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Original Article

Undergraduate researchers' graduate school intentions during COVID-19

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There is emerging literature on the disruptive effects of the COVID-19 pandemic on college students, but little is known about the impacts on undergraduate researchers (UGRs). On the basis of survey data collected in Summer 2020, this paper examines how less competent mentorship and COVID-19–related difficulties shaped UGRs' graduate school intentions. Results suggest that the pandemic strengthened UGRs' graduate school intentions when UGRs experienced fewer COVID-19–related difficulties. The pandemic weakened URG's graduate school intentions when they had a less competent faculty mentor. Having a more competent postgraduate mentor had a positive effect on UGRs' graduate school intentions in response to the pandemic. Those findings indicate that higher quality postgraduate mentorship may serve as an effective surrogate for lower quality faculty mentorship. Findings suggest that immediate strategies are needed to bolster graduate school aspirations among specific groups of UGRs in response to the pandemic. UGRs of particular concern include those who were highly impacted by COVID-19 with less competent mentors, were first-generation college students, had less prior research experience, had their Summer 2020 research experiences canceled, and were social/behavioral sciences majors.

Keywords: mentorship; graduate school intention; undergraduate research experiences; COVID-19

Introduction

Owing to the widespread implementation of undergraduate research programs (URPs) over the past 25 years, increasing numbers of American college students have had the opportunity to be undergraduate researchers (UGRs). In 2019, 22% of U.S. college seniors had conducted research by graduation.[1] When participating in research, students have opportunities to receive professional training and financial support, engage with the scientific community through research dissemination, and, most importantly, be guided by mentors.[2] Owing to those opportunities, UGRs, as compared with undergraduates who are not involved in research, have better academic performance, a greater likelihood of completing their undergraduate degrees, and improved preparedness and enhanced motivation to pursue graduate education.[3,4] However, UGRs might have negative experiences, which are detrimental to their psychosocial and career development, which are often related to challenges with mentorship.[5–9]

UGRs faced unprecedented challenges in 2020. With the spread of the COVID-19 pandemic in the United States, most colleges and universities transitioned from in-person engagement to online delivery modes.[10] This transition was particularly difficult for URPs, as there was no preexisting remote framework in place to support the online management of undergraduate research experiences. As a result, in Spring 2020, many institutions required UGRs to either postpone their projects or conduct research remotely. About half of Summer 2020 research programs in the United States were also canceled (unpublished data). Many UGRs, like

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other college students, had to navigate their undergraduate lives while facing financial and health shocks caused by COVID-19.[11] But unlike other students, UGRs experienced added research-related challenges. That is, when conducting research remotely, they often struggled with time management, felt uncertain about their research tasks, and lacked access to the research tools needed for their projects (unpublished data). The vulnerable situation of UGRs during COVID-19 might have placed their development at heightened risk to low-quality mentorship.

One might assume that UGRs became less enthusiastic about their intellectual journeys and less motivated to pursue graduate education in science because of the obstacles they encountered in 2020. If a large proportion decides to leave the science training pathway during or after the pandemic, the U.S. scientific workforce will face a critical talent supply problem later. According to the Association of American Medical Colleges, however, the number of medical school applicants increased 18% in 2020.[14] Medical school admission officials believe this was driven by the positive example that medical workers and public health figures, such as Dr. Anthony Fauci, set during the pandemic; thus, they referred to this as the "Fauci effect."[12] There are distinctions between the pursuit of medical school versus graduate school, yet it is plausible that the ongoing pandemic also raised college students', especially UGRs', intentions to further their research training in graduate school. In this study, we ask two fundamental questions: did the pandemic alter current UGRs' intentions to pursue graduate school? Did mentor competency play a role?

Review of literature

Faculty mentorship and undergraduate researchers

Faculty mentorship is a central element of undergraduate research. Studies have documented the advantageous effects of faculty–undergraduate mentoring relationships on various student outcomes, such as improved research skills, accelerated professional and career development, and increased persistence in science-related disciplines.[13–15] The mentee-perceived quality of faculty mentorship is both an outcome of actual mentor competency and a predictor of mentee career outcomes.[16]

Not all mentors are equally effective. A handful of studies have acknowledged some problematic elements of negative mentoring experiences for undergraduate students, such as mentors being absent, setting unrealistic expectations, and failing to provide adequate career or psychosocial support.[5–9] Low-quality mentorship can limit the mentee's socialization into a profession.[16] In the context of undergraduate research, faculty mentors often act as socializing agents, drawing the mentee into the science profession by providing research support and encouraging the mentee to internalize the norms, behaviors, and values of the scientific community.[17] Those with less competent faculty mentors may lose out on these important socialization opportunities.[18]

Given that interactional dynamics between faculty mentors and UGRs were interrupted by the pandemic and that many faculty mentors were new to the virtual environment and faced pandemic burnout,[19] UGRs might very likely have experienced less favorable mentoring in 2020. Research shows that students who have negative mentoring experiences are less likely to continue with scientific research.[20] Therefore, it is important to investigate whether having a less competent faculty mentor during the pandemic weakened UGRs' graduate school intentions.

Postgraduate mentorship and undergraduate researchers

Graduate students and postdoctoral fellows (postgraduates) may serve as mentors for UGRs, in addition to faculty. In many research laboratories and teams, faculty delegate postgraduates the task of mentoring undergraduates.[6,21] These relationships are often referred to as mentoring triads (i.e., faculty, postgraduate, and undergraduate), as opposed to dyads (i.e., faculty and undergraduate). Besides managing the day-to-day operations of research projects, postgraduate mentors also provide technical, psychosocial, and informational support to UGRs.[6,9] Compared with faculty, postgraduates often have more opportunities to interact individually with UGRs and may develop stronger relationships with them due to age similarities and more recent experiences as undergraduates themselves.[6] UGRs benefit from observing postgraduates as they navigate the research team and conduct research.[22]

However, not all postgraduates have the necessary mentoring knowledge and skills, and an incompetent postgraduate mentor can affect UGRs negatively. Dolan and Johnson[6] found that some postgraduates pressured UGRs to work long hours, and having postgraduate mentors also reinforced a sense of hierarchy in the research team. Morales *et al.*[23] observed a "penalty" among UGRs for having a postgraduate mentor, specifically in terms of suppressed gains from their research experiences. Those studies support the position that mentorship research should not overlook the impact of postgraduate mentors on students.[24] Unfortunately, few studies have focused on postgraduate mentors, and no studies have investigated the effects of postgraduate mentor competency on URGs in the context of COVID-19.

