Gains and Losses in Virtual Mentorship: A Descriptive Case Study of Undergraduate Mentees and Graduate Mentors in STEM Research during the COVID-19 Pandemic

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ABSTRACT

Participating in mentored undergraduate research experiences can improve students' grade point averages, retention, and job placement. Graduate students also benefit from serving as mentors, as they gain teaching and research management experience. In early 2020, the SARS-CoV-2 (COVID-19) pandemic caused many institutions to shut down physical work spaces and move research and teaching online. In this study, we explore how graduate student mentors and undergraduate student mentees at Washington University in St. Louis adapted to virtual research mentoring during the COVID-19 pandemic. We examined changes in mentoring methods, research productivity, and the impact on the future plans of both mentors and mentees across six science/engineering departments. Survey responses from 79 mentees and 38 mentors indicated that a majority of mentees were able to have meaningful and productive virtual mentoring experiences, while other mentors failed to adequately involve their mentees in continued mentoring. Focusing virtual research experiences on activities such as literature review and data analysis and collaborating on goal setting can serve as a way for mentors to engage mentees even when they are unable to access lab equipment. Data from the present study reveal opportunities and challenges of virtual mentoring and can be used to inform effective research mentoring practices in the future.

INTRODUCTION

The SARS-CoV-2 (COVID-19) pandemic has necessitated social distancing and changed how education is delivered. One example of an institution where these changes occurred is Washington University in St. Louis, a private, R1 institution in the United States. Starting March 23, 2020, classes at Washington University in St. Louis transitioned to being held online pursuant to an emergency order from the St. Louis City Health Commissioner (Echols, 2020a). Similarly, most research labs (except those engaging in COVID-19 research) closed their doors and transitioned to a work-from-home model while local stay-at-home orders were in place, which lasted through the end of the academic year (Echols, 2020b). This situation posed two challenges for undergraduates who were engaging in research in a laboratory (lab) setting for credit (e.g., independent study) or as part of their academic curriculum (e.g., working on an undergraduate thesis). Many students were expected to continue research efforts without access to wet lab equipment (e.g., centrifuges, chemical/biological hoods, specialized chemicals) and to maintain productivity in a remote working environment. Institutions, including Washington University in St. Louis, made many resources available to faculty to help them transition their courses to virtual delivery only, including seminars and training on using online platforms. In contrast, little guidance was provided to graduate students as to how to mentor undergraduate researchers without access to wet lab equipment or in-person contact. Graduate students themselves may have also faced significant challenges continuing their own thesis research remotely.

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Much contemplation has already been given to the effects of the COVID-19 pandemic on the learning environment (Lall and Singh, 2020; Sintema, 2020), and research on how to mentor wet lab research without access to the bench is still ongoing (Sutherland *et al.*, 2020). The purpose of this article is to add to this body of literature by presenting a case study on the virtual mentoring experiences of graduate student mentors and undergraduate student mentees at one research institution during the COVID-19 pandemic.

A survey-based approach was used to determine: 1) how researchers adapted previously in-person mentoring and research efforts to remote work spaces due the rapid onset of the pandemic and the effect of virtual mentoring on the relationship between mentors and mentees; 2) whether this particular research experience altered participants' future plans for science, technology, engineering, and mathematics (STEM) careers or serving as a mentor; and 3) what unique challenges were posed by the abrupt shift to virtual mentoring and what unexpected benefits it had for those affected by it. Research mentorship describes a dynamic, collaborative, and developmentally focused relationship between a more senior researcher and a more novice member of the lab in which the team engages in research activities together and both operate as learners (Hurst and Eby, 2012; Pfund *et al.*, 2014; Talents, 2017). In the present study, the more senior researchers were graduate students serving as mentors to undergraduate student mentees. Before the pandemic, research mentorship largely occurred face-to-face and took place within the physical research lab. However, with the onset of COVID-19 and subsequent lab closures, the need for social distancing, and remote working requirements, research mentorship was maintained through virtual interactions only (virtual mentoring). Virtual mentoring uses virtual platforms (such as email, phone calls, or videoconferencing) instead of in-person communication to facilitating mentoring. Virtual mentoring has been less commonly used in wet labs, but research on how to best engage in virtual mentoring dates back over two decades.

