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Engaging Undergraduates in Research Experiences at a Distance: Insights and Recommendations for Remote URE†

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Undergraduates phenotyping *Arabidopsis* knockouts (unPAK) is a biology research network that has provided undergraduate research experiences (URE) since 2010. In 2019, unPAK expanded to include a summer URE that engaged undergraduate researchers from across the network in an intensive collaborative program. In response to the COVID-19 pandemic in 2020, unPAK rapidly shifted to provide the summer URE program remotely. This article describes (i) the instructional and communication processes of unPAK in the remote URE; and (ii) a summative assessment of the outcomes associated with the remote summer program as compared with the 2019 in-person program. We conclude by offering timely recommendations for educators in biology that emerged from the 2020 remote summer research experience, which may be applicable to other remote UREs and course-based research experiences (CUREs).

INTRODUCTION

Participation in undergraduate research experiences (UREs) develops students' science identities, creating (i) an internal sense of being a "science person" and (ii) a recognition of oneself in a scientific context, especially in the company of scientific professionals (e.g., professors, mentors, peers) (1–3). Experiential learning and discovery are central to building a science identity (4) as well as undergraduate student skill development in plant science in the classroom (5, 6), and in UREs (7, 8). The 2020 Decadal Vision in plant science calls for "reimagining the workplace to nurture adaptive and diverse scientists" (Goal 5) and "building capacity and interest to engage with plant science" (Goal 6) to revitalize plant science through greater participation and broader perspectives (9). UREs provide such participation as students engage in novel research, professional development, and peer-networking cohort activities (7, 10, 11).

Undergraduates phenotyping *Arabidopsis* knockouts (unPAK) is a research and mentoring program in which undergraduate student researchers are the focus of both training and scientific discovery (12, 13). The focus of unPAK research is to expand, enhance, and sustain an existing network of diverse scientists and undergraduates dedicated to phenomics while researching the role of genes in influencing plant traits. In 2019, unPAK transitioned from an entirely distributed approach across 21 institutions to include a central summer URE program recruiting undergraduate student researchers from across the network. In response to the COVID-19 pandemic (14), unPAK rapidly shifted to provide a remote summer research experience for undergraduates. While most research internships and UREs were postponed in the United States during the summer of 2020, the funding agency for this program (United States Department of Agriculture) supported this change of delivery. This paper describes (i) the instructional and communication processes in the remote URE and (ii) a summative assessment of the outcomes associated with the remote summer program compared with the 2019 in-person URE program. We conclude by offering timely recommendations for educators in biology that emerged from the 2020 remote summer research experience, which may be applicable to other remote UREs and course-based research experiences (CUREs).

Study context: unPAK summer URE

In 2010, unPAK began as an interdisciplinary collaboration among five faculty at three primarily undergraduate institutions. As of 2021, the research network has expanded to 23 faculty supervising undergraduate research at 21 institutions, including research-intensive, primarily undergraduate, 2-year community college, and minority-serving institutions. To date, over 200 undergraduates have participated in laboratory-centric unPAK UREs for credit and/or wages with over 1,000 students engaged in CUREs.

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The 2019 and 2020 summer URE programs recruited from the unPAK network. The overall objectives of this URE are to train students in conceptual knowledge, scientific process, research skills, and data science through collaborative cohort experiments and an independently chosen experiment focused on plant vigor and yield. Faculty directly mentor students both individually and in group cohort projects and prepare weekly professional development activities (reading primary literature, serving as facilitators for discussions, developing annotated bibliographies, presenting scientific results, etc.) for varied aspects of agricultural science. During and after the summer program students maintain connections to "home" institution faculty, and several bring components of their summer projects back to their institution for continued work in the subsequent fall semester.

In-person URE (2019)

Undergraduate students in the summer 2019 program engaged in in-person laboratory research experiences, working together on two cohort projects and an independently chosen project while growing plants in the lab, learning data management, statistical analysis (R, in particular), and presenting their work. As the summer progressed, students began individual projects while continuing data analysis and writing activities on the cohort projects. All of the individual projects used unPAK resources, including Salk mutants and the database of previous *Arabidopsis thaliana* research results.