Assessing mentor competency

In the literature on mentoring, scholars have developed multidimensional scales to measure the multiple dimensions of mentor competency. Cohen[25] was the first to create a mentor competency scale, which includes six interrelated behavioral functions. Similarly, Zachary[26] identified a series of skills to measure mentor competency, such as building and maintaining relationships, coaching, communicating, goal setting, listening, and managing conflict. More recently, the Mentoring Competency Assessment (MCA) was designed specifically for undergraduate mentees to evaluate their research mentors through a national trial of an educational intervention involving more than 200 pairs of faculty mentors and undergraduate mentees at 16 universities.[27] The MCA is a validated mentoring skills inventory[27] and has been used by recent studies on undergraduate research.[28–30]

The MCA asks the mentee to assess six specific competencies, that is, maintaining effective communication, aligning expectations, assessing understanding, addressing diversity, promoting professional development, and fostering independence.[27] Maintaining effective communication refers to mentors' skills regarding productively giving, receiving, and exchanging ideas with mentees, such as engaging in active listening and providing constructive feedback. Aligning expectations refers to mentors' abilities to establish shared expectations for the mentoring relationship. Assessing understanding refers to mentors' skills for evaluating mentees' knowledge of core research concepts and processes and using multiple strategies to enhance understanding. Addressing diversity relates to mentors' abilities to recognize the potential impact of conscious and unconscious biases on mentoring relationships and identify concrete strategies to address issues of equity and inclusion. Promoting professional development refers to mentors' capacities to guide mentees along their professional paths, such as helping mentees set professional and career development goals and engaging in open dialogue with mentees on balancing competing demands (e.g., work–family balance). Fostering independence refers to mentors' skills in helping their mentees become independent researchers. A list of the items under each competency can be found in Appendix A (online only). The six competencies are integrated into a composite MCA score.

Graduate school intentions

The global competitiveness of the United States depends on enrolling more students, especially those from underrepresented backgrounds, in science graduate school programs.[31] The transition from undergraduate to graduate education is a critical stage for the students' pursuit of scientific careers. Many decide to leave science at this junction.[32] Undergraduate research experiences have long been shown to correlate with graduate school matriculation and success.[4,33–35] In addition, student background characteristics, such as gender, race/ethnicity, socioeconomic status, and academic performance, influence students' motivations and decisions to pursue graduate science degrees.[36,37]

It may be that the pandemic has affected students' interest in graduate education. Research suggests that staying motivated during COVID-19 has been particularly challenging for college students. Their decreased motivation is related to online learning, the lack of regular class routines, the chaos of the pandemic, and the lack of interaction with their professors.[38–40] Since college students, including UGRs, have struggled with motivation in online courses, they may also be struggling with motivation to pursue graduate school, but this has not yet been empirically examined.

Contribution and research questions

The literature has clearly documented the effects of low-quality mentorship on undergraduate

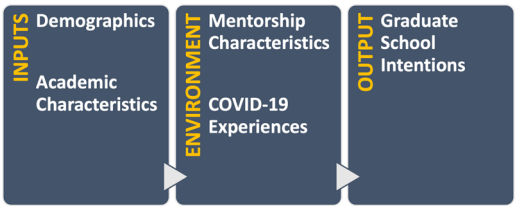

Figure 1. The input-environment-output (I-E-O) model.

students; however, attention has centered on faculty mentors, and those effects have not been tested in a context of a major crisis like the COVID-19 pandemic. There is also emerging literature on the disruptive effects of the pandemic on college students, which has documented impacts on student mental health,[41–44] learning experiences,[38,39] and academic outcomes.[11] This nascent literature, however, has not focused on the experiences of UGRs, leaving questions regarding impacts on their graduate school intentions unexplored. In this paper, we address those gaps by answering three research questions using survey data collected in Summer 2020: (research question (RQ)-1) How has the COVID-19 pandemic impacted UGRs' graduate school intentions? (RQ2) Was having less competent faculty and postgraduate mentors associated with a decline in UGRs' graduate school intentions during COVID-19? and (RQ3) How did COVID-19 impacts intersect with less competent faculty mentorship to influence UGRs' graduate school intentions?

Conceptual model

We designed our analyses based on an Input-Environment-Output (I-E-O) model. The I-E-O model was developed by Austin and Antonio[45] and has been used in educational studies of UGRs.[23,46] Similar to random assignment enabled in controlled experiments, the I-E-O model isolates the effects of specific educational environments on student outcomes by adjusting for the effects of initial student attributes.[46] In other words, the I-E-O model orients multivariable analyses that comprehensively adjust for potential biasing factors. "Inputs" are attributes that a student initially brings to a specific educational environment, "environment" represents the student's experiences in the educational environment, and "outputs" generally refer to student development outcomes.[46] Figure 1 depicts the I-E-O model for this study. Here, we used student demographics and academic characteristics as inputs. The environment variables were mentorship characteristics, including our focal variables of faculty and postgraduate mentor competency and COVID-19 experiences. For the output, we examine UGRs' graduate school intentions.

Methods

Data collection

The authors developed an online survey to collect data. The survey took UGRs approximately 30 min to complete and included six domains: (1) personal and educational circumstances in Spring 2020; (2) research disruption due to COVID-19; (3) prior research experiences; (4) strength of mentoring relationships; (5) general COVID-19 experiences; and (6) sociodemographic characteristics. To recruit study participants, we collaborated with URP directors across the country. We reached out to potential participating directors through two channels: we emailed program directors affiliated with a National Institutes of Health–funded multi-institutional partnership, and we posted to the Council on Undergraduate Research listserve. We established working relationships with URP directors from 18 universities to help us identify student participants for the study. Some of these directors oversaw multiple programs at that same institution, and several others liaised with other program directors at the same institution to identify additional participants. Students were eligible to take the survey if they were current undergraduate students who conducted research in Spring 2020 and/or did (or were selected to do) research in Summer 2020. To increase the response rate, we asked the program directors to send out survey invitations and reminders, which we provided. Starting on July 6, 2020, students were invited to take the survey. Nonrespondents received weekly reminders for 2 weeks. We officially closed the survey on July 31. The study was approved by the second author's university IRB board (#00133477), and all participants received an Amazon eGift card as an incentive after taking the survey.

