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Zooming into the Lab: Perspectives on Maintaining Undergraduate Biological Research through Computationally Adapted Remote Learning in Times of Crisis

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At the onset of the COVID-19 pandemic, many academic institutions attempted to limit viral spread throughout their communities by suspending face-to-face student instruction. The rapid transition from in-person to remote learning dramatically altered student-instructor interactions and ushered in a new set of educational challenges. Despite recent publications by experienced researchers that address the impacts of remote instruction on undergraduate research at a holistic level, we currently lack evidence for successful implementation of best practices in a remote research environment during the COVID-19 pandemic. Therefore, to enhance remote scientific experiences and improve the skills of young biologists facing uncertain challenges in their future academic careers, we make nine recommendations for best practices in maintaining quality undergraduate research experiences, especially for computationally adapted projects, during online learning periods in times of crisis. Based on our experience participating in an undergraduate Stanford Summer Research Program (SSRP) that was conducted entirely remotely during the summer of 2020, we describe nine recommendations for best practices that institutions, faculty mentors, and undergraduate mentees can execute to maintain a high quality of biological research. Further elucidating the ways in which distance learning can be improved at the undergraduate research level will offer insights into making the most out of remote biological research in the months and years ahead.

INTRODUCTION

As a result of the COVID-19 pandemic, non-essential institutions like universities were mandated to postpone in-person instruction. Due to this unexpected change, universities had quickly transitioned from an in-person classroom experience to a remote format. Not only did the delivery of classes change for students, but all in-person programs affiliated with the universities had to accommodate unpredictable circumstances. Some of these initiatives that were forced to transition into an online format included essential research programs for undergraduate students. Despite a growing literature on how in-person research laboratory closures alter the dynamic of the laboratory as a whole, there is little knowledge surrounding how the quality of biology research can be maintained specifically for undergraduate students transitioning into a remote format. Preserving high-quality research in remote undergraduate

programs will be critical for students to develop laboratory skills, avoid academic and career setbacks, and improve future remote experiences in the months to come. In this article, we offer nine recommendations (Fig. 1) to maintain best practices for remote undergraduate research from the perspectives of a senior undergraduate and a junior faculty member who have conducted computationally adapted remote neuroscience data analysis in the first-ever remote Stanford Summer Research Program (SSRP) during the COVID-19 pandemic. These nine recommendations, directed especially toward research faculty and administrators, are:

- 1) Schedule weekly one-on-one meetings with the students.
- 2) Invite students to attend relevant research seminars, journal clubs, and conference presentations.
- 3) Include students in group lab meetings.
- 4) Guide students through reading and critiquing scientific papers in the field.
- 5) Provide opportunities for students to write and speak about the project in formal and informal settings.
- 6) Offer and encourage students to attend professional development workshops.
- 7) Direct students to collect and/or analyze data to advance the goals of the research project.
- 8) Offer networking opportunities for students to interact with other faculty and trainees.

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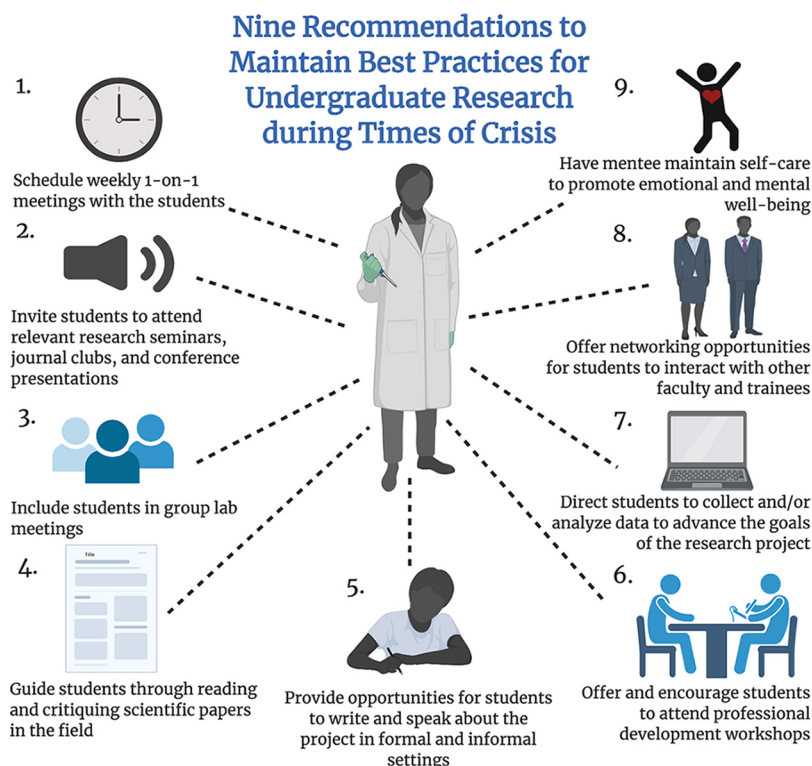


