Differential Impact of the COVID-19 Pandemic on Female Graduate Students and Postdocs in the Chemical Sciences

Renee J. Sifri, Elizabeth A. McLoughlin, Brett P. Fors,* and Shima Salehi*

ABSTRACT: Over the past two and a half years, the COVID-19 pandemic severely disrupted almost all aspects of life as people throughout the world were instructed to work-from-home. Scientific researchers, whose work is reliant on access to laboratory equipment, have been acutely impacted by these global changes. In this study, we surveyed graduate students and postdocs in the chemical sciences at a selected number of academic institutions in the United States. We found that many survey participants, especially women, experienced severely diminished research progress and increased anxiety levels during the COVID-19 pandemic. Through factor analysis and multiple regression modeling, we found that during this challenging time participants who reported greater levels of professional support also reported greater research progress and lower levels of anxiety. We also found that, although advisors and departments provide some forms of professional support, there are other types of support that students and postdocs still desire. This phenomenon is magnified for female and underrepresented minority participants, as they need greater levels of professional support and place immense value on the quality of their work environments. Based on these results, we have identified some ways in which departments and advisors can provide the needed support for their graduate students and postdocs, thereby providing timeless advice that is applicable to improving academic work conditions not only during a global pandemic but also in a postpandemic world.

KEYWORDS: Graduate Education, Interdisciplinary, Collaborative, Career Counseling, Graduate Research, COVID-19

INTRODUCTION

Beginning in March 2020, many schools and academic research laboratories temporarily shut down to slow the spread of the novel coronavirus, SARS-CoV-2. The resulting COVID-19 pandemic challenged many graduate students, postdocs, and faculty to continue pursuing their research at home without the resources that are often provided by university campuses. Although this disruption in research has affected everyone, it has not affected everyone equally.\(^1,2\) Female scientists, scientists whose research primarily occurs at a lab bench, and scientists with children have experienced a substantial decline in their time devoted to research due to the stay-at-home orders.\(^3\)\(^\text{-}5\) These observations align with the broader body of the literature highlighting the differential impact that the COVID-19 pandemic has had on women and caregivers.\(^6\)\(^\text{-}11\)

The pandemic-induced reduction in scientific research likely has a profound effect on the well-being of graduate students and postdocs, whose career progression is often predicated on experimental results. Furthermore, several studies have shown that students and young professionals (ca. 20–29 years old) are more susceptible to experiencing mental health challenges due to the COVID-19 pandemic than the general popula-

\(^{7,9,10,12\text{-}15}\) Before the pandemic, stress and anxiety was already ubiquitous among students in graduate programs.\(^16\)\(^\text{-}18\) Female and underrepresented racial minority (URM)—broadly defined as non-White, non-Asian—students are more likely to experience these negative emotions and are more likely to experience mental health disorders than their male and non-URM peers.\(^19,20\) One way to minimize the extent of mental health disorders among these minority groups is through a sturdy support structure from academic departments and advisors. Numerous studies have shown a correlation between graduate student anxiety and the strength of their relationship with their advisor; graduate students who report lower anxiety levels also report strong relationships with their advisors and substantial support from their peers and friends.\(^21\)\(^\text{-}26\) In this way, advisors and departments have the opportunity to provide invaluable support to help graduate students and postdocs, thereby providing timeless advice that is applicable to improving academic work conditions not only during a global pandemic but also in a postpandemic world.
students and postdocs manage their anxiety. Notably, female and URM graduate students often report that they want more support from their advisor and department than their male and non-URM peers.\textsuperscript{16,27} These support structures also help foster graduate students’ and postdocs’ sense of belonging, which is known to impact persistence and success in STEM fields.\textsuperscript{28,29}

Understanding the ways in which departments and advisors can provide support for the needs of a diverse body of junior professionals, particularly as a result of a global crisis, is a valuable approach to mitigate the negative aspects of graduate school and thereby improve graduate student and postdoc well-being.\textsuperscript{10,11} Toward this goal, we sought to understand how the COVID-19 pandemic has impacted graduate students and postdocs from different demographic groups within the chemical sciences. Given that anxiety is common among graduate students, we were interested in assessing participants’ anxiety about their research, their finances (e.g., job prospects), and their health before and during the COVID-19 pandemic. We refer to these collective measures of anxiety as participants’ personal well-being. We also assessed participants’ professional well-being, which we defined as participants’ work characteristics (e.g., hours spent working), their perceived research progress, the effectiveness of research collaborations, and their thoughts on their degree/position timeline and their career goals. We were also interested in probing the ways in which participants’ family and friends, co-workers, department, and advisors have supported them throughout the pandemic and how these support structures have impacted participants’ personal and professional well-being (Scheme 1).