Sample characteristics

In total, 2400 survey invitations were delivered via email; 1220 students answered some or all of the questions. For this paper, we selected students who had a science-related major and reported having a

faculty mentor ($n = 820$). Those students were from over 100 universities representing a wide variety of institutional contexts across the country. Generally speaking, the universities providing the most participants were research-intensive second-tier state, flagship state, and private universities. Among these students, 26% were conducting research at the start of Spring 2020 but stopped midsemester due to the onset of COVID-19; 22% conducted research for the duration of the Spring 2020 semester; 21% participated in Summer 2020 research but did not conduct research in Spring 2020; and 31% conducted research in Spring and Summer 2020.

The 820 UGRs included in this study were from diverse backgrounds. About 60% were women, 39% were men, and 1% were students with nonbinary gender identities (e.g., trans man, trans woman, genderqueer, and gender nonconforming). In terms of race/ethnicity, 35% of the UGRs were non-Hispanic White, 34% Hispanic, 21% non-Hispanic Asian, 5% non-Hispanic Black, and 6% were from Native American, Pacific Islander, multiracial, or other racial/ethnic backgrounds. For classification, 44% of the UGRs were seniors, 37% juniors, and the rest were first- or second-year college students. About 30% were first-generation college students, defined as not having a parent with a college degree. Finally, the UGRs had various levels of prior research experience as of the Spring 2020 semester: about 13% were first-time researchers, 37% had less than a year of research experience, and half had a year or more of research experience.

Measures

Following the I-E-O model, inputs were used as *independent variables*. For demographics, we included three categories of gender (i.e., man [reference], woman, and those outside the gender binary), underrepresented minority (URM) status (1 = yes [Hispanic, Black, Native American, Pacific Islander, Multiracial]; 0 = no [White, Asian]), and first-generation college student status (1 = yes, 0 = no). Academic characteristics were student self-reported cumulative major grade point average (GPA), self-reported major categories (engineering; health sciences; social/behavioral sciences; math/computer/physical sciences; and life sciences [reference]), and a continuous measure of pre-2020 research experiences in months.

Environment variables were also used as *independent variables*. The first group of environment variables was related to mentorship. Respondents were asked to answer 26 Likert survey items (1 = low competency to 5 = high competency) from the MCA to assess their mentors' competency. We averaged the 26 items to create a mentor competency score.[27] All respondents had a competency score for their faculty mentor. On the basis of the value of the score, we created two categories of faculty mentors (i.e., a more competent faculty mentor [competency score $\geq$ average value of the sample] versus a less competent faculty mentor [competency score $<$ average value of the sample]). About 52% of the UGRs had a more competent faculty mentor, and the average competency score for these mentors was 4.6; 48% had a less competent mentor, and the average score for those mentors was 3.3.

For those who had a postgraduate mentor, a competency score for the postgraduate mentor was similarly calculated. Then, three categories were developed for postgraduate mentors (i.e., a more competent postgraduate mentor, a less competent postgraduate mentor, and no postgraduate mentor). The majority of UGRs (i.e., 69%) did not have a postgraduate mentor; 16% had a more competent postgraduate mentor, and the average score was 4.7 for these postgraduate mentors. The rest had less competent postgraduate mentors whose average competency score was 3.5.

Previous studies used the MCA score as a continuous variable,[28–30] as they only focused on faculty mentors. In the current study, we take into account both mentoring dyads, when students worked only with a faculty mentor, and triads when they worked with faculty and postgraduate mentors. Therefore, to include all UGRs in the analyses, we created these categorical mentor competency variables, which could be a useful strategy for future research on postgraduate mentorship.

Students were also asked to report how often they communicated with their faculty mentors during COVID-19 (ranging from 1 = less than once a month to 6 = daily). They indicated the mode of communication (i.e., virtual meetings [reference]; in-person; and phone/text/email). They also reported the duration of the relationship with that faculty mentor in months.

The second group of environment variables quantifies the impacts of COVID-19. We listed 17

Table 1. COVID-19 impacts ($n = 820$)

	COVID-19 impacts	N (Yes)
1	Had to move out of a dormitory or university housing due to COVID-19	226
2	Experienced difficulties in traveling	299
3	Lost your job permanently or temporarily	241
4	Your family members lost their jobs permanently or temporarily	214
5	You experienced a salary cut	105
6	Your family members on whom you rely on for at least some financial support experienced a salary cut	169
7	The amount of your scholarship was reduced	34
8	Your scholarship was canceled	26
9	Payment of your scholarship was postponed	19
10	Your experienced racial/ethnic discrimination related to COVID-19	48
11	You experienced domestic abuse during the quarantine	9
12	Those you live with acted irresponsibly with regard to social distancing	177
13	You had to take care of others who were sick	41
14	You worried whether your food would run out before you (or your household) got money to buy more	83
15	The food that you or the adults in your household bought just didn't last, and you didn't have money to get more	20
16	You or other adults in your household cut the size of your meals or skipped meals because there wasn't enough money for food	23
17	You lost weight because there wasn't enough money for food	16

common COVID-caused difficulties in the survey (see Table 1) and asked students to indicate whether they experienced each of them. On the basis of the authors' experiences of mentoring UGRs during the pandemic, we coded students who reported four or more difficulties as highly impacted by COVID-19 (1 = yes, 0 = no), and those who reported less than four difficulties as less impacted by COVID-19 (1 = yes, 0 = no). One-fifth of UGRs experienced more than four difficulties. We created this dichotomous variable for COVID-19 impacts to enable the analysis for the third research question. For students' research involvement during COVID-19, we included four categories (i.e., began Spring 2020 doing research but stopped due to pandemic; did research for the duration of the Spring 2020 semester only; did research only in Summer 2020; and did research during Spring 2020 semester and through at least July 2020 [reference]).