Remote URE (2020)

Undergraduate students in the summer 2020 program engaged remotely in research experiences, working together on a plant-based cohort project, a data-focused cohort project, and an independently chosen project while growing plants remotely, learning data management, statistical analysis (in R) (14), and communicating science. The difference between the 2019 and 2020 URE was the replacement of the centrally located experiment with the distribution of a plant growth kit to test hypotheses associated with natural *Arabidopsis* accessions in remote settings. In addition, a series of instructional protocol videos were filmed with a webcam which were then uploaded to Google Drive and/or YouTube. Voice Thread was also used to convert PowerPoints to add audio demonstrating unPAK's rigorous protocols. A detailed discussion of the plant growth kits, the cohort projects, and the independently chosen project is provided below, followed by the outcomes associated with the remote summer program compared with the 2019 in-person program.

Overall, we examined the hypothesis that in-person and remote summer URE improve students' research, discovery, and data analysis techniques while strengthening unPAK network collaboration for researching the role of genes in influencing plant traits. We focused on the following research questions: Do students report positive gains in learning how to conduct research and data analysis in a remote URE as previously reported during in-person unPAK UREs and CUREs (3, 15)? Do students report positive outcomes associated with collaborating and bonding with students and faculty across the unPAK network as demonstrated during previous unPAK in-person UREs and CUREs (3, 15)?

Remote preparation, distribution, and execution. Plant experiment size was determined by the number of students in the URE, grow-space size restrictions, and number of desired replicates. Natural accessions of *A. thaliana* were selected to represent natural geographic variation. Materials were ordered and assembled into kits for each of the students and senior scientists participating in the remote plant-based cohort experiment. Appendix 1 provides a list of all materials and photos of remote set-up; no safety issues were present, and procedures conformed to traditional ecological methods for natural plant material disposal. Two weeks prior to the start of the program, students received research kits, including tools, supplies, and seeds of natural accessions of *A. thaliana*, via FedEx or in-person pick-up. Instructional videos included protocols for vernalization of seeds, constructing grow space, sowing seeds following the experimental design, plant care and maintenance, measuring and recording plant phenotypes, and data quality assurance and quality control. Throughout the program, daily work week meetings via Zoom and a dedicated Slack workspace were used for conversation, to answer questions, to facilitate cohort building, and to share scientific findings among participants. Appendix 2 provides an example schedule for the program.

Remote instruction

Student introduction and research procedure. Upon receipt of their plant growth kits, students were instructed to watch an unboxing video to familiarize themselves with their equipment, and a vernalization instruction video to ready their seeds for sowing the following week. At the start of the program, students planted replicates of each accession under standard photoperiods, learned and implemented protocols for plant care, and collected initial phenotypic data. Appendix 3 provides the protocols, and Appendix 4 provides additional details of the research procedure.

Student projects. Students participated in two cohort projects and one independently chosen project. The first cohort project was based on the live plant experiment conducted remotely and the second on phenotype data collected by previous research interns. For the independently chosen project, faculty prepared a list of broad ideas aligned with unPAK research goals. Appendix 5 provides details of unPAK research goals and representative student questions. Students selected two initial ideas to explore further.

Students pitched their refined research ideas to the senior scientists via individual Zoom meetings. After their meeting with faculty, students further examined feasibility and chose one project to pursue for the duration of the URE, with the option to continue their research at their home institution with the help of their home institution mentor. Students with similar research interests had the opportunity to work collaboratively or individually.

Data visualization and analysis using R. Students were introduced to and coached in the use of R for data visualization and statistical hypothesis testing as it was used to complete all three projects. All URE participants were provided an account on a cloud-based Rstudio (16, 17) server that allowed students software access through a web browser. During the program, three Zoom-based "Statistics using R" sessions were conducted with all students and faculty present, aided by shared Google drive folders where students would save and share code. Appendix 6 provides an R exercise created for the virtual program.