identifying the types of support participants want, compared to the types of support they receive, we discovered that the types of support that received are not the ones they value most.\textsuperscript{15} Notably, we found that female and URM participants want more support from their advisors and departments and have had higher anxiety levels than their male and non-URM peers throughout the pandemic. By analyzing the results of this study, we have recognized some ways in which departments and advisors can better assist their diverse population of graduate students. We believe this survey is a valuable resource to convey to graduate students and postdocs in the scientific community that they are not alone in dealing with anxieties about research progress, social isolation, and career progression as a result of this global crisis. More importantly, much of the lessons learned from this survey can be extracted beyond COVID-19, improving graduate students’ well-being in a postpandemic world.

\section*{Materials and Methods}
We surveyed graduate students and postdoctoral fellows within the Chemistry departments at 15 academic institutions across the United States (Scheme 2). We sent out the survey to these institutions based on the selectivity of their Ph.D. program (ranked in the top 50 by U.S. News and World Reports) and their geographic location (i.e., Northeast, South, Midwest, West Coast). The survey was emailed to chemistry departmental chairs and faculty to share with their graduate students and postdocs via email beginning October 1st, 2020, and the survey was closed on December 2nd, 2020. Based upon the size of these departments, we estimated our survey response in each program to be on average 15%. A link to the survey can be found in the Supporting Information (SI).

At the beginning of the survey, participants were polled about the work-from-home period that occurred around March 2020. They were then asked a series of questions that probed their professional and personal well-being during the pandemic relative to their professional and personal well-being before the pandemic. Next, participants were presented with a series of questions about the extent of professional and personal support they have received from their advisor, co-workers, department, and family and friends before and during the pandemic.

Furthermore, participants were queried about the type of support they have received from their advisor and their department and the importance of each support type. Next, participants were questioned about their thoughts and feelings about returning to lab after the work-from-home period. It is important to note that, during this period of time, vaccines were still not available to the general public. Thus, even upon returning to lab, students were still unvaccinated and were required to socially distance, creating underlying additional stresses with a lack of social connection and collaboration. In the last section of the survey, we collected demographic data (gender and URM status) and other participant information including their academic status (graduate student vs postdoc, year in Ph.D. program, completion of candidacy exam) and chemistry subfield (organic, polymer, computational, physical,
quantitative analysis; thus, our analysis focused only on male and female genders. The demographic characteristics of our themselves gender nonbinary was too low to be included in the survey sample are in good agreement with the demographic characteristics of chemistry Ph.D. programs reported by the National Science Foundation. If you were to name a single thing that has been the most challenging for you since the start of the COVID-19 pandemic, what would it be? (see the SI for details). The breakdown of participants who took the survey can be found in Scheme 2. The response rate from participants that considered themselves gender nonbinary was too low to be included in the quantitative analysis; thus, our analysis focused only on male and female genders. The demographic characteristics of our survey sample are in good agreement with the demographic characteristics of chemistry Ph.D. programs reported by the National Science Foundation. Given the relatively small number of URM participants, it is possible that we may not observe statistically significant differences across URM status, but qualitatively there might well exist important differences.

All of the analysis was conducted in R platform. For analyzing Likert scale questions, we used ordinal multivariable regression models as the dependent variables with categorical ordering (e.g., five-level Likert scale from strongly agree to strongly disagree). For analyzing binary questions (e.g., yes/no), we used logistic multivariable regression. We also used factor analysis and structural equation modeling to further explore the relationship between different variables. Given the small number of participants from each program, the data were analyzed all together without controlling for the institutions. In these quantitative analysis, gender and URM status were used as binary variables. We acknowledge the limitations of this approach to consider gender as a binary variable with only two levels of men and women and to group all racially marginalized students together. However, we did not have enough data points to include more nuanced categorizations of these demographic variables in our analyses. For all the regression analyses, we used the simplest best fitting models to explore the data. To do so, we started with a basic additive model for each analysis that had gender and URM variables as well as other required predictors for a given analysis (e.g., time interval of during or before the work from home). Then to that model, we added the interaction terms of the included predictors one by one and tested whether the addition of each interaction term significantly improved the fit of the model. For the model comparison to examine the fit improvement, we used AIC values of models. To explore intersectionality, we tested whether the interaction between gender and URM would significantly improve the fit of a model. If the model fit improved significantly by including an interaction term, then we used that interactive model for our analysis. The details of the regression models are included in the SI.

