survey) believed their mentee gained only moderate ability to work independently. At the same time, three witnessed good or great gains in mentee independence. While faculty attempted to express the expectation for independence, most undergraduate students could not meet those expectations. Despite the mentor perception of moderate gains in independence, the mentees demonstrated a significant gain in confidence to independently perform scientific research, as measured in the intern pre- to post-survey results, in particular for the 2024 cohort as compared to the non-mentorship trained 2023 cohort. By allowing more autonomy and encouraging students to work independently, students did show significant gains in their independence as researchers.

To answer the research question- what effect did PD have on mentoring- faculty were encouraged to focus on particular mentoring practices bringing awareness to a specific aspect of mentoring, in this case effective communication and establishing expectations. This intentional focus brought greater awareness to their mentoring approach and prompted them to reflect on their methods in a more deliberate and professional way. In alignment with adult education theory, mentors engaged with reflective practices that were sustained throughout the course of the summer program. In addition, the open discussion allowed for self-direction in their learning. The prominent positive aspect of the PD was the camaraderie established among faculty mentors when given the opportunity to discuss personal experiences mentoring. Considering social learning theories and communities of practice, mentors learned effective practices primarily through experiences and interactions with students and other faculty mentors. While this study did not directly measure improvement of mentoring skills due to professional development, it indirectly measured effects through growth of the REU participants from the perspectives of the mentors and mentees, with statistically significant positive gains for the PD mentorship trained 2024 cohort. Through primed awareness and opportunities for socialization among colleagues, the professional development overall was valuable for mentors regardless of years of experience.

Limitations

One of the primary limitations of this study is the small sample size of mentors which may reduce the statistical power of the results. Although survey and interview participation were voluntary, the response rate from mentors was strong. The limited number of participants (11 mentors) was primarily due to the study being conducted at a single site and during a single program session. Future studies exploring the effects of mentorship PD should aim to include larger samples in order to validate these findings and strengthen the conclusions.

Another limitation of the study was the sampling of mentors that overlapped from prior years of the REU program who had not received the professional development training in mentorship who then also served as faculty research mentors to the program participants. There was a total of six faculty mentors who overlapped between the 2023 program year and the 2024 program year in which the mentorship professional development program was implemented. This small sample size of faculty mentors who had prior experience serving as an REU mentor in the prior year's program before the professional development had been implemented and then returned to mentor again in the year the professional development training was being offered could have had an impact on the observed results.

In addition, a limitation of the study was the wide range of physics and astronomy content knowledge among the REU fellows. Some had just completed their freshman year of college, while others were preparing to enter their senior year. This variation in prior knowledge and conceptual understanding likely contributed to differing levels of mentorship needs, as less experienced fellows may not have had the background necessary to work as independently as their more advanced peers.

Conclusion

The information gathered from this research can help inform similar REU programs interested in providing resources and professional development for mentors. Future studies should focus on PD surrounding other "Salient practices of undergraduate research mentors" (Shanahan et al., 2015) and exploring how mentors can engage with these practices and overcome challenges they may face. As found in our study, while mentors may have awareness of what constitutes "good" mentoring, they may be less aware of *how* to achieve those mentoring practices, such as how to set well-scaffolded expectations or how to balance autonomy with control. Overall, this study found significant benefit from a mentorship professional development for the mentors and the mentees. Mentors established a community of practice and approached their mentees' program experiences with greater intentionality. As a result, mentees demonstrated significant growth in research skill confidence, had more accurate expectations of the REU program, and increased confidence in future career outlooks in physics/astronomy research. Further improving mentoring practices and the relationships built in undergraduate research programs will benefit not only the mentor but also the many outcomes for the undergraduate researchers and their trajectories into STEM fields.

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Appendix

REU Faculty Mentor – Interview Question Protocol

1. How did you get involved with the project?
   a. How long have you been involved?
2. What's been the most memorable thing about participating in REU?
3. Describe your experience with involving undergraduates with research.
   a. What have you learned about mentoring undergrads through this process?
   b. Looking back before this project and to now, have you changed how you approach working with undergraduates to do research? **Did you supervise this project in any different way?**
   c. **As a mentor, what was the biggest challenge you faced?**
4. What about how you approach your research and teaching?
   a. Has the way you approach research changed since starting this project? How?
   b. Has participating in REU changed your approach to teaching undergraduates? How?
5. Now thinking about the REU fellows, what do you think was the best part of the experience for them?
   a. Do you feel like this program was effective for the REU fellows? In what ways?
   b. **Did you discuss expectations with your REU fellow? How did you set expectations? Were they formalized in any way?**
   c. **Did you ask your REU fellow what their internship expectations were of you?**
   d. **Did your expectations of your REU fellow change over time?**
   e. How do you determine if your REU fellows are successful? How do you measure success?
   f. *What advice would you give to a faculty member who is going to get involved in undergraduate research?*
6. Do you feel like the program has been successful? In what ways?
   a. What things make a program like this successful?
   b. What ways could the REU program be improved moving forward?
7. **Did you attend the Professional Development for Mentors at the beginning of the program?**

   a. **What were some benefits of that PD?**
   b. **What suggestions do you have for future PD for undergraduate mentors?**