FIG 1. Nine recommendations to maintain best practices for undergraduate research during times of crisis. Schematic shows nine recommended best practices for research faculty and administrators to refer to while guiding undergraduate researchers through remote research during the COVID-19 pandemic and other times of crisis. Created with BioRender.

9) Have mentee maintain self-care to promote emotional and mental well-being.

We call upon academic institutions, administrators, instructors, senior researchers, and undergraduate researchers to implement and execute these nine recommendations (Fig. 1) as a means of maintaining best practices and preserving the quality of biological research for undergraduates who are participating in remote research in future programs. This is crucial, as the next generation of scientists is currently being trained in an unconventional manner, based on a new format that relies heavily or entirely on remote learning. Our execution of these nine recommendations can provide the foundation for the successful implementation of future research programs to preserve the quality of biological research for undergraduate students.

HOW COVID-19 AFFECTS BIOLOGICAL RESEARCH FOR UNDERGRADUATES

The COVID-19 pandemic or any time of crisis can impact biological research on numerous levels: by altering instructor-student interactions, by forcing students to rapidly adapt to new online environments, by accentuating previously existing gaps in academic success due to socioeconomic factors, and by exacerbating the negative effects of psychological challenges. We discuss various ways in which

these elements affect student learning and their potential effect(s) on undergraduate student learning in a remote research experience.

Remote instruction alters instructor-student interactions

The transition from in-person to remote instruction due to the COVID-19 pandemic altered all instructor-student interactions within academic institutions. As a result of the transition to an online format, there are concerns over how the remote educational environment affects the quality of student learning. This view holds that students may not have access to the resources they need in order to receive a quality learning experience as remote instruction may prevent students from receiving help on assignments (1, 2). Indeed, recent literature demonstrated that help-seeking and network connections served as a predictor of academic performance in a non-COVID-19 online classroom experience (2). During COVID-19 remote learning in science education, one study showed that interaction between a student and an instructor can influence student attitudes toward learning outcomes (1). Additionally, students tend to have more enthusiasm toward their field of study if they have the opportunity to contribute their beliefs about the subject with other students (2–4). Therefore, there is a legitimate basis to the concern that the absence of access to an in-person instructor and interacting with peers to discuss academic ideas may deter students from academic

excellence that would have otherwise been achieved (regardless of whether remote learning occurs during an crisis like COVID-19).

Remote research shifts projects to virtual format

In addition to the lack of in-person interaction in the transition to online learning, undergraduate students also face the struggle of transitioning their research projects to an entirely different format such as learning new programming languages or projects and managing how to effectively work and communicate with a faculty mentor in a remote setting. Learning how to use new programming languages and software may prove difficult for undergraduate students as they learn new analytical techniques under the stressors of the COVID-19 pandemic. Furthermore, students may need assistance to troubleshoot code by actively searching for ways to do so using the Internet. However, students may find themselves at an impasse when forums for troubleshooting code are dominated by experienced coders using different styles of coding languages. Undergraduates may also look to work with their faculty mentor to troubleshoot code and communicate regarding project direction and ideas (5). Students must learn to adapt to a new online format and schedule which best suits the communication and mentoring style of both the research mentor and the undergraduate mentee. This can prove difficult as students may not have met their faculty mentor in-person and have to develop their relationship remotely. With all of these factors involved in the transition to a remote research experience, it is clear that the transition of the project and in-person interactions can prove difficult for undergraduate students who seek to maintain the essential components of a quality research experience during a time of drastic change.