**RESULTS AND DISCUSSION**

**Work Characteristics and Research Progress**

We first asked survey participants to estimate the amount of time they spent working before the COVID-19 pandemic and during the work-from-home period. Due to the nature of research in the chemical sciences, we suspected that most participants would report a significant decrease in the amount of time working as a result of the COVID-19 pandemic. As expected, all participants reported working less during the work-from-home period ($b = -2.51 (0.18)$, $p < 0.0001$, Figure 1) (SI, Tables S1 and S2), and there was no difference based on gender ($p = 0.34$) or URM status ($p = 0.75$). Not surprisingly, most respondents also reported significantly less research progress during the work-from-home period (60% reported significantly less progress and 25% slightly less progress) with no difference based on gender ($p = 0.65$) or URM status ($p = 0.92$) (SI, Tables S3 and S4 and Figure S4). To better understand the challenges faced by graduate students and postdocs in their transition from working in a lab to working from home, we asked participants to rate the extent to which external factors (Internet access, family living situation, health concerns, distractions, housing situation, time zone differences, quality of home office, childcare responsibilities, and family member care responsibilities) impacted their ability to work from home. Participants ranked the quality of their home office and distractions as the greatest impediments to their work during the work-from-home period. Overall, female and URM participants believed that all listed external factors more negatively impacted their ability to work from home than their male and non-URM colleagues ($b = 0.19(0.06)$, $p_{gender} = 0.001$; $b = 0.39(0.04)$, $p_{URM} < 0.0001$) (SI, Tables S5 and S6).

We also asked participants to share their experiences returning to lab after the work-from-home period. Even when the majority of participants were allowed to return to lab, 82% reported that they were working less than they did before.
the pandemic. There was no difference in response based on
gender ($p = 0.99$) or URM status ($p = 0.81$) (SI, Tables S7 and
S8). Many students expressed frustration with their inability to
continue working like they did before the pandemic. One
participant commented: “[The pandemic] completely put a halt
to any and all progress that I was making when we shifted to
work-from-home schedules. Since the return to labs, I have been
unable to truly accomplish 85% of the work that I would otherwise
be doing because the instruments that I need are university-shared
instruments, which means that the activation barrier to get
anything done is astronomical compared to where it was pre-
pandemic.” Overall, respondents reported significantly less
research progress after the work-from-home period and there
was no difference based on gender ($p = 0.71$) or URM status
($p = 0.29$) (SI, Tables S9 and S10).

Quality of Collaborations

As a natural result of social distancing and more difficulties in
virtual communication during this time, we hypothesized that
many graduate students would express that the quality of their
collaborations decreased. When asked about the collaborations
before and during the pandemic, respondents reported that the
quality of research collaborations have decreased compared to
prepandemic. This was the case during the work-from-home period ($b = -2.52$ (0.23), $p < 0.0001$) as well as after the work-
from-home period and returning to the lab ($b = -1.72$ (0.18),
$p < 0.0001$). This finding is particularly important as the
majority of participants (65%) reported being involved in a
collaborative project. Notably, URM participants reported a
greater decrease in the effectiveness of research collaborations
($b = -1.42$ (0.65), $p = 0.03$), and furthermore, these
participants rated these collaborations as more effective
prepandemic ($b = 1.1$ (0.45), $p = 0.01$). The effect that the
pandemic has had on collaborations is exemplified by the
comments we received at the end of the survey. For example,
several students experienced “reduced collaboration with other
labs at my university and also labs at other universities” and noted
difficulties in “the inability to work in the office with a normal
flow of academic and non-academic communication. These more
casual interactions really benefit new students to feel secure with
their group and with their research.” These results suggest that
collaboration and communication about research is an essential
aspect of professional well-being within graduate research
programs that has been compromised due to the resulted
constraints of the pandemic (SI, Tables S11–S14).

Career Aspirations

With respect to their career prospects, the majority of
participants were either unsure how the COVID-19 pandemic
impacted their degree/position timeline (41%) or reported
that the COVID-19 pandemic prolonged their degree/position
timeline (30%). We believed that a significant number of
graduate students began to second-guess their career goals due
to the COVID-19 pandemic, and thus, we probed how
students’ career goals have changed. Although the majority of
participants (85%) reported that their career goals have not
changed during the pandemic, roughly half of these
respondents (41%) reported that they were less certain of
their career goal. Inconsequential of the COVID-19 pandemic,
approximately 25% of graduate students change their initial
career aspirations throughout the course of their graduate
training. However, we observe an even further increase in the
percentage of students whose career aspirations have changed
in the course of several months, with an emphasis on COVID-
19 as the result of this change. Notably, there was no difference
in the rate at which participants changed their career goals