Student science communication. Students developed communication skills throughout the program: they read primary literature, served as facilitators for article discussion, developed a collaborative annotated bibliography, provided daily oral reports of ongoing projects via Zoom, and wrote and presented final projects. The last day of the program was a celebration of science, where students orally presented to the host senior scientists and faculty from across the unPAK network. Students collaboratively presented on the two cohort projects (remote plant-based and data-focused) while also presenting on their independently chosen project. Faculty and students alike provided supportive and constructive feedback for each other after presentations.

QUALITATIVE RESEARCH METHODOLOGY

An examination of student and faculty expectations and outcomes began in the summer of 2019 with the in-person URE. Qualitative methodology is used as this approach is particularly suited to evaluate outcomes associated with research in undergraduate institutions (4). For the evaluation of the 2019 and 2020 summer programs, two data collection techniques were used: in-depth interviews (pre- and post-program) individually with faculty and students and a mid-program student focus group. Appendices 7 to 11 provide the interview and focus group questions. The research interviews conducted in 2019 and 2020 provided a summative assessment of the URE while the 2020 focus group provided a formative assessment of the in-process remote URE solely used for faculty purposes and not for the purposes of this paper.

Students who participated in this URE were generally sophomore students majoring in biology but with little prior experience with laboratory research or CUREs, conducted either in-person or remotely. Seven students completed the in-person summer program in 2019. A total of 13 (7 pre- and 6 post-program) student interviews and 9 faculty interviews were conducted in 2019. Eleven students completed the remote summer program in 2019. Twenty (11 pre- and 9 post-program) student interviews, a focus group with nine students, and 8 faculty interviews were conducted in 2020. All interviews took place in line with the Institutional Review Board (IRB). Appendix 12 provides the IRB letter of exemption.

Interviews were transcribed verbatim, reviewed for accuracy, and imported into Atlas.ti (a qualitative software analysis program) to systematically analyze and code for recurring themes (18–21). Author DJ-R analyzed all interview data using ethnographic content analysis (22), specifically using the inductive concept coding approach (23). This approach uses an iterative method designed to uncover meaningful concepts and verify relationships among them (24). As in coding protocols used in grounded theory methodology (18), concept coding examines ethnographic content for emerging themes and places them into categories and subcategories. During this process, codes were added, code definitions were redefined, code categories were collapsed, and interviews were reexamined at the summation of coding to ensure consistency in our analysis (23).

Comparing student interview results with faculty results provided a robust assessment of two perspectives directly involved in the summer programs. This comparison allowed for a more holistic understanding of the URE, as the direct experiences of those involved are captured for analysis. In addition, all students were asked to provide valid results regardless of student outcomes (i.e., students who produced poster presentations or publications compared with those who partook in the URE and decided they may no longer want to pursue research).

The de-identified coding results of the 2019 in-person program were distributed to the lead faculty in a 2019 report for cross-checking and to provide a formative assessment on which to build the 2020 program. Appendix 13 provides the formative assessment for unPAK's 2019 in-person URE program. The results of coding for the 2020 remote URE were distributed to the lead faculty for cross-checking during the creation of this paper and to provide a summative assessment comparing the 2019 and 2020 programs.

We drew heavily on the set of interviews from the 2020 remote URE to provide specific insights for educators developing remote research experiences. However, the current analysis also draws on the 2019 in-person summer program for a summative assessment of key differences between the programs to provide recommendations steeped in both student and faculty perspectives (19). The interview templates were consistent from the 2019 to the 2020 program, with the exception of including an additional section regarding remote learning and practice in 2020. The consistency of the interview protocols made a summative assessment regarding student expectations and outcomes possible.

