INTRODUCTION

Due to the COVID-19 pandemic, social distancing and other safety measures have been particularly challenging to course-based undergraduate research experiences (CUREs). In order to achieve ‘CURE pedagogical goals of students’ research competency (1), sense of project ownership (2), and self-identification with science and research communities (3), STEM CUREs rely on a range of in-person activities; namely, lab work, field work, and face-to-face mentoring. There are also concerns about the adverse impact of moving to an online environment on students’ teamwork and communication skills (4, 5). The disadvantages of abandoning in-person activities for CUREs necessitate that educators identify remote alternatives which can be quickly adopted in future catastrophic events (6).

In Binghamton University’s First-year Research Immersion (FRI) program, to comply with social distancing requirements, we implemented a technology-based solution for “wet-lab” CUREs. FRI consists of 10 research tracks that provide first-year students with three sequential CUREs. In the first fall semester, students learn foundational research method skills which are continually utilized as students progress through the CURE sequence. In the following spring semester, students learn the discipline-specific research skills needed to complete their own research projects during the third and final CURE in the following fall semester (7). For this manuscript, we focused on four tracks (Biofilms, Biogeochemistry, Biomedical Anthropology, Ecological Genetics) which, in the second semester CURE (normally with two 3-h lab sessions per week) used the strategy described below on a regular basis during the spring semester of 2021. Our primary goal in designing and implementing this strategy was to continue delivering the learning outcomes for our CUREs despite pandemic challenges, including accommodation of remote learners and social distancing, which resulted in a 50% reduction of lab capacity and in-person lab hours. The learning outcomes were as follows:

1. Generate testable scientific hypotheses and develop research plans to test these hypotheses
2. Evaluate and discuss primary research literature and evaluate the validity of hypotheses generated by others
3. Work on research projects independently and in small group settings
4. Apply research protocols and instrumentation appropriately
5. Collect and analyze research data appropriately
6. Communicate research effectively orally and in writing

A growing body of pedagogical literature proposes hybrid and virtual approaches to teaching wet-lab (8) and undergraduate research courses (9–11) during the COVID-19 pandemic. Particularly in the case of hybrid solutions (remote and in-person students), the versatility and relative affordability of mobile devices and cameras provide opportunities to improve students’ experiences in wet-lab courses. These devices can be paired with video conferencing software (12) or adopt more innovative solutions, such as incorporating virtual reality (VR) technology into teaching lab courses (13).

Our strategy utilized mobile devices and video conferencing software to maximize the time synchronously engaged in research activities each week. Students were paired and rotated through in-person and remote roles. Overall, this technology allowed all students (in-person, remote choice for semester, or temporarily quarantined) to engage in the research environment synchronously (live), collaborate within teams, and have meaningful responsibilities.

Although the intended audience of this report is primarily CURE educators, for whom wet-lab and field work training is an essential part of their students’ research and learning, this method can also be beneficial for synchronous remote teaching of any lab courses.
PROCEDURE

Zoom conferencing software on iPod Touch devices was used to connect remote students to wet-lab or field research experiences. Thus, students interacted synchronously with their peers, undergraduate peer mentors (UGPMs), and research educators (REs) despite social distancing limitations (Table 1). In some cases, the technology allowed temporarily remote (quarantined) students to engage with an in-person lab partner, team, or UGPM to synchronously participate in wet-lab or field experiences. In other cases, the technology was used to permanently pair students in order to reduce the number of students in the lab. To optimize the utility of this strategy, in-person students were typically required to execute the physical lab or field work as in a traditional in-person CURE. Remote learners were typically responsible for procedures such as directing and guiding their in-person lab partner through experimental procedures and maintaining an electronic lab notebook (ELN). Together, the in-person and remote students were to share and discuss their troubleshooting, findings, and conclusions.

We asked for student feedback via Google Form twice throughout the semester (1/3 and 2/3 into the semester) to understand what was and was not working for students with regard to their remote lab experience (see Appendix I in the supplemental material). We were looking to understand whether they were feeling engaged and productive with remote lab learning, what was working well with remote lab learning, and what suggestions they had for improvement. We also surveyed students about their remote learning experiences as part of our summative, end-of-semester, online Qualtrics survey. A complete list of survey questions is included in Appendix I. Students also spoke to these interventions in their end-of-semester reflection essays (300 to 500 words), where they were asked to reflect on their professional and personal growth during the spring CURE. The study was approved by the Binghamton University IRB (no. STUDY00000104).

Safety issues

Public health and lab safety were driving factors in the purchase of iPod Touch devices. All university and discipline-specific safety guidelines for teaching and research laboratories were followed. For example, in the Biofilms stream, the American Society for Microbiology's Guidelines for Biosafety in Teaching Laboratories was referenced for implementation (14). One primary safety guideline to follow across all disciplines was to avoid the use of students’ personal devices. The iPods provided the most affordable, convenient, and adaptable technology, with audio and video capabilities to facilitate mobile Zoom conferencing in the lab. Additionally, to address cleaning and disinfection guidelines, plastic cases and screen protectors were purchased.