Remote learning and socioeconomic disparities during COVID-19

Socioeconomic status can influence student learning as a whole, specifically since additional stressors associated with socioeconomic status can interfere with student learning in the research experience. Socioeconomic status is one of the most prominent influences to affect student learning, particularly with regard to low-income individuals living below the poverty line. Low-income individuals are classified as 80% of the median family income for a given area as described by the Department of Housing and Urban Development Office of Policy Development and Research (NP Retsinas, KE Marchman). To demonstrate the particularly deleterious effects of COVID-19 as a factor of socioeconomic status, one study showed that more than half of lower-income students were more likely to delay graduation compared with higher-income students during the COVID-19 pandemic (6). This study also found that COVID-19 worsened the already-existing disproportionate academic outcomes that specific socioeconomic groups faced prior

to COVID-19 (6). Therefore, it is clear that socioeconomic status plays a more significant role in academic performance during periods that further widen the socioeconomic gap such as during COVID-19.

The psychological challenges of transitioning to remote research

Lastly, many other factors impact student learning during biological research, some of which are exacerbated by the COVID-19 pandemic. Student responses were affected by, but not limited to, an ill-suited learning environment, family distractions, unemployment stress, financial burdens, personal or family illness, and mental/emotional distress (6, 7). Additional studies found that anxiety and stress negatively impact students' academic performance (7) and that over 25% of students experienced moderate-to-high levels of psychological anxiety during the COVID-19 pandemic (7). As a result of social distancing guidelines, students have shifted their entire lives into the virtual format, including social relationships and corresponding ways for receiving social support. Given that social distancing can exacerbate psychological challenges like loneliness, anxiety, anger, depression, and even suicide (8), it is important to remember that these mental health issues pose a further threat to adequate student learning in the virtual format. Not surprisingly, students who felt that they had greater social support also reported lower levels of anxiety (9).

IMPROVING REMOTE RESEARCH PRACTICES FROM AND FOR UNDERGRADUATE STUDENTS

Previous scholarly attempts have been made to characterize how the transition to remote learning for undergraduate biological research can be improved. One paper discusses and compares findings from many studies that were conducted on face-to-face and remote laboratories but compares the top-down perspective of face-to-face and remote learning (1). Other literature discusses methods in which research practices can be maintained for undergraduate, graduate students, and postdoctoral fellows during neuroscience research. However, this perspective again offers the top-down approach of how to effectively implement best research practices for more junior researchers (10). Another article offers insight on how several senior researchers have been handling the shift to remote scientific research in their prospective laboratories, but again, these perspectives are from the top-down viewpoint (11). One study discusses three methods to engage students in research education such as: analyzing remote data, reading papers and science writing, and participating in science journal clubs (5). Despite this, this study offers a holistic view of implementing these practices as future solutions, rather than showcasing their successful execution in a specific research experience.