Figure 2. Personal well-being of women (red) and men (blue) during the work-from-home period normalized across all responses (left); positive
values for an item across genders mean that the anxiety about that item is above average anxiety about all items, and negative values mean that
anxiety about that item is lower than average anxiety about all items. The personal well-being of women (red) and men (blue) upon returning to
lab (right): number of respondents from each gender who report feeling a given emotion, e.g., 61 male resondents reported feeling anxious about
returning to the lab. "Normalized across all responses."
based on gender ($p = 0.48$) or URM status ($p = 0.81$) (SI, Table S15). Regardless of their career goals, the majority of respondents were less excited about them during the pandemic than they were prepandemic, and this effect was marginally more pronounced for URM participants ($p = 0.06$); whereas 66% of non-URM participants were less excited about their career goals, 80% of URM participants were less excited about their career goals. Furthermore, we observed a gender difference with respect to participants’ career goals (SI, Tables S16 and S17). Compared to men, women were significantly less interested in a tenure track academic position at a research institution ($p < 0.001$), which is in agreement with recent trends observed by other researchers (SI, Tables S18 and S19). This result suggests that the pandemic has exacerbated women’s existing disinterest in academia.

**Personal Well-Being**

Aside from the negative effects the pandemic has had on graduate students’ research progress and career aspirations, we believed that the toll of the pandemic severely impacted the personal well-being of our participants. In order to assess how participants’ personal well-being changed during the pandemic, we asked them to rate how anxious they were about the following factors: their research progress, research funding, timeline of their degree/position, job prospects, financial security, housing situation, personal health, and well-being of their friends and family. In this context, emotions relating to “anxiety” are based on the colloquial definition of “anxiety” and not the clinical definition. During the pandemic, participants’ greatest sources of anxiety were related to their research progress and their job prospects. Notably, female participants reported greater anxiety levels than male participants across all factors ($p < 0.0001$) (Figure 2, left panel) (SI, Tables S20 and S21).

Upon returning to lab following the work-from-home period, the most reported emotion was anxiety followed by stress and exhaustion. Although there was no difference in these emotions based on URM status ($p = 0.91$), there were significant differences in the emotions reported by male and female participants. Compared to men, women were more anxious ($p < 0.001$), less excited ($p < 0.001$), and felt less safe ($p < 0.001$) going back to lab (Figure 2, right panel) (SI, Table S22).

The effect that the pandemic has had on participants’ personal well-being is exemplified by the comments we received at the end of the survey. Many participants in their free-response to the pandemic challenges disclosed that they have suffered from chronic feelings of anxiety, depression, isolation, and loneliness, all of which have impacted their ability to work effectively. As one respondent reported: “my anxiety has been harder to manage than ever because of the stressors of my environment, the lack of regular social contact at work, loss of access to my social networks and destressing activities, and pressure of being productive from home.”

Another respondent similarly stated: “limited social interactions both professionally and personally [have been challenging]. They both help build moral and group dynamic as well as preserve mental health. Talking is limited at work currently due to shifts and social distancing. In addition, social gatherings at work are not as common as they were before the pandemic.”

Thus, it can be seen that the pandemic has led to increased anxiety among graduate students and postdocs, thereby exacerbating the negative impact that the pandemic has had on their professional well-being.

It is clear from these survey results that the COVID-19 pandemic has negatively impacted the professional and personal well-being of graduate students and postdocs within the chemical sciences. Most strikingly, participants reported a substantial decrease in their research progress, which is the key metric of professional success for most Ph.D. and postdoctoral positions. There was no gender and URM difference in research progress changes. However, while everyone was anxious about the effect of the COVID-19 pandemic, women have been more impacted by the stress and reported higher
anxiety levels overall, particularly related to anxieties about research and health.

**Support Structures**

A strong support network helps mitigate the stress and anxiety that accompanies a crisis. Consequently, we were interested in examining participants’ support network throughout the COVID-19 pandemic. We theorized that students who reported higher levels of professional and personal support would report less anxiety and stress during this time. Specifically, we assessed how participants’ family and friends, co-workers, departments, and advisors supported their professional and personal well-being before and during the pandemic.

**Professional Support.** Before the pandemic, participants reported receiving the least professional support from their departments and then their co-workers ($p_{\text{department}} < 0.0001$, $p_{\text{co-workers}} = 0.01$) and the most professional support from their family and friends and their advisor. During the pandemic, the pattern stayed the same with the most support provided from family and friends and the least support from departments. Overall, URM participants reported receiving more professional support than their non-URM colleagues ($p = 0.04$) (Figure 3) (SI, Tables S23 and S24).