We developed a matrix to conceptualize the interactions between low mentorship quality, mentoring dyads versus triads, and COVID-19 impacts (see Fig. 2). We created six mentoring scenarios for UGRs who worked with less competent faculty mentors during COVID-19. As shown in the matrix, Scenario I is that a UGR worked only with a less competent faculty mentor and was highly impacted by COVID-19. Scenario II refers to a UGR who had less competent faculty and postgraduate mentors and was highly impacted by COVID-19. Scenario III represents a mentoring triad where a UGR had a less competent faculty mentor, a more competent postgraduate mentor, and was highly impacted by COVID-19. Three corresponding scenarios (IV–VI) were created for students who were less (versus highly) impacted by COVID-19. As shown in Figure 2, we compare these six scenarios with all other UGRs who had a more competent faculty mentor (regardless of the postgraduate mentor and COVID-19 impacts) in our analyses.

Finally, the output of the I-E-O model is the *dependent variable*. In the survey, we asked, "how has the COVID-19 pandemic influenced your motivation to pursue a graduate degree in science?" Response options include 1 = much less motivated, 2 = somewhat less motivated, 3 = a little less motivated, 4 = not more or less motivated, 5 = a little more motivated, 6 = somewhat more motivated, and 7 = much more motivated. We emphasized in the survey that a science degree was broadly defined, which could include engineering, social/behavioral sciences, health sciences, or life sciences. Table 2

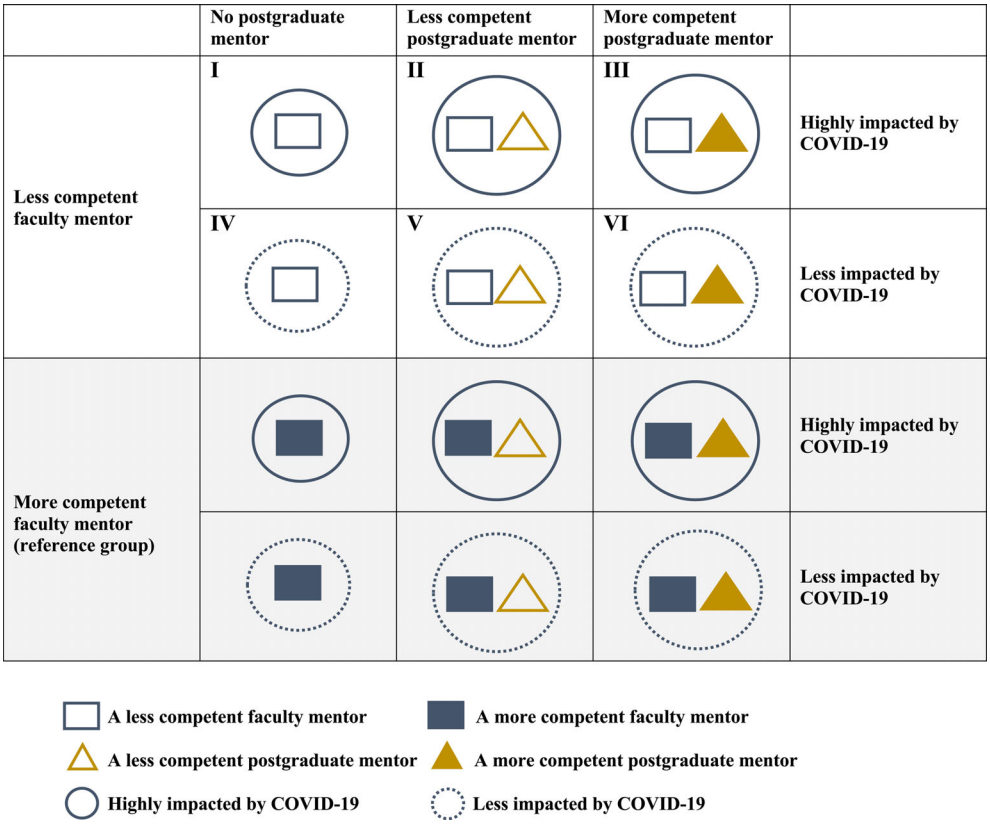

Figure 2. The mentoring relationship matrix.

presents descriptive statistics of all analysis variables.

Missing data

We used multiple imputation (MI) to estimate the missing values of all analysis variables. The MI approach involves fitting a model to impute missing values for each variable.[47] Our MI process continued until 200 iterations were reached, and the imputed values at the maximum iteration were saved to the imputed dataset. In total, 20 complete multiply imputed datasets were created ($n = 820$ in each dataset). After MI, we treated originally ordinal measures, such as the output, as continuous variables because rounding off imputed values based on discrete categorical specifications produces more biased parameter estimates than treating them as continuous.[48]

Statistical modeling

To address RQ1, we ran univariate descriptive statistics on the output using the original dataset. Then, to address RQ2 and RQ3, we used generalized estimating equations (GEEs) to predict the output. GEEs are appropriate because: first, similar to generalized linear models, GEEs relax the assumptions of traditional regression models (e.g., normality of variable distribution);[48–50] second, GEEs are more suitable than generalized linear models to analyze clustered data;[51] and our data had a clustered structure. The 820 students in the sample were clustered within 114 home institutions and three classification categories (i.e., seniors; juniors; and first-/second-year college students). Thus, we used each student's home institution and classification to define clusters for our models. There were 160 clusters in total, and the number of students in each cluster ranged between 1 and 76 students. By accounting for the institution as a clustering variable, we were able to address potential institutional effects (e.g., institution type, characteristics, and research culture) by design. This is appropriate because our focus