Additionally, previous literature also outlines several best in-person practices from the top-down perspective in which the undergraduate research experience (URE) is provided through mentors. These practices include teaching technical skills, emotional and personal support for the student, building community, providing networking opportunities, and peer interaction (12). Another study discusses five in-person practices in undergraduate research programs from the mentor perspective such as: having weekly one-on-one meetings with undergraduates, faculty motivation for students in an URE, reading literature in which concepts are reinforced by the mentor, presentation opportunities for students in undergraduate research, and publication in a journal (13). Previous literature that discusses best practices in an in-person URE from the top-down perspective demonstrates that there is a need for the undergraduate student perspective, specifically in the remote format, to confirm the validity of these best practices. As we align previous best practices for in-person UREs with our own, we use our experiences in an undergraduate remote research program as a senior undergraduate researcher and a junior faculty member. We aim to leverage our success in employing nine recommendations (Fig. 1) for best research practices as evidence of the effective implementation and execution of these recommendations in preserving undergraduate research in the remote format, specifically from the bottom-up perspective of an undergraduate researcher. Similar to in-person undergraduate research, we employ these nine recommendations with the goal of maintaining similar best practices in a remote setting to preserve the quality of undergraduate research for computationally adapted projects.

A remote Stanford Summer Research Program during COVID-19

The transition from in-person to remote instruction due to the COVID-19 pandemic altered all instructor-student interactions within academic institutions. As a result, many in-person research opportunities for undergraduate students were cancelled for summer 2020. However, several summer research programs such as SSRP transitioned to a completely remote research experience. As a result, the curriculum of the in-person experience had to be completely reconfigured to fit the remote format. To provide a quality URE, SSRP's remote curriculum consisted of the following:

- 30 hours of coding workshops during the first week to teach students necessary programming languages
- 25 to 30 hours working directly on the remote project following the first week for 7 weeks
- attending a professional development workshop every week
- practicing research presentation and scientific writing with graduate students
- attending a scientific talk every week

- social events to interact with other SSRP students and graduate students
- meetings with research mentor as schedule permitted

The experiences of an undergraduate student and junior faculty mentor who participated in SSRP's remote program form the basis of our recommended best practices for the implementation of future remote research experiences for undergraduate students.

To contribute toward progressing the neuroscience research project, the student analyzed mouse behavioral videos from experiments that aimed to understand amygdala neurocircuitry contributions to stress response and reward-seeking behavior. For the duration of this project, the undergraduate student was consistent in participating in the following practices within these recommendations: 1) Schedule weekly one-on-one meetings with the students, 2) Invite students to attend relevant research seminars, journal clubs, and conference presentations, 4) Guide students through reading and critiquing scientific papers in the field, 5) Provide opportunities for students to write and speak about the project in formal and informal settings, 6) Offer and encourage students to attend professional development workshops, 7) Direct students to collect and/or analyze data to advance the goals of the research project, 8) Offer networking opportunities for students to interact with other faculty and trainees, and 9) Have mentee maintain self-care to promote emotional and mental well-being. The best practice of #3 ("Include students in group lab meetings") was not applicable to our situation, since there was a scheduling conflict between the lab meeting times and the program curriculum agenda.

1) Schedule weekly one-on-one meetings with the students. The undergraduate student organized and communicated with the faculty mentor via email to schedule Zoom videoconferencing meetings at least once-a-week for 1 to 1.5 h and sometimes scheduled another meeting within the same week about 2 to 3 days later for another hour using the same format. The meetings first consisted of slide presentations from the mentor providing educational background on the research, followed by discussing project ideas (e.g., explaining how using behavioral analysis software to quantify mouse behavior was important to understanding the role of neural circuits), ways to find an open-source behavioral analysis software online, troubleshooting code, discussing scientific articles, practicing oral presentation skills, and relaying data that was analyzed via behavioral software. The success of organized weekly meetings with a research mentor depended on transparency of expectations through verbal communication and through a signed contract that detailed expectations regarding student and mentor teaching styles.

2) Invite students to attend relevant research seminars, journal clubs, and conference presentations. The undergraduate student attended at least one, 1-h webinar series per week via Zoom videoconferencing

within the related neuropsychiatry field to help understand current research projects, methods, and approaches in the field. Additionally, the undergraduate student signed up for the SSRP symposium to give a 12-minute-long presentation toward the end of the 9-week SSRP program and also signed up to give a presentation at two virtual national conferences. Successful accomplishment of this recommendation can be achieved through attending once-a-week, 1-h virtual research seminars and signing up for journal clubs and conference presentations where the student can prepare by communicating their science to others in the following days leading up to the journal club or conference.