Previous literature has demonstrated a role for virtual mentoring for various populations. (Ensher *et al.*, 2003; Cantrell *et al.*, 2010; Adams and Hemingway, 2014; Gregg *et al.*, 2016, 2017; Tanis and Barker, 2017; Welch, 2017; Xu *et al.*, 2017; Breck *et al.*, 2018; Oppenheim and Knott, 2018; Mack *et al.*, 2019; De and Cavanaugh, 2020). These studies demonstrate that virtual mentoring provides social, academic, and career support and promotes development of transferable and technical skills, similar to the benefits found from in-person mentoring. Virtual mentoring can also have added benefits, such as increased flexibility in meeting times/locations, providing records of interactions, and creating a more comfortable environment for mentee communication (Ensher *et al.*, 2003; Cantrell *et al.*, 2010; Owen, 2015). However, shifting from in-person to virtual mentoring can require a period of adjustment and presents its own challenges, including home access to technology, privacy, and increased potential for miscommunication of verbal and nonverbal cues (Ensher *et al.*, 2003; Owen, 2015).

Taken together, these studies demonstrate that virtual mentoring can provide many of the benefits of face-to-face mentoring, but the methods used in the virtual mentoring session and the training of mentors are important for the beneficial effects to be realized (Gregg *et al.*, 2016; Jeannis *et al.*, 2018; Menzel *et al.*, 2019). This is critical because of the demonstrated role that research mentorship plays for both the undergraduate student mentee and the graduate student mentor. Participating in undergraduate research improves grade point averages, retention in STEM fields, graduation rates, and matriculation into graduate-level STEM programs, particularly for students with underrepresented identities (Byars-Winston and Dahlberg, 2019; Kendricks *et al.*, 2019; Trott *et al.*, 2020). Positive research experiences also promote nonacademic benefits, including improved self-confidence, intellectual curiosity, self-efficacy, and communication (Gregg *et al.*, 2016; Kendricks *et al.*, 2019; Trott *et al.*, 2020). In contrast, negative research or mentoring experiences can have lasting effects on students' mental health, self-confidence, and/or careers. Students who have negative mentoring experiences can feel stressed and excluded from the scientific community and may perceive that their contributions are not valued (Dolan and Johnson, 2009; Jeannis *et al.*, 2018; Menzel *et al.*, 2019). Graduate students also benefit from mentoring more novice students in research activities as they gain assistance in their own research efforts and learn teaching and management skills that are valuable for careers in both academia and industry (Dolan and Johnson, 2009; Limeri, Asif, and Dolan, 2019). Whether mentoring occurs face-to-face or virtually, it is important for the mentor and mentee to work and learn together for both parties to succeed.

In the present study, we sought to understand how graduate student mentors and their undergraduate mentees at a private research institution (Washington University in St. Louis) adapted their research mentorship to use virtual modalities instead of in-person communication during the COVID-19 pandemic. Specifically, we examined what elements of research mentorship were gained or lost in the transition by surveying students engaged in wet lab research. We present results of a survey that capture what resources were utilized and what practices were employed in order to continue research activities and the mentoring relationship during the COVID-19 pandemic. While these findings were informed by experiences of research mentorships in wet labs, the results are also applicable across disciplines to guide the use of virtual mentoring during COVID-19 or as a tool to supplement in-person pedagogy.

METHODS

Survey Creation and Distribution

In May and June 2020, a survey-based research study was conducted at Washington University in St. Louis, a private institution with a Carnegie classification of R1 (very high research activity) in the United States with approval from the Washington University in St. Louis Institutional Review Board (IRB ID: 202005062).

The survey was generated using Qualtrics software in June 2020 (Qualtrics, Provo, UT) and asked students to reflect on the impact of the COVID-19 pandemic on their mentored research experiences during the Spring 2020 semester and how it has influenced their future goals. The survey included multiple-choice, Likert-scale, and short-response questions that allowed for both quantitative and qualitative data to be collected. Questions asked students to reflect on their experiences and to determine whether mentorship during COVID-19 contributed to an improvement or worsening in their own self-ratings of their experiences.

An invitation to participate in the study was distributed via email by department administrators to the departmental list of both the undergraduate student mentees and graduate student mentors in six departments that in part or fully conduct research in wet lab settings: biology, chemistry, physics, biomedical engineering, mechanical engineering, and earth and planetary sciences. This communication briefly described the goals of the study and invited individuals who had engaged in a mentored research experience during the Spring 2020 semester to participate using a link to the survey shown in Supplemental Material 1. While mentorship in research and academia can occur in multiple contexts, for this study, we define "mentors" as graduate students who are mentoring an undergraduate researcher and "mentees" as undergraduate students being directly mentored in a research laboratory by a graduate student.