**Personal Support.** Before the pandemic, participants reported receiving the most personal support from their family/friends, followed by their co-workers ($p < 0.0001$), then their advisor ($p < 0.0001$), and finally their department ($p < 0.0001$). During the pandemic, participants reported a marginal increase in personal support from their family and friends ($p = 0.09$), significantly less personal support from their co-workers ($p < 0.0001$), and marginally less support from their departments ($p = 0.05$) (Figure 3). Notably, female participants reported receiving significantly more personal support from their family and friends than their male co-workers before and during the pandemic ($p < 0.0001$) (SI, Tables S25 and S26).

**Relationship between Research Progress, Professional Support, and Personal Well-Being**

To further assess how participants’ research progress has been impacted by their personal well-being and professional support structures, we performed factor analysis (see the Supporting Information for the details of factor analysis SI Tables S27–S32). We found that personal well-being could be categorized by three factors: anxiety about research security, anxiety about health security, and anxiety about financial security. “Research security” describes participants’ anxieties about their research progress and degree timeline. Anxiety about “Health Security” describes participants’ anxieties about the health of themselves, their family, and their friends. Anxiety about “Financial Security” describes participants’ anxieties about job prospects and their current financial situation. Similarly, the four sources of professional support (family/friends, co-workers, departments, and advisors) could be categorized into one variable called “professional support” and the same four sources of personal support (family/friends, co-workers, departments, and advisors) could be categorized into one variable called “personal support.” We ran structural equation modeling to further explore the relationship between professional support, personal support, and research progress. The SEM model used for this analysis was a good fit for the data, and all the fit indices fell within an acceptable range (CFI = 1.00, RMSEA = 0.004, SRMR = 0.023). We found that participants’ anxieties about research security and health security strongly correlated with their research progress during the work-from-home period ($b_{\text{research}} = -0.29 (0.05), p < 0.0001; b_{\text{health}} = -0.07 (0.04), p = 0.10$) and upon returning to lab ($b_{\text{research}} = -0.16 (0.05), p = 0.001$); students’ who were more anxious about their research or health security during the work from home reported less research progress. Similarly, women are significantly more anxious than men about both their research and health security ($b_{\text{research}} = 0.44 (0.11), p < 0.0001; b_{\text{health}} = 0.25 (0.13), p = 0.05$). Additionally, professional support during work from home was also marginally correlated with research progress ($b = 0.011 (0.06), p = 0.06$); participants’ who reported receiving more professional support throughout the pandemic also reported more research progress (Scheme 3) (SI, Tables S33–S36).

**Scheme 3. Factors Impacting Participants’ Research during the Work-at-Home Period (top) and upon Returning to Lab (bottom)**

As previously highlighted, participants’ advisors and departments contribute to their professional support. To ensure the well-being of their graduate students and postdocs, advisors and departments need to provide the support that their graduate students and postdocs desire most. Our results indicated that professional support can mitigate the negative
The pandemic has had on research progress. We explored the types of support respondents have received and wish to receive from their advisors and department. With respect to advisor support, participants reported that maintaining a respectful work environment, respecting commitments outside lab, and receiving advice on research projects and degree requirements were the most valuable types of support their advisor could provide. In contrast, the most common support that advisors provided was research group meetings. Importantly, the types of support advisors provided did not change despite the onset of a global pandemic, suggesting that this discrepancy is unrelated to the pandemic (Figure 4A). This observation is further validated in our analysis of participants’ perception of their graduation timeline. As previously noted, 41% of participants reported being unsure about their timeline, suggesting that advisors are not properly communicating this information with their students and postdocs. With respect to department support, participants reported that maintaining a respectful work environment, supporting an inclusive work environment, and providing mental health resources were the most important types of support. Before the pandemic, however, the most common form of department support was hosting departmental seminars and symposia. During the pandemic, participants reported a decrease in almost all types of departmental support ($p < 0.0001$) except those related to departmental efforts to support an inclusive environment ($p < 0.0001$) and solicit feedback ($p < 0.0001$), which have increased during the pandemic (Figure 4C) (SI, Tables S37–S42).

This difference in realized vs valued support is magnified for researchers from traditionally underrepresented groups (women, URM). With respect to advisor support, female
participants view respecting commitments outside of lab, providing mental health support, and maintaining a respectful work environment as more important than their male colleagues ($p = 0.03, p = 0.05, p = 0.06$, respectively) (Figure 4B). Additionally, female participants report receiving less professional support from their advisor than male participants. With respect to departmental support, female participants view almost all types of support as more important than their male colleagues ($p_{respected} = 0.004$, $p_{inclusive} < 0.0001$, $p_{mental health} = 0.01$, $p_{career progress} = 0.005$, $p_{degree} = 0.002$, $p_{feedback} = 0.002$) (Figure 4D). Similarly, all departmental supports, regardless of type, were deemed more important to URM participants than non-URM participants ($p = 0.02$). Although many graduate students and postdocs value various types of support from their advisor and department, researchers from under-represented groups (women, URM) find these supports to be significantly more important. Notably, the types of supports that these underrepresented groups value most have less to do with research and more to do with work environment. Overall, we observe that the types of support valued the most by graduate students and postdocs is not the type of support they receive the most from their advisors and departments (SI, Tables S19–S22).