3) Include students in group lab meetings.

Although the undergraduate student was not able to attend virtual lab meetings due to a conflict, this recommendation can be successfully followed as students can attend virtual lab meetings as permitted by the lab and COVID-19. Lab meetings provide opportunities to interface with other lab members besides the Principal Investigator, and to stay up-to-date on other projects within the research lab. They also offer a forum for raising logistical issues that may arise during remote research, and give important insights into a particular lab's hierarchical dynamics and the overall attitude/culture of the research group.

4) Guide students through reading and critiquing scientific papers in the field. Every 2 weeks, the undergraduate student was given a peer-reviewed research paper to read that was related to the neuropsychiatry field. The student was then given 5 to 10 days to read the article depending on their availability due to program demands and deadlines. After the student read the article, the data, results, and conclusion of the paper were then discussed with the faculty mentor in the scheduled weekly meetings for roughly 30 min. The student asked questions regarding the paper and was asked by the faculty mentor to analyze data within the figures of the paper. Successful implementation of this recommendation can be accomplished by giving the student adequate time to read the paper by effectively communicating the bimonthly schedule. Literature review is an important component of undergraduate research because it encourages self-directed learning of scientific principles via exploration of relevant journals and publications.

5) Provide opportunities for students to write and speak about the project in formal and informal settings. The undergraduate student was required by SSRP to submit a revised abstract three times throughout the duration of the 9-week program. The undergraduate student was also required to give a weekly oral slideshow presentation of the research project in a small four-person group setting where there was a graduate student present to give feedback. The student revised the slides every week and applied the feedback given by the graduate student. The undergraduate student also practiced the same oral slideshow presentation in the weekly scheduled meetings with the faculty mentor as needed. The student also submitted

abstracts for and virtually attended the SSRP symposium and two national conferences to practice research communication to a diverse range of audiences. Successful implementation of this recommendation can be accomplished through weekly writing assignments such as an abstract or small paragraph detailing the project and through giving scientific talks formally and informally at least 10 to 12 min once a week to the faculty mentor, senior researchers, and peers.

6) Offer and encourage students to attend professional development workshops. To aid in professional development while conducting academic neuroscience research, the undergraduate student attended a weekly 1- or 2-h professional development workshop offered by SSRP. These workshops included topics such as funding for graduate school research, PhD graduate school funding, what graduate school entails, scientific writing, presenting workshops, etc. For the successful implementation of this recommendation, it is important that institutions, programs, and faculty mentors offer these as weekly workshops and relay information regarding availability of these workshops so that the undergraduate student can attend.

7) Direct students to collect and/or analyze data to advance the goals of the research project. The undergraduate student worked remotely for 5 h per day, 25 h per week on developing a methodological workflow for data analysis; in this case, testing and piloting multiple behavioral analysis software packages before arriving at an optimal program used to quantify mouse behavior. To do this, the student participated in the SSRP program required coding workshop week at the beginning of the remote program where students were taught the Python programming language for 6 h a day, for a total of 30 h that week to ensure as much preparation for the remote research projects as possible, especially as many students did not have experience with coding. The student also sought external assistance on coding troubleshooting through online forums and through the SSRP Slack Channel where coding workshop instructors were available to assist with troubleshooting coding errors. The drawback to this was that online forums were often too advanced for troubleshooting coding errors for coding beginners and troubleshooting coding errors via Slack messaging was often time-consuming. For this recommendation to be successfully followed, it is important that the students who are in a remote program have access to adequate resources offering coding solutions that are at their coding level in order to troubleshoot. Additionally, it is important for students to have access to instructors who are proficient or experienced in these coding languages as coding office hours for beginners would be extremely helpful. For students to successfully benefit from progressing the remote research project through implementation of coding language(s), it is imperative that the student work on the project consistently.