Respondents were required to state their research roles (mentor or mentee) but could leave other answers blank. If participants indicated that they underwent a change to their research modality (e.g., changed from primarily in person to primarily virtual), they were asked to rate their overall experiences (e.g., "how do you rate the following: your relationship with your mentor/mentee, your communication with your mentor/mentee, the research productivity of your mentoring") and to indicate whether their experiences differed as a result of this change (e.g., "Since COVID-19 has altered how you communicate with your mentor/mentee, how do you rate … your relationship … communication … and research productivity?"). Alternatively, students who indicated that the research modality did not change (e.g., always primarily digital) were asked to rate their overall experiences, but because they had not undergone a change in modality, they were not asked to respond to that follow-up question. After these Likert-scale questions, respondents were asked open-ended questions about their mentoring experiences on each of these topics and their experiences overall (e.g., "What has been the most unexpected effect of the COVID-19 pandemic on your mentoring experience?"). At the end of the survey, students could choose to provide their primary academic department, academic year, and mentor/mentee's first name. The last item was included to allow for the option of pairing mentor and mentee responses.

Sample Population

One hundred seventeen students (undergraduate mentees: n = 79; graduate mentors: n = 38) participated in the study. Although not all students indicated their academic year or department, responses from undergraduate mentees indicate that students of all academic years participated in the survey (year 1: n = 9; year 2: n = 14; year 3: n = 18; year 4: n = 8). Similarly, graduate mentors at all levels of study were among the respondents (year 1: n = 5; year 2: n = 2; year 3: n = 2; year 4: n = 2; year 5: n = 1; year 6: n = 1). Additionally, the undergraduate mentee and graduate mentor participants combined represented all departments surveyed (physics: n = 4; chemistry: n = 3; biomedical engineering: n = 7; biology: n = 10; mechanical engineering: n = 1; earth and planetary sciences: n = 1). Individual mentor and mentee responses could not be paired for further analysis due to an insufficient number of responses indicating the name of the mentor/mentee. No questions were asked regarding demographic data such as race, gender, or ethnicity.

Survey Analysis

Analysis of the data was conducted in aggregate, and responses were considered both separated by research role (mentor or mentee) and as a whole. Multiple-choice and Likert-scale responses are presented as percent of responses. Differences in the distribution of responses to Likert-scale questions were assessed using a modified Fisher's exact test. Figures were generated using Prism 8 (GraphPad).

Free-response questions were assessed using an open coding, two-pass approach to identify emergent themes (Blair, 2015; DeCarlo, 2018; Suter, 2012). First, response categories were generated based on common themes in responses. During the second pass, responses were assigned to these categories which were altered, combined, or generated as needed. This categorization was performed by author M.L. initially and reviewed by J.S. with agreement from J.J. Quotes from the free-response sections were used throughout this study to give insight into the categories or to provide context for an answer.

To more deeply examine the effectiveness of virtual mentoring, we quantified the responses of some Likert-scale and multiple-choice questions based on free-response data (e.g., how respondents who indicated that they did not accomplish their research goals perceived their research productivity).

RESULTS

Both Graduate and Undergraduate Students Participated in Research Mentorship to Develop Practical Skills and Gain Experience

Open-ended short-answer responses indicated a variety of reasons why students chose to partake in research and mentored research specifically (Supplemental Material 2 and 3). Most commonly, undergraduate mentees sought to gain practical laboratory skills (n = 30; e.g., "expertise in bioinformatics tools") or to work on a specific research question (n = 21; e.g., "Understanding more of the molecular pathogenesis of tuberculosis"). Other responses indicated that they wanted to learn more about how research is performed (n = 14; e.g., "understanding of how research is conducted") and gain insight into future careers and how to achieve them (n = 13; graduate skills and career; e.g., "gain research experience in order to prepare for graduate school"). Graduate mentors were primarily motivated by gaining experience mentoring and teaching (n = 12; e.g., "I hoped to gain mentoring skills and better communication") followed by making progress in specific research projects (n = 7; e.g., "[Mentoring] an undergraduate student that I would be able to train to benchtop assays and help to complete a paper").

COVID-19 Caused Most Students to Shift Their Mentoring Experience Online, Requiring Some to Alter Research Goals

A minority of respondents indicated that their research mentorship had always been virtual (n = 9; 8%), however, most indicated that the pandemic required them to shift from in-person mentoring to an exclusively virtual environment (n = 108; 92%; Figure 1A).