Table 2. Descriptive statistics

	Min.	Max.	Mean	SD	Yes	No	% missing
Independent variables							
Inputs							
Gender:							
Man [ref]	0	1	–	–	285	458	9.4
Woman	0	1	–	–	449	294	9.4
Beyond binary	0	1	–	–	9	734	9.4
Underrepresented minority	0	1	–	–	328	413	9.6
First-generation college student	0	1	–	–	238	582	0.0
Major GPA	2	4	3.73	0.34	–	–	2.7
Major:							
Engineering	0	1	–	–	197	623	0.0
Health sciences	0	1	–	–	53	767	0.0
Math/Computer science/Physical sciences	0	1	–	–	76	744	0.0
Social/Behavioral Sciences	0	1	–	–	103	717	0.0
Life sciences [ref]	0	1	–	–	391	429	0.0
Pre–COVID-19 research experiences (in months)	0	28	13.00	8.31	–	–	0.1
Environment							
COVID-19 research timeline:							
Spring and summer [ref]	0	1	–	–	253	567	0.0
Early spring	0	1	–	–	216	604	0.0
Full spring	0	1	–	–	179	641	0.0
Summer only	0	1	–	–	172	648	0.0
COVID-19 impacts:							
Less impacted [ref]	0	1	–	–	660	160	0.0
Highly impacted	0	1	–	–	160	660	0.0
Frequency of communication with a faculty mentor during COVID-19	1	6	3.29	1.38	–	–	4.5
Primary communication mode (faculty mentor/mentee):							
Virtual [ref]	0	1	–	–	374	408	4.6
In-person	0	1	–	–	31	751	4.6
Phone/text/email	0	1	–	–	377	405	4.6
Mentoring relationship duration (faculty mentor/mentee) (in months)	0.50	66.00	16.40	10.33	–	–	6.8
Faculty mentor competency:							
Having a more competent faculty mentor [ref]	0	1	–	–	407	374	4.8
Having a less competent faculty mentor	0	1	–	–	374	407	4.8
Postgraduate mentor competency:							
Having a more competent postgraduate mentor [ref]	0	1	–	–	120	700	6.6
Not having a postgraduate mentor	0	1	–	–	529	291	6.6
Having a less competent postgraduate mentor	0	1	–	–	117	703	6.6

Continued

Table 2. (Continued)

	Min.	Max.	Mean	SD	Yes	No	% missing
Mentoring scenarios:							
I (a less competent faculty mentor + highly impacted by COVID-19)	0	1	–	–	48	772	6.2
II (less competent faculty and postgraduate mentors + highly impacted by COVID-19)	0	1	–	–	18	802	6.2
III (a less competent faculty mentor + a more competent postgraduate mentor + highly impacted by COVID-19)	0	1	–	–	12	808	6.2
IV (a less competent faculty mentor + less impacted by COVID-19)	0	1	–	–	191	629	6.2
V (less competent faculty and postgraduate mentors + less impacted by COVID-19)	0	1	–	–	68	752	6.2
VI (a less competent faculty mentor + a more competent postgraduate mentor + less impacted by COVID-19)	0	1	–	–	25	795	6.2
Dependent variables							
Output							
Motivation to pursue a graduate degree in science	1	7	4.32	1.43	–	–	18.8
Output by mentoring scenarios:							
I (a less competent faculty mentor + highly impacted by COVID-19)	1	7	3.78	1.44	–	–	14.6
II (less competent faculty and postgraduate mentors + highly impacted by COVID-19)	1	7	3.53	1.25	–	–	16.7
III (a less competent faculty mentor + a more competent postgraduate mentor + highly impacted by COVID-19)	1	7	4.82	1.60	–	–	8.3
IV (a less competent faculty mentor + less impacted by COVID-19)	1	7	4.21	1.31	–	–	19.9
V (less competent faculty and postgraduate mentors + less impacted by COVID-19)	1	7	4.07	1.20	–	–	18.8
VI (a less competent faculty mentor + a more competent postgraduate mentor + less impacted by COVID-19)	1	7	4.62	1.12	–	–	16.0

Table 3. The GEE model predicting student graduate school intentions

	Model 1		
	B	Exp(B)	*P*
Inputs			
Man	ref	ref	ref
Woman	−0.025	0.975	0.101
Beyond binary	−0.091	0.913	0.149
Underrepresented minorities	0.035*	1.036	0.027
First-generation college student	−0.039*	0.962	0.040
Major GPA	−0.024	0.977	0.325
Life sciences	ref	ref	ref
Social/Behavioral sciences	−0.060*	0.942	0.011
Engineering	−0.008	0.992	0.707
Health sciences	0.004	1.004	0.926
Math/Computer Science/Physical sciences	−0.026	0.974	0.417
Pre–COVID-19 research experiences	0.003*	1.003	0.030
Environment			
Spring and Summer	ref	ref	ref
Early spring	−0.051	0.951	0.053
Full spring	−0.085**	0.919	0.001
Only summer	−0.017	0.983	0.425
Frequency of communication with mentor	0.002	1.002	0.778
Virtual communication	ref	ref	ref
In-person communication	0.087*	1.091	0.013
Phone/text/email	0.003	1.003	0.842
Mentoring relationship duration	−0.002	0.998	0.079
Having a more competent faculty mentor	ref	ref	ref
Having a less competent faculty mentor	−0.037*	0.963	0.037
Having a more competent postgraduate mentor	ref	ref	ref
Not having a postgraduate mentor	−0.059**	0.943	0.004
Having a less competent postgraduate mentor	−0.073**	0.929	0.004
Less impacted by COVID-19	ref	ref	ref
Highly impacted by COVID-19	−0.037*	0.964	0.037

Note: Model specification: an inverse Gaussian distribution with a log link function and the exchangeable correlation matrix. $^{**}P < 0.01$. $^{*}P < 0.05$. Ref, reference.

is on graduate school intentions at the individual level and not on specific institutional-level effects.

Since we used the multiply imputed data for the GEE models, our dependent variable was continuous and did not include 0. Therefore, when selecting the best fitting models, we tested normal, gamma, and inverse Gaussian distributions with logarithmic (log) and identity link functions under different specifications of the intracluster dependency correlation matrix (i.e., independent, exchangeable, and unstructured).[49,50,52] The inverse Gaussian distribution with a log link function and the exchangeable correlation matrix was best fitting for both models because it resulted in the lowest quasi-likelihood under the independence model criterion (QIC) value. Although the dependent variable was continuous, due to the log link function of the model, we exponentiated each coefficient (shown under the Exp(B) column in Tables 3 and 4). To interpret results, we subtracted one from Exp(B) and multiplied by 100, which clarified the percentage change in the dependent variable associated with a unit change in the independent variable.