8) Offer networking opportunities for students to interact with other faculty and trainees. In order

to ensure that the student is able to network with students and faculty, the undergraduate student attended office hours of graduate students, emailed faculty at Stanford to set up a 15-minute one-on-one meeting to discuss research and future plans for graduate school, and formed connections with other SSRP students during unscheduled SSRP hours. Additionally, the student took advantage of weekly workshops, responding to questions being asked by the presenter, having discussions with guest speakers such as faculty, and asking clarification on topics that were being discussed. The student also attended bi-monthly 30-minute office hours of graduate students to ask questions about graduate school, discuss research, and receive feedback on graduate school application materials. The student emailed several faculty members to set up a 15-minute one-on-one meeting and eventually met with one of the faculty to discuss research and future graduate school plans. To successfully implement this recommendation, undergraduate students must take advantage of all opportunities to network with faculty and other students. It is also the institution's and program's responsibility to create as many opportunities as possible for students to enhance their communication and networking skills. This can be done by requiring students to email and invite five faculty members to a 15-minute one-on-one Zoom videoconferencing meeting, offering interactive workshops 1 h per week via Zoom videoconferencing that allow students the opportunity to speak up and ask questions of guest speakers and presenters, and offering weekly 30-minute office hours for undergraduate students to network with graduate students.

9) Have mentee maintain self-care to promote emotional and mental well-being. In order for the undergraduate student to maintain self-care to promote emotional and mental well-being, the student attended weekly virtual socials that were offered by the SSRP program. These socials included playing online team games, watching movies, and having breakout rooms to socialize with other SSRP undergraduate students and graduate students via Zoom videoconferencing. Additionally, the undergraduate student took breaks when needed from the computer when working remotely. The student made sure to get adequate sleep and eat healthy food in order to promote well-being. Most of all, the student took advantage of social networks during the COVID-19 pandemic by communicating with others via social media and videochatting. When feeling overwhelmed, the student communicated their struggles with the faculty mentor and with their social networks to ensure transparency and support. For this recommendation to be successfully executed, it is important that the student be able to practice self-care tips to relieve stress by taking some time off for themselves and/or leaning on support networks for help during these times. Most importantly, it is important for institutions, programs, and mentors to be mindful that each student's situation is different and that the COVID-19 pandemic exacerbated already existing disparities. Therefore, transparency, mindfulness,

and support must be given to each student as many grapple with the uncertain outcomes associated with remote learning during the COVID-19 pandemic.

RECOMMENDATIONS TO MAINTAIN AND IMPROVE UNDERGRADUATE BIOLOGICAL RESEARCH IN THE REMOTE FORMAT

Since we provided several tips and techniques to maintain the quality of biological research during the transition to the remote format during times of crisis, we are calling upon senior researchers and mentors, program directors, and university department leaders to take these recommendations into consideration in order to preserve UREs. Offering essential resources for undergraduate student success in research settings is crucial to increasing students' knowledge and propelling their academic careers. With COVID-19 affecting the lives of many, it is important to be mindful that each person's situation is different. We recommend that students communicate any hardships or struggles that arise as a result of COVID-19 so that expectations can be reasonably adjusted to accommodate each student. This is important as COVID-19 has proven to disproportionately affect those of specific socioeconomic status and those who are struggling with mental health issues, especially in higher education (2, 4). Therefore, academic institutions must be considerate and flexible with students on a case-by-case basis during these uncertain times. Academic institutions can provide resources to help students mitigate the negative effects of the COVID-19 pandemic in biological research.

CONCLUSION

The COVID-19 pandemic has been shown to significantly impact the magnitude and quality of research in many different ways. As we zoom into the future of academic science during times of crisis, it is essential to maintain best practices for undergraduates and for institutions to implement the highest caliber of research during remote work circumstances. Although COVID-19 has caused some major shifts in higher education, the primary goal to improve remote research for undergraduates can be accomplished through effective planning, collaboration, and transparency between undergraduates, mentors, and academic administrators to uphold these nine recommendations for the next generation of future scientists.

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