The majority of undergraduate mentees indicated that their broad research goals remained largely unchanged in the wake of COVID-19 (Supplemental Material 2; n = 41 unchanged, n = 15 changed). They also indicated that they were able to achieve

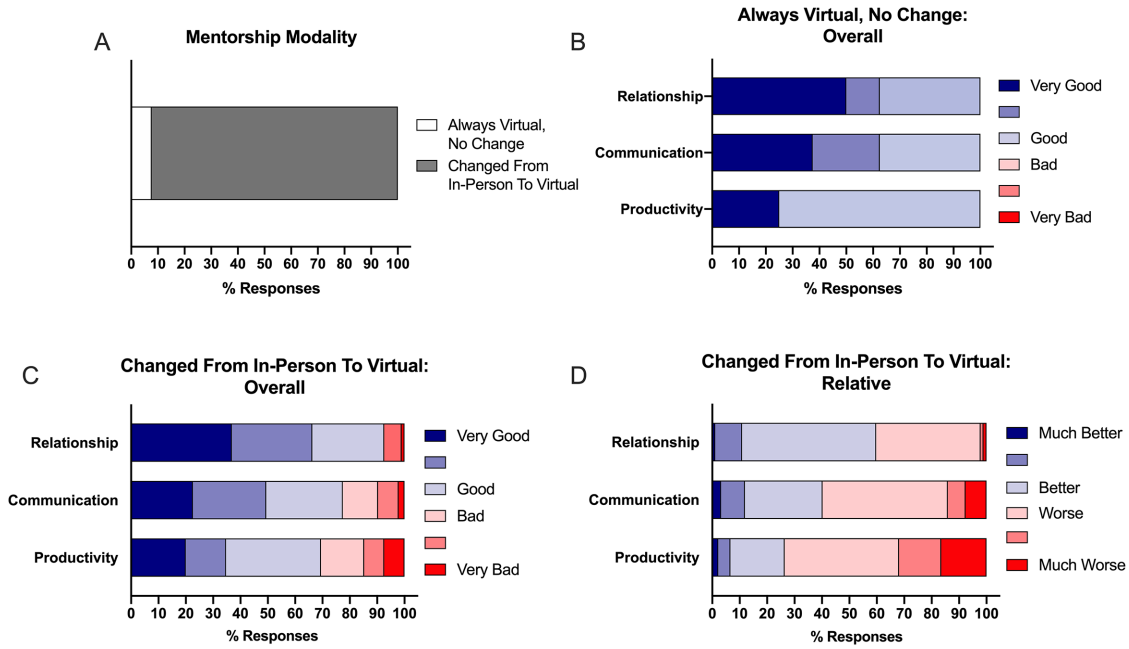

FIGURE 1. Responses (from both undergraduate and graduate students in aggregate) showing whether their mode of mentorship was altered due to the COVID-19 pandemic (A; $n = 117$). Overall perceptions of mentoring relationship, communication, and productivity were positive among mentors and mentees (aggregate responses) who engaged in virtual mentorship both before and during the COVID-19 pandemic (B; $n = 9$). Respondents (aggregate responses of mentors and mentees) who underwent a change to virtual mentoring with the onset of the COVID-19 pandemic rated their overall perceptions of the mentoring relationship, communication, and productivity (C; $n \geq 91$) and indicated how these changed relative to their experiences with in-person mentoring earlier in the semester (before the pandemic; D; $n \geq 91$).

their goals either partially or fully (Supplemental Material 2; $n = 37$ partially/fully achieved, $n = 12$ unachieved). In contrast, responses from graduate mentors suggested that this population changed their broader mentorship and research goals approximately half of the time (Supplemental Material 3; $n = 6$ unchanged, $n = 5$ changed) and achieved them with similar frequency ($n = 12$ partially or fully achieved, $n = 12$ unachieved—no or research halted).

A majority of responses also showed that the experience of research was greatly altered due to a switch to primarily virtual mentorship and research activities (Supplemental Material 2). Undergraduate mentee responses indicated that many research goals became centered around literature review; something that was beneficial to many students ("It has given me a better understanding of another side of research that as an undergrad I often don't get to focus too much time on"). Similarly, other responses indicated that, while they could not collect data in the laboratory, they took time to build their understanding of scientific theory ("My experience became more theoretical … which I appreciate because I usually found myself confused as to why I was assigned to do something"). Other students felt that the switch to literature review was undesirable and less meaningful than data collection ("As such it was substandard. My paper ended up being mostly a literature review"). Undergraduate mentees also engaged in research tasks such as designing experimentation and analyzing previously collected data ("[I've worked on] data analysis … [I've also] helped with some minor programming and troubleshooting"). Furthermore, a subset of undergraduate mentee responses suggested that, in the wake of the COVID-19 pandemic, their research completely halted or became significantly diminished ("[My] mentor failed to include me in continuing research").