It is important to emphasize that the support desired by participants is independent of the COVID-19 pandemic. While it is essential to provide extra compassion and support during a global crisis, our survey results reveal the ways in which chemistry advisors and departments can generally improve regardless of the pandemic. Based on our data, we have identified tangible steps that advisors and departments can take to better support their graduate students and postdocs, particularly those from underrepresented groups. Advisors should focus on creating and maintaining a respectful environment within their lab and respecting students’ and postdocs’ commitments outside of lab. For example, advisors could actively discourage poor lab citizenship practices, and they could schedule meetings on days/times that enable students and postdocs to fulfill their out-of-lab roles and responsibilities. Similarly, departments could reallocate some of the time they spend coordinating seminars to coordinating events that promote an inclusive work environment and providing mental health resources. For example, departments can organize workshops that discuss stress management techniques, host forums to solicit feedback from graduate students and postdocs, and place greater emphasis on inviting guest speakers that identify with underrepresented groups.$^{36}$ As stated by one participant: “I would say the best thing advisors can do for us now would be the same as before the pandemic: a commitment to good mentoring. I think departments should be more proactive in encouraging their training in this regard.” Improved communication and empathy from advisors and departments would greatly assist in supporting the professional and personal well-being of graduate students and postdocs, especially those from underrepresented groups. More importantly, creating an inclusive and supportive environment for students of all backgrounds is more valuable than ever for promoting a more equitable working environment for graduate students. Notably, these recommendations are timeless; they will enable graduate students and postdocs to thrive in the best of times and the worst of times.

**CONCLUSION**

In surveying graduate students and postdocs in chemistry programs across top schools in the United States, we observed that a majority of students have been extremely anxious about their research progress during the COVID-19 pandemic. Of these respondents, women have reported feeling more anxious overall. Furthermore, our survey revealed that many graduate students, particularly women and URM students, desire more support from advisors and departments in topics related to graduation timeline and research progress. A recent ACS Survey analyzing the graduate student experience has also noted that students who identify as URM and/or female have been less likely to receive desired support from their advisors.$^{37}$ Thus, the importance of one’s advisor and department during graduate school, especially for women and URM students cannot be underemphasized. By identifying the types of support participants value and receive, we discovered that what participants typically receive from their advisor and department is not what they value most. Participants report that research group meetings are the most common type of aid that they receive from their advisor. Notably, advice on research projects and efforts to maintain a respectful work environment are the types of advisor assistance that participants, especially female and URM students, value most. Similarly, participants report that seminars and symposia are most commonly hosted by their departments. However, efforts to promote an inclusive work environment and provide mental health resources are the types of support that participants, especially female and URM students, value most. Such results provide insight into ways in which advisors and departments can best mitigate stress and anxiety during a global crisis as well as in general. Advisors and departments should more explicitly: (1) guide advisees in their degree progress, (2) provide feedback on their research progress, (3) aid in helping students achieve their career goals, and (4) promote an inclusive work environment. While COVID-19 provided a global scale experiment that allowed us to gain insight into the well-being of graduate students, the results from this survey are not limited to the COVID-19 era; the insights derived from this survey can be used irrespective of a global pandemic to create a more inclusive, equitable, and supportive scientific community.

**ASSOCIATED CONTENT**

**Supporting Information**

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00412.

Details of survey, additional figures, and survey results (PDF)

Printed version of the full survey (PDF)

**AUTHOR INFORMATION**

**Corresponding Authors**

Brett P. Fors — Department of Chemistry and Chemical Biology, Cornell University, Ithaca, New York 14853, United States; orcid.org/0000-0002-2222-3825; Email: brettfors@cornell.edu

Shima Salehi — Graduate School of Education, Stanford University, Stanford, California 94305, United States; Email: salehi@stanford.edu

https://doi.org/10.1021/acs.jchemed.2c00412

J. Chem. Educ. XXXX, XXX, XXX--XXX
ACKNOWLEDGMENTS

This work was supported by the National Science Foundation Center for Sustainable Polymers at the University of Minnesota, a Center for Chemical Innovation (CHE-1901635). B.P.F. thanks the Alfred P. Sloan foundation for a Sloan Research Fellowship. The authors would like to thank Professor Natasha Holmes and her group for all her assistance with the initial survey logistics and planning. Finally, the authors would also like to acknowledge all the individuals that helped us distribute the survey and collect this data.