To test the independent effects of mentor competency and COVID-19 impacts on student graduate school intentions (RQ2), we estimated a GEE model

Table 4. The GEE model predicting student graduate school intention

	Model 2		
	B	Exp(B)	*P*
Inputs			
Man	ref	ref	ref
Woman	−0.025	0.975	0.091
Beyond binary	−0.093	0.911	0.145
Underrepresented minorities	0.033	1.033	0.056
First-generation college student	−0.040*	0.960	0.034
Major GPA	−0.023	0.977	0.341
Life sciences	ref	ref	ref
Social/Behavioral sciences	−0.064**	0.938	0.005
Engineering	−0.010	0.990	0.628
Health sciences	0.002	1.002	0.966
Math/Computer Science/Physical sciences	−0.030	0.970	0.350
Pre–COVID-19 research experiences	0.003*	1.003	0.020
Environment			
Spring and Summer	ref	ref	ref
Early spring only	−0.052*	0.949	0.046
Full spring only	−0.082**	0.921	0.002
Only summer	−0.016	0.984	0.442
Frequency of communication with mentor	0.002	1.002	0.763
Virtual communication	ref	ref	ref
In-person communication	0.082*	1.086	0.017
Phone/text/email	0.002	1.002	0.900
Mentoring relationship duration	−0.002	0.998	0.060
Having a competent faculty mentor	ref	ref	ref
Scenario I: a less competent faculty mentor + highly impacted by COVID-19	−0.087*	0.917	0.024
Scenario II: less competent faculty and postgraduate mentors + highly impacted by COVID-19	−0.122*	0.886	0.016
Scenario III: a less competent faculty mentor + a more competent postgraduate mentor + highly impacted by COVID-19	0.048	1.049	0.368
Scenario IV: a less competent faculty mentor + less impacted by COVID-19	−0.041*	0.960	0.031
Scenario V: less competent faculty and postgraduate mentors + less impacted by COVID-19	−0.052*	0.949	0.030
Scenario VI: a less competent faculty mentor + a more competent postgraduate mentor + less impacted by COVID-19	0.010	1.010	0.793

Note: Model specification: an inverse Gaussian distribution with a log link function and the exchangeable correlation matrix. $^{**}P < 0.01$ and $^{*}P < 0.05$. Ref, reference.

(Model 1) to predict graduate school intentions, in which faculty mentor competency (more competent [reference] versus less competent), postgraduate mentor competency (more competent [reference], less competent, no postgraduate mentor), and COVID-19 impacts (less impacted [reference] versus highly impacted) were the focal independent variables, while inputs and other environment variables were used as controls. Next, to answer RQ3, we incorporated the six mentoring scenarios from the mentoring relationship matrix (versus all UGRs with more competent faculty mentors,

with or without a postgraduate mentor, regardless of the COVID-19 impacts) into one GEE model (Model 2) to examine the interactions between low faculty mentor competency and COVID-19 impacts.

Sensitivity analysis

Since some mentoring scenarios have small counts (e.g., scenarios II and III), results from those scenarios might be affected by statistical fluctuations. Thus, we conducted a sensitivity analysis to test the robustness of the results from Model 2. Specifically, we combined scenarios I and IV into A (having a less competent faculty mentor, $n = 239$), II and V into B (having less competent faculty and postgraduate mentors, $n = 86$), III and VI into C (having a less competent faculty mentor and a more competent postgraduate mentor, $n = 37$). We then used those combined categories in a GEE model (Model 3) wherein model specifications and all other variables were kept the same. In Model 3, the reference category for mentoring scenarios A and B was UGRs with more competent faculty mentors (with or without a postgraduate mentor), and the impacts of COVID-19 were not included in mentoring scenarios but used as an independent predictor.

In addition, the COVID-19 pandemic affected different regions of the United States unequally, which might affect students' intentions to pursue graduate education. We conducted the second sensitivity analysis to address this issue. We categorized students into four U.S. geographic regions (Northeast, Midwest, South, and West, defined by the U.S. Census Bureau) based on the locations of their home institutions. Then, we used the four regions as independent variables and reestimated Models 1 and 2 (referred to as Models 4 and 5).

Results

RQ1: How has the COVID-19 pandemic impacted UGRs' graduate school intentions?

One-fifth of UGRs reported that the pandemic made them less motivated to pursue a graduate degree in science, 33% reported more motivation to pursue graduate education due to the pandemic, and 47% reported that their motivations to pursue graduate school were unchanged during the pandemic (as of July 2020).

RQ2: Was having less competent faculty and postgraduate mentors associated with a decline in UGRs' graduate school intentions during COVID-19?

Table 3 reports the results of Model 1. Less competency among faculty and postgraduate mentors was significantly associated with reduced student motivation to pursue a graduate degree in science. Specifically, those who had less competent faculty mentors (versus more competent) were 3.6% less motivated by COVID-19 to pursue a graduate degree in science ($P = 0.037$). Students without a postgraduate mentor or with a less competent postgraduate mentor were 5.7% and 7.0% less motivated by COVID-19 to pursue graduate school ($P = 0.004$; $P = 0.004$) as compared with UGRs who had a more competent postgraduate mentor. In terms of COVID-19 impacts, those who were highly impacted were 3.6% less motivated by COVID-19 to pursue graduate school compared with UGRs who were not highly impacted ($P = 0.037$).

Other environment variables were also significant predictors. Students who usually had in-person communications with their faculty mentors during the pandemic (versus those who primarily communicated with their faculty mentors through virtual meetings) were 9.1% more motivated by COVID-19 to pursue graduate school ($P = 0.013$). Compared with students who did research throughout spring and summer of 2020, those who did research only in spring were 8.1% less motivated by COVID-19 to pursue graduate school ($P = 0.001$).

Table 3 also reports findings from the inputs. Social/behavioral sciences students were less motivated by COVID-19 to pursue graduate school than life sciences students (5.8% less; $P = 0.011$). Every 1-month increase in students' pre-2020 research experience duration was associated with a 0.3% COVID-caused increase in motivation to pursue graduate school ($P = 0.030$). Finally, first-generation UGRs were 3.8% less motivated by COVID-19 to pursue graduate school compared with continuing-generation students ($P = 0.040$), while URM students were 3.6% more motivated by COVID-19 to pursue graduate school than non-URM students ($P = 0.027$).