Virtual Mentoring Can Support Mentor–Mentee Relationships

Responses from both mentors and mentees who had always engaged in virtual mentoring indicated that their relationships were good to very good (Figure 1B). Ninety-two percent of all respondents who changed from in-person to virtual mentoring indicated overall positive relationships (Figure 1C). Sixty percent of respondents indicated that their relationships improved since the change (Figure 1D). Furthermore, responses from mentors and mentees differed in their perceptions of how their relationships changed since working remotely, with a higher percentage of mentors indicating an improvement in relationships compared with mentees ($p < 0.0001$; see Supplemental Material 4B).

Undergraduate mentee free responses indicated that many felt a positive change in their relationships with their mentors due to the "less formal" nature of virtual mentorship in general and videoconferencing in particular ("My mentor's family often walks in the background of video calls, which causes meetings to have a more personal and less stiffly formal feel"). However, for a different group of students, limited or reduced contact with their mentors may have negatively impacted their relationships ("Lack of in person connection hinders building meaningful relationships with mentors").

Graduate mentors indicated similar reasons for improved relationships ("I get to see [pet] photos and learn more about my mentee and her life") and also displayed concern for their mentee's mental health and well-being ("having to more thoroughly account for mental and emotional health of my mentee during the pandemic"). However other responses showed frustration with the virtual format and expressed a struggle to connect with their mentee ("Mentoring is a two-way street, and I've been having trouble scheduling a common time to contact and meet with my mentee"). Furthermore, the relationships with the mentees did not seem to be impacted by whether research was able to continue virtually or not. Of mentors who said that their mentees were not able to contribute to research during the pandemic, most said that their relationships were better when using virtual modalities. This was similar to the graduate mentors who said that their mentees were able to perform data analysis, 87% of whom said their relationships improved since the COVID-19 pandemic began.

Respondents Ranked Virtual Communication Positively but Worse than In-Person Communication

All mentors and mentees who had always engaged in virtual mentorship indicated that their communication was good to very good (Figure 1B). In contrast, 77% of respondents who switched to virtual mentoring due to COVID-19 indicated that communication with their mentees/mentors was good to very good (Figure 1C). Following the switch to virtual mentorship, only 40% indicated positive (better to much better) improvements in communication (Figure 1D). Examining the responses of the undergraduate mentees and graduate mentors separately revealed that the distributions of responses for communication varied between the two populations for overall rating (p = 0.047; see Supplemental Material 4C), with more graduate responses falling into the "very good" and "very bad" categories compared with the undergraduate mentees. In contrast, the distribution of the ratings for the change in communication from in-person to virtual mentoring was not different between the two groups (p = 0.400; see Supplemental Material 4D).

Results further indicate that that the most frequently used communication methods to support virtual mentorship were email (40%) and videoconferencing (34%) (Figure 2). When asked to indicate the most useful method for communicating, 57% said videoconferencing, followed by email at 29%. Qualitative responses indicated that, in general, videoconferences were perceived as being "as close to face to face as possible" and also played an important role because students were able to share "data collected … and go over them." Responses also indicated that videoconferences allowed students a "safe" place to express uncertainty ("I feel open to saying that I don't understand a subject over videoconferencing as compared with an email where I'm expected to figure out something if I don't understand it"). Mentors and mentees alike indicated that videoconferencing was perceived as more personal and less formal. Several graduate mentor responses indicated that improved communication was an unanticipated outcome of switching to virtual mentorship ("[A benefit of virtual mentoring was] improving communication outside of in person contact"). These individuals also indicated that they used a combination of communication platforms to communicate with their mentees.

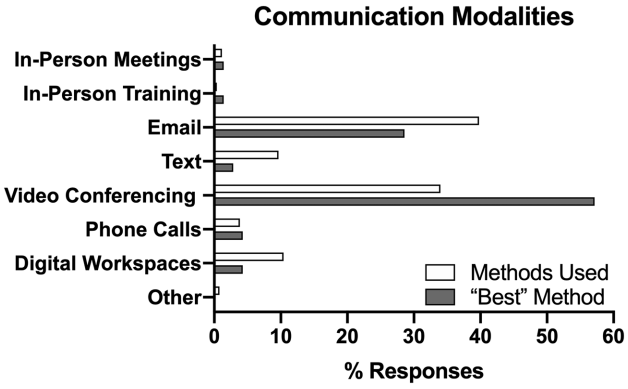

FIGURE 2. Communication platforms used to facilitate virtual mentorship (n = 259 responses) as well as those methods respondents said worked the best (n = 70 responses). Reponses were aggregated from both undergraduate mentees and graduate mentors.

Responses, primarily from undergraduate mentees, indicated that altered communication during virtual mentorship was a major change in their research experiences. This generally fell into two categories, where responses indicated mentees either felt 1) communication from their mentors was slower or had halted completely during the pandemic, and that this posed a major challenge to their research efforts; or 2) that while they were able to continue communicating with their own mentors, they missed speaking with other lab members.