REFERENCES

(1) Krukowski, R. A.; Jagi, R.; Cardel, M. I. Academic Productivity Differences by Gender and Child Age in Science, Technology, Engineering, Mathematics, and Medicine Faculty During the COVID-19 Pandemic. *Journal of Women's Health* 2021, 30, 341–347.
(2) Woodston, C. Signs of depression and anxiety soar among US graduate students during pandemic. *Nature* 2020, 585, 147–148.
(3) Myers, K. R.; Tham, W. Y.; Yin, Y.; Cohodes, N.; Thursby, J. G.; Thursby, M. C.; Schiffer, P.; Walsh, J. T.; Lakhani, K. R.; Wang, D. Unequal effects of the COVID-19 pandemic on scientists. *Nature Human Behaviour* 2020, 4, 880–883.
(4) National Academies of Sciences, Engineering, and Medicine. Impact of COVID-19 on the Careers of Women in Academic Sciences, Engineering, and Medicine: The National Academies Press: Washington, DC, 2021.
(5) Malisch, J. L.; Harris, B. N.; Sherrer, S. M.; Lewis, K. A.; Shepherd, S. L.; McCarthy, P. C.; Spott, J. L.; Karam, E. P.; Moustaid-Moussa, N.; Calarco, J. M.; Ramalingam, L.; Talley, A. E.; Canas-Carrell, J. E.; Ardor-Dryer, K.; Weiner, D. A.; Bernal, X. E.; Detloff, J. Opinion: In the wake of COVID-19, academia needs new solutions to ensure gender equity. *Proc. Natl. Acad. Sci. U. S. A.* 2020, 117, 15378.
(6) Fauville, G.; Luo, M.; Queiroz, A. C. M.; Bailenson, J. N.; Hancock, J. Nonverbal Mechanisms Predict Zoom Fatigue and Explain Why Women Experience Higher Levels than Men. *Social Science Research Network* 2021, e3820035.
(7) Ahmed, M. Z.; Ahmed, O.; Aibao, Z.; Hanbin, S.; Siyu, L.; Ahmad, A. Epidemic of COVID-19 in China and associated Psychological Problems. *Asian Journal of Psychiatry* 2020, 51, 102092.
(8) Guadagni, V.; Umilta, A.; Iaria, G. Sleep Quality, Empathy, and Mood During the Isolation Period of the COVID-19 Pandemic in the Canadian Population: Females and Women Suffered the Most. *Frontiers in Global Women's Health* 2020, 23, 13.
(9) Saunders, R.; Buckman, J. E. J.; Fonagy, P.; Fancourt, D. Understanding different trajectories of mental health across the general population during the COVID-19 pandemic. *Psychological Medicine* 2021, 1.
(10) Xiong, J.; Lipsitz, O.; Nasri, F.; Lui, L. M. W.; Gill, H.; Phan, L.; Chen-Li, D.; Iacobucci, M.; Ho, R.; Majeed, A.; McIntyre, R. S. Impact of COVID-19 pandemic on mental health in the general population: A systematic review. *Journal of Affective Disorders* 2020, 277, 55–64.
(11) Connor, J.; Madhavan, S.; Mokashi, M.; Amanuel, H.; Johnson, N. R.; Pace, L. E.; Bartz, D. Health risks and outcomes that disproportionately affect women during the Covid-19 pandemic: A review. *Soc. Sci. Med.* 2020, 266, 113364.
(12) Cao, W.; Fang, Z.; Hou, G.; Han, M.; Xu, X.; Dong, J.; Zheng, J. The psychological impact of the COVID-19 epidemic on college students in China. *Psychiatry Res.* 2020, 287, 112934.
(13) Olagoke, A. O.; Olagoke, O. O.; Hughes, A. M. Exposure to coronavirus news on mainstream media: The role of risk perceptions and depression. *Br. J. Health Psychol.* 2020, 25, e12427.
(14) Wang, C.; Pan, R.; Wan, X.; Tan, Y.; Xu, L.; Ho, C. S.; Ho, R. C. Immediate Psychological Responses and Associated Factors during the Initial Stage of the 2019 Coronavirus Disease (COVID-19) Epidemic among the General Population in China. *International Journal of Environmental Research and Public Health* 2020, 17, 1729.
(15) Samadarshi, S. C. A.; Sharma, S.; Bhatta, J. An online survey of factors associated with self-perceived stress during the initial stage of the COVID-19 outbreak in Nepal. *Ethiopian Journal of Health Development* 2020, 34 (2), 84–89.
(16) Stockard, J.; Rohlling, C. M.; Richmond, G. L. Equity for women and underrepresented minorities in STEM: Graduate experiences and career plans in chemistry. *Proc. Natl. Acad. Sci. U.S.A.* 2021, 118 (4), e2020508118.
(17) Nagy, G. A.; Fang, C. M.; Hish, A. J.; Kelly, L.; Nicchitta, C. V.; Drarasa, K.; Rosenthal, M. Z. Burnout and Mental Health Problems in Biomedical Doctoral Students. *CBE-Life Sciences Education* 2019, 18 (2), ar27.
(18) Offstein, E. H.; Larson, M. B.; McNeele, A. L.; Mjoni Mwale, H. Are we doing enough for today's graduate student? *International Journal of Educational Management* 2004, 18 (7), 396–407.
(19) Mallinckrodt, B.; Leong, F. T. L. Social Support in Academic Programs and Family Environments: Sex Differences and Role Conflicts for Graduate Students. *Journal of Counseling & Development* 1992, 70, 716–723.
(20) Bostwick, V. K.; Weinberg, B. A. Nevertheless she persisted? Gender peer effects in doctoral STEM programs. *Journal of Labor Economics* 2018, 40 (2), 397.
(21) Tompkins, K. A.; Brecht, K.; Tucker, B.; Neander, L. L.; Swift, J. K. Who matters most? The contribution of faculty, student-peers, and outside support in predicting graduate student satisfaction. *Training and Education in Professional Psychology* 2016, 10, 102–108.
(22) Russo, G. Graduate students: Aspirations and anxieties. *Nature* 2011, 475, 533–535.
(23) Munir, S. S.; Jackson, D. W. Social Support, Need for Support, and Anxiety among Women Graduate Students. *Psychological Reports* 1997, 80, 383–386.
(24) De Clercq, M.; Devos, C.; Azzi, A.; Frenay, M.; Klein, O.; Galand, B. I Need Somebody to Lean on. *Swiss Journal of Psychology* 2019, 78, 101–113.
(25) Evans, T. M.; Bira, L.; Gastelum, J. B.; Weiss, L. T.; Vanderford, N. L. Evidence for a mental health crisis in graduate education. *Nat. Biotechnol.* 2018, 36, 282–284.
(26) Charles, S. T.; Karnaze, M. M.; Leslie, F. M. Positive factors related to graduate student mental health. *J. Am. Coll. Health* 2022, 70 (6), 1858.
(27) Ong, M.; Wright, C.; Espinosa, L. L.; Orfield, G. Inside the double bind: A synthesis of empirical research on undergraduate and graduate women of color in science, technology, engineering, and mathematics. *Harvard Educational Review* 2011, 81, 172–208.
(28) Ferreira, M. Gender issues related to graduate student attrition in two science departments. *International Journal of Science Education* 2003, 25, 969–989.
(29) Blickenstaff, J. C. Women and science careers: leaky pipeline or gender filter? *Gender and Education* 2005, 17 (4), 369–386.
(30) Scott, H.; Takarangi, M. K. T. Measuring PhD Student’s Psychological Well-being: Are we seeing the whole picture? *Student Success* 2019, 10, 14–24.
(31) Juniper, B.; Walsh, E.; Richardson, A.; Morley, B. A new approach to evaluating the well-being of PhD research students. *Assessment & Evaluation in Higher Education* **2012**, *37*, 563–576.