RQ3: How did COVID-19 impacts intersect with less competent faculty mentorship to influence UGRs' graduate school intentions?

Table 4 reports the results of Model 2. The results show that Scenarios III and VI were not statistically significant ($P > 0.05$). That is to say, regardless of the students' level of COVID-19 impacts, for UGRs who had less competent faculty mentors, their changes in motivation to pursue graduate school caused by COVID-19 did not differ from UGRs who had more competent faculty mentors, as long as they had more competent postgraduate mentors. Compared with UGRs who had more competent faculty mentors, those who were highly impacted by COVID-19 and had less competent faculty and postgraduate mentors (scenario II) were 11.5% less motivated by COVID-19 to pursue graduate school ($P = 0.016$), while those who had only a less competent faculty mentor (scenario I) were 8.3% less motivated by COVID-19 to pursue graduate school ($P = 0.024$). When the COVID-19 impacts were low, a mentoring triad with less competent faculty and postgraduate mentors (scenario V) was associated with a 5.1% reduction in motivation ($P = 0.030$), and a mentoring dyad with a less competent faculty mentor (scenario IV) was associated a 4.0% reduction in motivation ($P = 0.031$). In terms of direction and significance, the results of other variables were generally the same as those in Model 1 except that URM students maintained the same direction but became nonsignificant ($P = 0.056$), and students who did research in early spring before stopping in late spring became significant ($B = -0.052$, $P = 0.046$).

Results of sensitivity analysis

Results from the sensitivity analyses (Models 3–5) are presented in Appendix A (Tables S1 and S2, online only). Model 3 indicates that students who had only less competent faculty mentors (scenario A) or less competent faculty and postgraduate mentors (scenario B), respectively, reported 5% ($P = 0.009$) or 6% ($P = 0.008$) reductions in motivation to pursue graduate education. However, among UGRs with less competent faculty mentors and more competent postgraduate mentors (scenario C), graduate school intentions were statistically equivalent to UGRs with more competent faculty mentors ($P = 0.492$). This indicates that results for the six mentoring scenarios in Model 2 are robust.

Models 4 and 5 show that UGRs' graduate school intentions did not vary significantly across the four regions ($P > 0.05$) and that results for other variables did not differ in terms of the direction and significance of associations from Models 1 and 2. Therefore, this sensitivity analysis indicates that results of Models 1 and 2 are also robust after taking into consideration regional effects.

Discussion

The COVID-19 pandemic has changed the landscape of undergraduate education in the United States. College students are facing financial difficulties, academic interruptions, and health challenges.[38,39,41,42,44] Despite those barriers and struggles, a motivational Fauci effect was observed among students pursuing medical school.[12] Can we expect a similar motivational effect of COVID-19 on students' graduate school intentions? Our descriptive results indicated that more students experienced an increased motivation to pursue graduate education (33%) than decreased motivation (20%) due to the pandemic. The multivariable model results provide nuance with regard to how other variables influenced motivation. COVID-19 became a motivator for UGRs' graduate school intentions only when those UGRs experienced fewer difficulties caused by the pandemic. This finding aligns with previous research suggesting that challenges caused by COVID-19 negatively affected college students' motivations.[38–40]

The main contribution of the current study is that we extend the mentoring literature by investigating the effect of less competent faculty mentorship in the context of a global disaster. Most previous studies on undergraduate research mentoring focused on the beneficial effects of having highly competent mentors on students,[13–15] and a handful of them documented the issues caused by negative mentoring.[5–9] Our results reveal the unique role of mentorship quality during COVID-19. Specifically, the effect of the pandemic on UGRs' graduate school intentions was conditional on whether UGR's had more or less competent mentors. Having a less competent faculty mentor made COVID-19 detrimental to UGRs' graduate school intentions. Another novel element of this paper is our focus on postgraduate mentors and their competency. Prior

research on postgraduate mentors is limited,[24] and no previous studies used the MCA to quantify the quality of postgraduate mentorship. In our sample, 31% of students had a postgraduate mentor during the COVID-19 pandemic. If those students perceived the postgraduate mentor as less competent, their motivation to pursue graduate education was reduced.

To further understand the nuanced intersection between less competent faculty mentorship and COVID-impacts, we conceptualized six possible scenarios for UGRs who had less competent faculty mentors, based on the mentoring relationship matrix (Fig. 2). Importantly, we found that having more competent postgraduate mentors compensated for less competent faculty mentorship to positively influence UGRs' graduate school intentions (scenarios III and VI, $n = 37$ students). Notably, in scenario VI, when UGRs had less competent faculty mentors, faced more COVID-19–caused difficulties, and yet had more competent postgraduate mentors, they had statistically equivalent graduate school intentions to UGRs with more competent faculty mentors. Hypothetically, this is because they were buffered from those challenges by the more competent postgraduate mentor, although this remains speculative. On the other hand, more UGRs ($n = 325$) worked in a context characterized by less competent mentoring (scenarios I, II, IV, and V). Those scenarios were generally associated with reduced graduate school intentions due to COVID-19.

Informed by the I-E-O model, we also included inputs and other environment variables in analyses. Before the pandemic, first-generation students had lower intentions of going to graduate school than continuing-generation students.[53] Our results reveal that first-generation UGRs might have experienced a more pronounced reduction in graduate school intentions because of COVID-19. In contrast, URM students reported greater increases in motivation to pursue graduate school due to COVID-19 than White and Asian students did. Given that URM students bore more health and economic burdens of this pandemic,[54,55] these findings might indicate URM students' resilience in the face of the pandemic.[56] It might also be the case that since URM students experienced greater economic hardship than non-URM students during the pandemic,[57,58] they had increased motivation to pursue graduate school, which could provide them with immediate financial support and improve their long-term job prospects.