Switching from In-Person to Virtual Mentorship Negatively Impacted Perceptions of Productivity

Those who had always engaged in virtual mentorship all ranked the productivity of the experience positively (Figure 1B) compared with 69% of those who changed from in-person mentorship (Figure 1C). Responses indicated that the change in productivity was generally negative, as only 26% indicated positive improvements for productivity when research was conducted virtually (Figure 1D). Graduate mentors generally rated their productivity more strongly as "very good" or "very bad," while mentees rated it more neutrally as "good" or "bad" (p = 0.033; see Supplemental Material 4E). Statistical differences were not observed between undergraduate mentee and graduate mentor responses regarding the change in productivity (p = 0.105; see Supplemental Material 4F).

Both undergraduate mentees and graduate mentors generally indicated that their productivity worsened after their experiences became exclusively virtual irrespective of whether or not their goals changed (Figure 1D and Supplemental Material 2–4). For undergraduate mentees who responded that they accomplished their goals, 72% rated their productivity as worse following the switch to virtual mentorship. Similarly, 83% of students who said they did not accomplish their goals rated their productivity as worse during the COVID-19 pandemic (Supplemental Material 2). Despite the negative trend, some students found that their productivity increased: "I actually better accomplished [my] goals during the pandemic. While I miss being in the lab, I really liked the remote work, because it forced me to think about my work more conceptually and engage with the material." This was similar for graduate mentors as well.

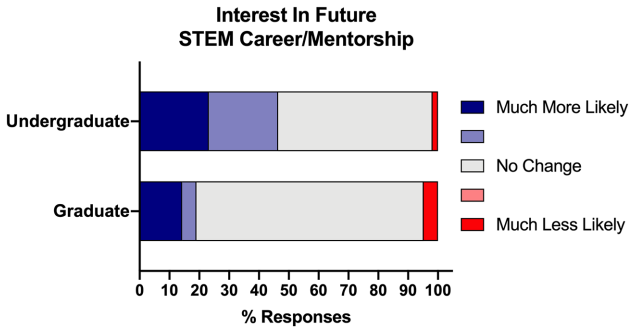

FIGURE 3. Responses indicating interest in pursuing future STEM careers (undergraduate mentees; *n* = 56) or future mentorship opportunities (graduate mentors; *n* = 21) following this experience with virtual mentorship.

Decreased productivity was cited by both mentors who said a major goal of theirs was to gain mentorship experience and by those who sought this mentoring opportunity with the hopes of gaining research assistance from their mentees. Several graduate mentors reported that their mentees were able to contribute and be meaningfully productive, such as by contributing to data analysis. However, several graduate mentor responses did indicate that they decreased the research tasks they were assigning to their mentees because they wanted to allow space for the mentees to focus on their classwork and to be considerate of the increased stress levels and other responsibilities during the global pandemic ("My mentee has been focusing on their school work, which is reasonable," and "I have had to balance home responsibilities with working on my lab assignments").

Changing to Virtual Mentoring Did Not Discourage Future Engagement in STEM or Mentoring

Forty-six percent of undergraduate mentees said that they were more likely to pursue a career in STEM after this experience, while 52% said that their plans were unchanged, and only 2% said they were less likely (Figure 3). Of the undergraduate mentees who indicated that they participated in research for career experience or graduate skills, 54% said that their career goals were unchanged, and 45% said they were at least more likely to stay in STEM.

Nineteen percent of graduate mentors indicated that they were more likely to engage in future mentorship, while 76% remained unchanged, and 5% said they were much less likely to mentor (Figure 3). Among graduate mentors who indicated that they wanted to develop their mentoring skills, 83% indicated their interest in future mentorship was not changed, and in fact, one person reported increased interest. Similarly, for graduate mentors who indicated that their goals were data collection, 60% said their interest in future mentorship had not changed, while one said it was much more likely, and one said it was much less likely.

Unexpected Outcomes of Virtual Mentorship

Many among the undergraduate mentee population cited that continuing in research this semester provided them continuity, structure, and feelings of productivity during a challenging time ("It felt much less lonely having scheduled calls and gave me a sense of purpose") It also contributed to learning transferable skills like adaptability and allowed them to gain insight into the full goings-on of professional scientific work environments ("a helpful connection to see how other scientists handled the shift to home during the pandemic"). Other students discussed the ability to use this time to get help from their mentors on other tasks like graduate school applications. However, others did not seem to find any benefits of virtual mentorship ("Well, it's better than receiving no mentorship at all I suppose").