RESULTS

Our evaluation focused on whether students would report positive gains in learning how to conduct research, data analysis, and effectively collaborate and network with students and faculty across the unPAK network in a remote URE as demonstrated during previous unPAK in-person UREs and CUREs (3, 15). Overall, unPAK students reported positive gains in learning how to conduct research and data analysis in a remote URE as well as positive outcomes associated with networking across the unPAK network as demonstrated during previous unPAK in-person UREs and CUREs. A detailed description of coding results of the research interviews with students and faculty involved in both URE programs follows.

Research and data analysis outcomes

Students discussed varying levels of experience with research and data analysis prior to the unPAK URE. Even those students with some research experience initially reported anxiety associated with making potential mistakes that might lead to failure for their own research projects and/or the larger scientific goals associated with unPAK (especially for the virtual program). However, coding revealed students experienced a balanced learning environment, both during the in-person and remote URE through teaching and self-discovery that allowed them to overcome their fears of conducting research and data analysis. Overall, student interviews yielded two themes associated with how faculty helped assuage student fears associated with conducting research and data analysis remotely: (i) using a variety of instructional techniques and (ii) using several communication platforms for support. When discussing these themes, we also include areas of opportunity for future UREs based on the lessons learned from both the in-person and remote unPAK student programs.

Instructional techniques

Student and faculty interviews described how remote instruction occurred through pre-recorded videos, video-conferencing via Zoom, shared collaborative Google drives (for code and for other science documents), meeting with students virtually, and the discussion software Slack. Our results indicated the prerecorded remote research set-up, video protocols, and Zoom meetings were helpful to students. Each student reported the prerecorded video tutorials were effective in demonstrating the processes to set up, supervise, and measure the growth of plants, a process described as "rewarding" by the students: "When I initially started, I was really worried that I might not actually get anything to sprout.…But after I saw my plant grow, it was a really rewarding process…So that was really exciting because I've never actually grown plants before."

Although positive outcomes were associated with instructional techniques for both UREs, students discussed difficulties with regard to the remote experience. First, some students indicated disappointment in the area they designated for plant growth (2 out of 9, or 22%): "I should have placed the plants probably in a better spot in my house because the light was a lot brighter than what I thought it would be. So, I ended up covering a section of my room." Secondly, several reported difficulties with extracting seeds from the test tube they were shipped in during the planting phase (7 out of 9; 78%): "The seeds coming in the vials was probably the most frustrating part about it…they [faculty] had spoke[n] about [how] normally, they do it on a petri dish, which would be so much more easy to use…But, I understand why that would be difficult for shipping purposes."

In addition, students in the in-person experience reported the need for faculty to provide additional beginner training associated with data analysis tools. Though students did report positive outcomes associated with learning R, they discussed difficulty in how this concept was introduced and how additional examples, other than those associated directly with the research they were completing, would provide a more "low-stake" environment for practice (3 out of 6; 50%). Building on students' response associated with data analysis in 2019, faculty revamped how R was introduced and taught to students in 2020 (see Appendix 5). Overall, students reported more positive outcomes associated with R in 2020, despite it being remote (8 out of 9; 89%).

Communication platforms and strategies

Students and faculty reported Zoom and Slack as the main platforms used for communication during the remote program, with Zoom lab meetings each weekday (see Appendix 2). These Zoom sessions lasted 2 to 3 hours. While students reported these as effective, they identified their attention span significantly decreased after 2 hours. To help ease Zoom fatigue, unPAK faculty promoted student participation; however, students discussed how additional breakout sessions, stretching, breaks, etc. could have been incorporated more frequently to allow to increase stimulation.

Students agreed Zoom meetings ran efficiently (9 out of 9; 100%), "I really liked them. At first, I thought they were going to be a little bit awkward…After a week [when] everyone somewhat got to know each other… it wasn't as awkward, and everyone followed the normal Zoom protocol." unPAK faculty also used breakout rooms in Zoom to foster student collaboration: "the break-out groups [in Zoom] helped as well because it allowed us to focus more on our specific projects, so individual projects as well as the two by two [group project] subgroups." Students also discussed how the "raise the hand" feature was useful in Zoom and provided meeting structure (8 out of 9; 89%). In addition, faculty consistently operated Zoom meetings in a similar pattern, with informal discussion before the meeting,

student check-ins/informal project update, paper discussion and/or R training, and questions for the day.