8. Is there anything else about participating in the REU program that we haven't discussed?

Modified Kardash (2000) Pre- and Post-Survey for Physics/Astronomy REU Interns

To what extent do you feel you can:

Q1. Understand current concepts in the field of Physics/Astronomy

Q2. Understand concepts in the area of Physics/Astronomy research you are working on in this program

Q3. Make use of the primary scientific research literature in the field of Physics/Astronomy (e.g., journal articles)

Q4. Make use of the primary scientific research literature in the area of research you are working on in this program (e.g., journal articles)

Q5. Identify a specific question for investigation based on the research in the field of Physics/Astronomy

Q6. Identify a specific question for investigation based on the research in the area of research you are working on in this program

Q7. Design a research study in the field of Physics/Astronomy

Q8. Design a research study in the area of research you are working on in this program

Q9. Understand the importance of "controls" in research in the field of Physics/Astronomy

Q10. Understand the importance of "controls" in research in the area of research you are working on in this program

Q11. Observe and collect data in the field of Physics/Astronomy

Q12. Observe and collect data in the area of research you are working on in this program

Q13. Statistically analyze data in the field of Physics/Astronomy

Q14. Statistically analyze data in the area of research you are working on in this program

Q15. Interpret data and research results in the field of Physics/Astronomy

Q16. Interpret data and research results in the area of research you are working on in this program

Q17. Relate results to the "bigger picture" in the field of Physics/Astronomy

Q18. Relate results to the "bigger picture" in the area of research you are working on in this program

Q19. Orally communicate the results of research projects in the field of Physics/Astronomy

Q20. Orally communicate the results of research projects in the area of research you are working on in this program

Q21. Write a research paper for publication in the field of Physics/Astronomy

Q22. Write a research paper for publication in the area of research you are working on in this program

Q23. Think independently in the field of Physics/Astronomy

Q24. Think independently in the area of research you are working on in this program

For the next set of questions, indicate the extent to which you believe that the internship has helped you develop each skill. Rate each skill on a 5-point scale ranging from 1 (not at all) to 5 (a great deal):

Q25. Understand current concepts in the field of Physics/Astronomy

Q26. Understand concepts in the area of Physics/Astronomy research you are working on in this program

Q27. Make use of the primary scientific research literature in the field of Physics/Astronomy (e.g., journal articles)
Q28. Make use of the primary scientific research literature in the area of research you are working on in this program (e.g., journal articles)
Q29. Identify a specific question for investigation based on the research in the field of Physics/Astronomy
Q30. Identify a specific question for investigation based on the research in the area of research you are working on in this program
Q31. Design a research study in the field of Physics/Astronomy
Q32. Design a research study in the area of research you are working on in this program
Q33. Understand the importance of "controls" in research in the field of Physics/Astronomy
Q34. Understand the importance of "controls" in research in the area of research you are working on in this program
Q35. Observe and collect data in the field of Physics/Astronomy
Q36. Observe and collect data in the area of research you are working on in this program
Q37. Statistically analyze data in the field of Physics/Astronomy
Q38. Statistically analyze data in the area of research you are working on in this program
Q39. Interpret data and research results in the field of Physics/Astronomy
Q40. Interpret data and research results in the area of research you are working on in this program
Q41. Relate results to the "bigger picture" in the field of Physics/Astronomy
Q42. Relate results to the "bigger picture" in the area of research you are working on in this program
Q43. Orally communicate the results of research projects in the field of Physics/Astronomy
Q44. Orally communicate the results of research projects in the area of research you are working on in this program
Q45. Write a research paper for publication in the field of Physics/Astronomy
Q46. Write a research paper for publication in the area of research you are working on in this program
Q47. Think independently in the field of Physics/Astronomy
Q48. Think independently in the area of research you are working on in this program

Indicate the extent to which you believe the following statements are true for yourself. Rate each statement on a 5-point scale ranging from 1 (not at all) to 5 (a great deal):
Q49. I have the ability to have a successful career as a Physics/Astronomy educator/researcher
Q50. I have the ability to be a successful researcher in my future career
Q51. I have the ability to conduct successful research
Q52. I possess the motivation and persistence required for a career as a Physics/Astronomy researcher
Q53. College faculty have encouraged and promoted my interest in pursuing a career in Physics/Astronomy
Q54. College faculty did encourage and promote my interest in pursuing a career in Physics/Astronomy

Corresponding Author Contact Information:

Author name: Heather McCall

Department: STEM Education

University, Country: University of Kentucky, United States

Email: Heather.McCall@uky.edu

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