The benefits that some undergraduate mentees felt may in part be due to the fact that some mentors found they had more time to devote to mentorship and to developing relationships with their mentees ("We have more time to discuss the project as we are not pressured by the need to accomplish work"). Additionally, some graduate mentor responses show that the mentors also gained skills like improving their own written/not in-person communication. But as with the undergraduate mentees, it was clear that not all mentors felt that virtual mentorship was in fact beneficial ("Not a lot [of benefit], it's way worse in basically every way than without the pandemic").

DISCUSSION

Prior literature has largely focused on the ability of virtual mentorship to assist students with career planning and troubleshooting current academic or interpersonal challenges and, in general, to provide a support system (Owen, 2015; Gregg *et al.*, 2017; Welch, 2017). The use of technology to facilitate virtual research in labs that typically collect data at the benchtop remains largely unexplored. This study represents one of the first case studies on the effects of COVID-19 on research mentorship experiences for undergraduate mentees and graduate mentors and reflects experiences from diverse areas of STEM research.

Virtual Mentoring Entails Different Expectations than In-Person Mentoring

The survey responses corroborated previous findings that undergraduate students engage in research to learn technical skills and progress toward their career goals (Seymour *et al.*, 2004; Beckman and Hensel, 2009; Fechheimer *et al.*, 2011; Trott *et al.*, 2020). Similarly, graduate mentor respondents had the expected goals of improving their own teaching and research productivity by serving as mentors (González, 2001; Dolan and Johnson, 2009; Limeri *et al.*, 2019). Our sample population was specifically selected such that the research mentorship would traditionally be dependent on experimental work that was halted during the COVID-19 pandemic. Many of the mentee respondents indicated that the work that they did changed; however, their goals were not necessarily reassessed to reflect this. There was also a disparity in how useful undergraduate mentees found the shift to remote research activities such as data analysis and literature review, indicating that the framing of the project can impact its benefits. Graduate mentors themselves indicated that they had less work for their mentees to do. Some used this as an opportunity to mentor on aspects of research or career development that they had not previously emphasized, while others withdrew, not wanting to burden their mentees. Based on these findings, we recommend that graduate student mentors engaging in virtual mentorship focus the goals of the research experience to include understanding

the usefulness of literature review, project design, and the scientific process (Hubbard and Dunbar, 2017; Symons *et al.*, 2017; Sen *et al.*, 2018) and emphasize development of both technical and transferable skills (Gregg *et al.*, 2016; Menzel *et al.*, 2019; Trott *et al.*, 2020). It is also important that research goals and activities are clearly communicated with undergraduate mentees to ensure all parties have shared expectations.

Virtual Mentoring Provides Challenges and Benefits for Communication

Mentored research is inherently collaborative and is therefore dependent on communication between mentors and mentees. The abrupt transition away from in-person research meant that many of the undergraduate mentee respondents felt "lost" and stopped being contacted by their mentors. While the mentors' intentions may have been to lower mentees' workload in a trying time, a failure to communicate that could be detrimental, particularly among individuals with disabilities or other underrepresented minorities who may have prior negative experiences in which they were assigned fewer active roles and tasks (Jeannis *et al.*, 2018). Even among mentees who remained in contact with their mentors, many missed the informal relationships and communications they had with the other members of their lab communities. These interactions can occur through email and videoconferencing, the communication platforms most commonly used by the respondents in this study. As working remotely reduces spontaneous interactions among co-workers, however, lab members may need to make more effort to facilitate dialogue with one another; intentionally taking advantage of informal relationships and communication opportunities may have positive impacts on mentees (Karukstis *et al.*, 2010; Holland *et al.*, 2012; Zaniewski and Reinholz, 2016).

For many students, virtual mentorship offered an ability to both continue training in STEM research and promoted feelings of interpersonal connection, contributions to meaningful work, and a sense of structure during an unprecedented time. In fact, data from the present study suggest that positive effects of mentorship were felt with or without corresponding research productivity. From the short-answer questions, this could be explained in part by the mentors and mentees having more intimate forms of communication through videoconferencing where they get to "see into each other's lives." Maintaining communication between mentors and mentees is absolutely vital to both parties benefiting from the experience. When deciding how to have those communications, it is important to be open to the benefits offered by these more personal forms of communication while making sure to respect (and gain an appreciation of) the circumstances and needs of each individual.