In addition to using Zoom, unPAK's faculty created a Slack account with several channels that provided space for student and faculty interaction, for formal scientific discussions and informal conversations. These channels were open 24/7, providing students with the ability to post questions, concerns, comments, etc. about their daily experience. The use of Slack was especially important for the remote URE, as student participants were located in two time zones, which introduced an added challenge in synchronous discussion and as students progressed with their work throughout the day. One student, who participated in both the 2019 in-person and 2020 virtual program, described positive outcomes associated with Slack and how Slack should continue to be used if the summer program resumed in-person operations in the future.

Though Zoom and Slack were helpful to provide mediums of communication for students during the program, students participating in the remote summer program highlighted that a detailed daily schedule distributed through email would have benefitted students prior to beginning the program (5 out of 9; 56%). While faculty sent a broader weekly schedule for this program, students discussed the need for a more detailed schedule to be able to work around other commitments. Students in the in-person experience did not discuss the need for additional scheduling due to their time in the lab resembling a typical workday.

Network outcomes

Students reported the daily Zoom meetings promoted connectivity among students and faculty while enhancing their motivation. Faculty reported that daily Zooms were particularly important due to the virtual environment diminishing student opportunities for connection and to keep students on track in their research and data analysis projects. Though some students were more active than others, as is typical in group settings, students and faculty reported that working in groups provided several advantages (7 out of 9 students, or 78%, and 4 out of 4 faculty, or 100%): (i) they allowed students to bond informally; (ii) they created a "safe space" for students to ask for help; and (iii) they resulted in successful group projects.

In addition, students in both the in-person and remote experiences reported the importance of "funPAKs (8 out of 9; 89%)." Each Friday students had the option to participate in funPAKs, which included informal games, icebreakers, and fun activities that were not associated with research or data analysis. Students who participated in these reported that they (i) helped students and faculty network; (ii) broke up the work schedule; and (iii) promoted positive working relationships. Especially since the Zoom meetings were described as mostly "business focused," these virtual events provided a lighter atmosphere for the remote students as they were unable to experience typical informal in-person laboratory interaction. Students in the remote experience also reported they would have enjoyed additional informal activities that occurred without faculty involvement but were scheduled by the faculty for students (e.g., Zoom get togethers, Netflix watch parties, etc.).

Ultimately, even with the variety of virtual techniques used by unPAK for the remote program, both students and faculty discussed feeling it was more difficult to meaningfully connect in the remote URE. Students and faculty discussed missing the "traditional" laboratory environment that allowed for informal conversations, as Zoom meetings represented "business meetings (7 out of 9 students, or 78%, and 4 out of 4 faculty, or 100%)." In addition, though students reported the Slack channels created by the faculty allowed for more informal discussion, they suggested it did not function as well as informal conversations during in-person courses or laboratory settings.

Finally, students and faculty reported it being easier for students in the remote experience to simply "check out" of the URE entirely through not participating in the cohort or independently chosen projects or through repeatedly missing Zoom sessions. In fact, faculty had to determine corrective actions (through contacting students' home institution faculty and withholding internship funds) for two students in the remote program who frequently missed the daily Zoom calls and did not participate in projects. Maintaining a channel of communication with students' home institution provided some buffer; however, during the pandemic, students still did not respond to these corrective actions with full participation.

DISCUSSION

Teaching applied research in a remote modality poses pedagogical and logistical challenges that require a combination of support such as providing necessary equipment to students, thoughtful remote program design, and focus on activities likely to be effective in a remote environment (25). Though challenging, unPAK's remote URE in the summer of 2020 builds on scholarly evidence indicating that undergraduate students can gain research experience and analytical tools in remote research settings (25, 26). In addition, unPAK's remote program further demonstrates the success students can achieve with growing plants in remote settings and conducting data analysis projects (27). Our research identifies direct challenges students faced when cultivating live plants in remote settings, such as the need to explicitly help students understand the importance of where to place growing stations. In addition, unPAK's experience with UREs and CUREs for over a decade provided foresight for faculty to not depend solely on students successfully growing plants. Instead, faculty created a separate data-based cohort project for students in case cultivating plants in remote settings was unsuccessful, ultimately resulting in two successful cohort projects.