With regard to student academic characteristics, we found that for UGRs pursuing degrees in social or behavioral sciences, COVID-19 decreased their graduate school intentions more so than UGRs pursuing degrees in life sciences. *The Chronicle of Higher Education* reported that more than 50 U.S.-based doctoral programs in the humanities and social sciences closed their admissions for Fall 2021.[59] Although this may have been a necessary financial strategy to enable the programs to fund their current graduate students, it might have reduced UGRs' interests in applying to graduate programs in the social and behavioral sciences. In addition, UGRs with longer-term research experiences before Spring 2020 had a greater increase in graduate school intentions during the pandemic. Perhaps those more experienced UGRs were better able to resolve challenges and thus were more resilient during the pandemic.

In terms of other environment variables, the results show that UGRs who usually had in-person communications with their faculty mentors were more motivated by COVID-19 to pursue graduate school than those with only virtual interactions. This aligns with a study conducted before the pandemic, in which being able to meet face-to-face with faculty mentors was found to increase the odds of undergraduate students publishing their research.[46] Finally, as compared with students who did research throughout spring and summer of 2020, those who conducted research for the duration of Spring 2020 (but not during Summer 2020) reported decreased intentions to pursue graduate school because of COVID-19. It is possible that the challenging and uncertain circumstances of trying to conduct research in Spring 2020 were energy-consuming and stressful (unpublished data). Then, because of summer research program cancelations, many such students lost the opportunity to recover their motivation through more positive, less chaotic experiences. The decreased motivation among UGRs who only did research in spring may also be partly attributable to the fact that those students were not doing research when taking the survey. Another possible explanation is that those UGRs not participating in Summer 2020 research might have secured employment, which led them

away from a research career path and decreased their graduate school intentions. However, this is speculative as we did not collect information on students' alternative employment in Summer 2020.

Although the present study addressed a number of gaps in the literature, there are limitations that require further inquiry. The first limitation concerns the measurement of the outcome, as it is the change in students' graduate school intentions caused by COVID-19. Although this measure allows us to examine the effects of the pandemic on students directly, we lack knowledge of UGRs' baseline intentions. That is to say, a decrease in graduate school intention does not imply the lack of desire to go to graduate school. As a self-assessed measure, the question is also subjective to the interpretation of each individual student taking the survey, and student intention may not translate into actual behavior. Thus, future studies should examine more objective measures, such as whether UGRs actually apply to, are accepted by, or enroll in graduate programs. In order to collect that information, researchers need to use longitudinal designs and follow participants for multiple years after graduation. We did not have access to such measures in this paper because we conducted the study while all participants were undergraduate students, and most had not yet become eligible to apply to graduate school. Second, we constructed the more competent and less competent mentor variables based on the mean value of the MCA. While logical, this approach created a measure that is relative to this study's sample.

Third, the current study focuses on the mentee's perspective. Future researchers should make efforts to collect data on faculty and postgraduate mentors' perceptions, which would enhance the understanding of mentor–mentee relationships and interactions. Fourth, when taking the survey in July 2020, some student participants were actively doing research, while others were not, which may have affected how they responded to some of the survey questions. Fifth, we examined individual-level factors influencing graduate school intention while controlling for institutional effects by design via GEEs. Future research could explore how institutional factors impact UGRs' intentions to pursue graduate education using hierarchical linear modeling. Sixth, COVID-19 is a fast-moving crisis, so it is possible that associations observed in this study, which are based on data collected in July 2020 and pertinent to the early months of the pandemic, might change as the pandemic evolves. However, we believe that documenting and understanding UGRs experiences during the period of a major crisis is itself critical. More importantly, future researchers should pay close attention to and continue examining the cohorts of UGRs that went through the pandemic, as it is possible that they will experience enduring effects.

Conclusions

The COVID-19 pandemic has made it more challenging for many UGRs to pursue the scientific journey. To support these students as well as the development of the U.S. scientific workforce more generally, education researchers, URP directors, and university administrators need new knowledge and innovative interventions. Results from this study offer a hopeful sign, as one-third of students reported increased graduate school intentions due to the pandemic, while only one-fifth reported decreased intentions. Many UGRs demonstrated resilience in the face of challenges in terms of their graduate school intentions. In other words, this study, to some extent, reveals a Fauci effect on UGRs' intentions to pursue graduate education in science.

The beneficial effects of having competent faculty and postgraduate mentors point to potential areas for intervention: promoting mentoring training across URPs and promoting face-to-face contact when possible. It has been well-documented that mentor training can effectively improve research mentors' competencies.[60–62] Given the importance of postgraduate mentors for UGRs, wide dissemination of mentoring training designed for postgraduates is needed. While results showed face-to-face contact to be beneficial for graduate school intentions, it is not always possible given university policies and individual faculty and student concerns under some circumstances (e.g., the COVID-19 pandemic). When possible, mentors should carefully weigh the pros and cons and, as appropriate, consider structuring meetings to permit some in-person interactions.

We should also recognize that less competent faculty mentorship might not be attributable to a lack of training or unwillingness to support students. There have been clear structural constraints

that limited faculty's abilities to effectively mentor students in the pandemic. During COVID-19, faculty themselves have struggled with teaching, research, and personal responsibilities.[19] Thus, collective efforts between URPs and institutions are needed to support undergraduate research mentors in these trying times. Finally, our results indicate that several groups of UGRs who were more likely to experience a reduction in motivation to pursue graduate school than others, such as UGRs who were highly impacted by COVID-19 with less competent mentors, were first-generation college students, had less prior research experience, had their Summer 2020 research experiences canceled, and were social/behavioral sciences majors. Program directors, university administrators, and policymakers need to work together to develop immediate strategies to reengage these more vulnerable students on their science training pathways.

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Author contributions

D.X.M. collaborated on the conception and design of the study, conducted data collection and analyses, and wrote and revised the manuscript. S.E.G. and T.W.C. collaborated on the conception and design of the study, oversaw data collection, analyses and interpretation, and wrote and revised the manuscript. All authors read and approved the final manuscript.

Supporting information

Additional supporting information may be found in the online version of this article.

Table S1. The GEE model predicting student graduate school intentions using mentoring scenarios A–C.

Table S2. The GEE models predicting student graduate school intentions: controlling for regional effects.

Competing interests

The authors declare no competing interests.

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