Impacts of Virtual Mentoring on the Future of STEM Mentoring

The ongoing COVID-19 pandemic is still limiting access to in-person mentoring. The experiences of researchers at all levels during this time will have a lasting impact on research practices for years to come. Prior research has indicated that positive research experiences can encourage undergraduate students to pursue future STEM careers, while negative experiences have the potential to prompt students to leave STEM (Kendricks *et al.*, 2019; Trott *et al.*, 2020). Similarly, graduate students may gain confidence and develop professionally from mentoring experiences they perceive to be positive but may lose confidence if they feel that the mentorship was "unsuccessful." In our sample population, neither undergraduate mentees nor graduate mentors said that their experiences substantially altered their future plans. This may speak to the general success of virtual mentorship but may also have resulted from the respondents having accomplished their goals before the pandemic started or may also reflect how many felt the situation was a temporary one. This study did not collect data before the pandemic, nor does it have a longitudinal component, and therefore future studies will be required to determine the long-term effects of virtual research mentorship, such as job placement and retention in STEM.

The impact of COVID-19 can also inform practices employed by STEM disciplines more broadly. This pandemic forced traditionally wet lab fields to adapt to virtual work spaces; the methods described here and other technologies may be helpful in reducing the barriers to entry for individuals who have been disproportionately excluded from STEM, such as those with disabilities, both during and after COVID-19 (Gregg *et al.*, 2016; Jones, 2016; Jeannis *et al.*, 2018; Lillywhite and Wolbring, 2019). In this way, virtual research and mentorship may demonstrate an opportunity to make STEM more accessible and inclusive, which can greatly benefit the field as well as individuals (Smith-Doerr *et al.*, 2017; Kendricks *et al.*, 2019; Menzel *et al.*, 2019; Asai, 2020). Data from the present study also demonstrate what research in work-from-home models has indicated, that productivity can occur outside "traditional" workplace environments and schedules when research productivity encompasses both data collection but also other research and professional development activities (Bloom *et al.*, 2015; Bao *et al.*, 2020). However, it remains important for researchers to be mindful that working remotely has made many individuals feel especially split between their home obligations and their academic ones.

Empowering Graduate Students as Mentors

In the present study, it is unknown how much mentoring experience each mentor had before the COVID-19 pandemic, or how much guidance/oversight was provided by the principal investigator(s) of a given laboratory. The graduate students' own confidence with mentoring or guidance provided to the research team by faculty may have impacted experiences, and future study will be required to assess these parameters. That said, at Washington University in St. Louis, there is no university-mandated training for graduate students before they serve as research mentors, nor were trainings specifically offered to graduate students about how to support the research progress of their mentees virtually. This lack of formal training in mentorship speaks to the need for departments and academic units to provide a wider array of programs to address the professional development needs of graduate students in STEM. Similarly, graduate students should receive training in identifying mental health needs and how to support students in accessing resources (Evans *et al.*, 2018; Huckins *et al.*, 2020). Efforts to address a gap in mentorship training are being developed (e.g., National Research Mentoring Network) and must be widely implemented (Pfund *et al.*, 2006, 2014; Balster *et al.*, 2010). Such programming is necessary to train graduate students not only

in responsible and effective STEM research practices, but to also in evidence-based pedagogy and best practices for mentorship. These skills, which are necessary for postdoctoral careers, are pertinent during "normal" university operations and are especially critical for navigating the technical and interpersonal challenges of facilitating research mentorship during the present pandemic.

CONCLUSIONS

A minority of respondents to our survey used virtual modalities for mentoring before the COVID-19 pandemic. Due to campus closures, most undergraduate and graduate students, however, had to shift from in-person to virtual mentoring, which had both positive and negative effects. Many undergraduate mentees and graduate mentors felt that their relationships improved in a virtual mentoring environment. One of the most common sentiments was that virtual meetings allowed mentors and mentees to learn more about one another as individuals and encouraged the researchers to be more conscious of one another's mental health. Virtual mentorship also provided an opportunity for mentees to focus on aspects of research outside data collection and to find a sense of community and purpose during a time of great uncertainty. At the same time, the abruptness of the transition also meant that many mentees felt lost as their mentoring modality changed and they were not included in ongoing communication or goal setting.

At the time of writing, virtual research mentorship continues to be required due to the ongoing pandemic. Unlike research experiences that were undertaken at the beginning of the pandemic, there is now an opportunity to intentionally plan and implement virtual research strategies. The results of this study demonstrate that successful virtual research mentorships use communication modalities effectively and emphasize a holistic research approach that values all laboratory research activities. Similarly, our results show that mentors and mentees who worked together to define their goals and expectations were able to maintain research productivity when access to vital laboratory equipment was limited. As these endeavors require adaptability and effective communication, institutions would benefit from training the mentors and mentees on best practices for virtual mentoring. Incorporation of these practices may demonstrate efficacy for virtual modalities and may uncover ways to leverage virtual research and mentorship broadly, even when social distancing is no longer required.

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