Of significance, studies are emerging demonstrating the importance of using a variety of communication platforms and strategies for instructional and collaborative purposes, such as Zoom, Slack, Microsoft Teams, etc. (26), as these platforms increase inclusivity for student participation in remote settings (28). Our research demonstrates that the platform Slack, for example, provided the means for students to ask faculty questions in a more informal manner while also serving as a medium for students to bond (unPAK faculty created informal Slack channels for students) and address each other's questions. In addition, our work shows the importance of using a communication platform such as Slack if the remote program occurs in various time zones as this allows for students and faculty to quickly and efficiently ask and answer questions throughout the day.

Our research further builds on the literature demonstrating the importance of creating spaces for informal student-to-student and faculty-to-student connections in remote settings as programs at a distance lack the typical interactions that occur in an in-person laboratory setting. Our research indicated positive associations with students engaging in remote "funPAKs" through the creation of Kahoots and other social activities. Our students also reported future unPAK remote UREs should include Zoom sessions and activities for student-only participation to further increase cohesiveness of remote cohort groups.

CONCLUSION

Participation in UREs helps students develop science identities and research skills while promoting their participation in a variety of STEM fields. The biology research network unPAK (21 institutions across the United States and Canada) engages undergraduates in research experiences while generating new knowledge of plant phenotypes. In 2019, unPAK launched a summer URE program that recruited undergraduate researchers from across the network for an intensive in-person collaborative program. In response to the COVID-19 pandemic in 2020, unPAK rapidly shifted to provide the summer URE program remotely. This article documents the instructional and communication processes unPAK used to provide URE remotely and provides the outcomes from student and faculty perspectives.

Overall, our results indicated in-person and remote summer URE both improve students' research and data analysis techniques while strengthening unPAK network collaboration for researching the role of genes in influencing plant traits. However, transitioning a URE remotely brought new challenges that required attention and a critical evaluation. Considering the successes and challenges of both the in-person and remote URE, unPAK recommends the following when quickly transitioning an in-person URE to a remote mode:

1. Provide a straightforward and detailed remote laboratory set-up
2. Distribute a detailed daily schedule for remote students prior to the program
3. Require daily online meetings, with student round-table check-ins
4. Require group work in remote settings
5. Provide foundational training for data analysis across multiple sessions
6. Encourage home-institution faculty participation and connection to research programs
7. Exercise consistent practices in Zoom meetings
8. Limit Zoom and provide frequent Zoom breaks
9. Use a 24/7 communication channel such as Slack
10. Provide informal student and faculty remote "gatherings"
11. Encourage students to focus solely on research experience (especially if URE is a paid full-time internship).

SUPPLEMENTAL MATERIALS

Appendix 1: Materials list for unPAK virtual REEU
Appendix 2: Sample schedule week one for unPAK virtual REEU
Appendix 3: Sowing, germination, and rosette data collection protocols for unPAK virtual REEU
Appendix 4: Additional details of research procedures for unPAK virtual REEU
Appendix 5: unPAK research goals and student questions
Appendix 6: R spoon exercise for unPAK virtual REEU
Appendix 7: Faculty interview template, pre-program for unPAK virtual REEU
Appendix 8: Student interview template, pre-program for unPAK virtual REEU
Appendix 9: Student focus group template (virtual), midpoint for unPAK virtual REEU
Appendix 10: Faculty interview template, post-program for unPAK virtual REEU
Appendix 11: Student interview template, post-program for unPAK virtual REEU
Appendix 12: IRB for USDA REEU evaluation exemption letter
Appendix 13: Formative assessment for unPAK's 2019 in-person URE program

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