(32) Heath, T. A Quantitative Analysis of PhD Students’ Views of Supervision. *Higher Education Research & Development* **2002**, *21*, 41–53.

(33) Kang, J. *Doctorate Recipients from U.S. Universities: 2019* | NSF - National Science Foundation. https://ncses.nsf.gov/pubs/nsf21308/data-tables#group3 (accessed 2021-06-06).

(34) Huang, J.; Gates, A. J.; Sinatra, R.; Barabási, A.-L. Historical comparison of gender inequality in scientific careers across countries and disciplines. *Proc. Natl. Acad. Sci. U.S.A.* **2020**, *117*, 4609.

(35) Beehr, T. A.; McGrath, J. E. Social support, occupational stress and anxiety. *Anxiety, Stress & Coping: An International Journal* **1992**, *5*, 7–19.

(36) Woloshyn, V.; Savage, M. J.; Ratkovic, S.; Hands, C.; Martinovic, D. Exploring professors’ experiences supporting graduate student well-being in Ontario faculties of education. *International Journal of Mentoring and Coaching in Education* **2019**, *8*, 397–411.

(37) Rohlfing, C. M.; Richmond, L. G.; Noviski, M.; Lewis, P.; Stockard, J. Policies and Practices to Improve the Chemistry Graduate Student Experience: Implications of the ACS Survey of Graduate Students. *J. Chem. Educ.* **2022**, *99*, 10–13.