Conclusion

Here, we report student feedback outlining the challenges and success of using iPods and Zoom to link remote and in-person students in CURE lab environments.

Formative assessment

Student responses to feedback surveys (survey no. 1 and 2) during the semester revealed engagement issues for remote students due to two factors: (i) distractions during remote sessions and (ii) communication issues between in-person and remote students, and between remote students and REs and UGPMs. Improvements made in response included (i) increasing the use of UGPMs for more intentional check-ins with remote students to help them stay connected and (ii) providing all students with more explicit in-person and remote student responsibilities. Although students indicated feeling less engaged during remote lab work compared to during in-person lab work, a notable proportion of students who experienced in-person and remote work during the semester indicated feeling engaged “frequently” or “always” during remote lab work (49%, survey no. 1; 58%, survey no. 2).

Summative assessment

In the end-of-semester assessment, the majority of students indicated while conducting lab work remotely that they “frequently” or “always” felt that they could connect and communicate in real time with their partner, UGPM, and/or RE (68%), and felt they were making meaningful contributions to the lab work and/or research project (62%). Considering the COVID-19 challenges and safety measures, student quotes from end-of-semester reflection essays (Table 1) indicated a positive student view of the iPod usage. When students were asked to rank their preferences for future lab experiences, an overwhelming majority of students indicated fully in-person lab experiences as their top preference (78%), followed by 50:50 Hybrid lab experience (9%), and Flipped lab experience (7%) (Fig. 1, with terms defined). Thus, while the students recognized the value of the hybrid iPod method for enhancing their experience, they also realized that it did not replace in-person, hands-on scientific research experiences for them. Student perceptions indicated that a hybrid experience did not provide as deep an immersion into research as a fully in-person experience does. For example, the level of iteration in a fully in-person wet-lab research experience contributes markedly to building students’ professionalism and confidence (15).

To keep remote learners engaged, we used ELNs and had UGPMs remotely jump through breakout rooms during lab to answer questions and ensure that remote learners were on task, as they had been instructed per their responsibility, to guide their partners and document experiments in the ELN. Due to this method’s complex...
| Example uses of iPods for connecting remote learners | Paired lab partners in-person students + remote students | Remote students + in-person UGPM | Remote students + in-person bench work student | Remote students + in the field students | Instructor demonstrations |
|-----------------------------------------------------|--------------------------------------------------------|--------------------------------|-----------------------------------------------|--------------------------------------|----------------------------|
| Description | One student in each pair attends lab in-person (A) while the other student attends remotely (B). Each wk, they rotate roles. | Remote learners (fully or temporarily) paired with an in-person UGPM in the lab. | Remote learners (fully or temporarily) paired with an in-person student or student team in the lab. | Remote learners (fully or temporarily) connected with UGPM, another student, or RE to participate in field work. | RE demonstrates detailed research skills live for in-person and remote learners while maintaining social distancing (doc-cam). |
| Remote responsibilities | • Directing and guiding in-person lab partner through experimental procedure (calculations, explaining next steps, etc.) | • Directing and guiding in-person UGPM through experimental procedure (calculations, explaining next steps, etc.) to demonstrate own understanding | • Directing and guiding in-person lab partner/team through experimental procedure (calculations, explaining next steps, etc.) to demonstrate own understanding | • Observation of samples and/or data in the field in real time | • All students, in-person and remote, watch RE demo via Zoom |
| | • Maintaining ELN (recording procedure and observations, data collection, data analysis, etc.) | • Maintaining ELN (recording procedure and observations, data collection, data analysis, etc.) | • Maintaining ELN (recording procedure and observations, data collection, data analysis, etc.) | • Maintaining ELN (recording procedure and field observations, data collection from field, data analysis, etc.) | • Ask questions about demo |
| | • Asking remote UGPMs clarifying questions | • Asking remote UGPMs clarifying questions | • Asking remote UGPMs clarifying questions | • Asking clarifying questions of RE or in-person UGPMs | • Take notes on tips and tricks provided by RE |
| In-person responsibilities | • Execution of lab techniques (protocols, instrumentation, etc.) | • UGPM carrying out lab techniques (protocols, instrumentation, etc.) under direction of remote student(s) | • Execution of wet lab techniques (protocols, instrumentation, etc.) | • Travel to and collection of samples and/or data in field | • Same as remote responsibilities |
| | • Asking clarifying questions of RE or in-person UGPMs | • UGPM guides students through issues with series of counter-questions to encourage students to own experimental outcome | • Asking clarifying questions of RE or in-person UGPMs | | |

(Continued on next page)
TABLE 1 (Continued)

| Example uses of iPods for connecting remote learners | Paired lab partners in-person students + remote students | Remote students + UGPM | Remote students + in-person bench work student | Remote students + in the field students | Instructor demonstrations |
|-----------------------------------------------------|-------------------------------------------------------|------------------------|-----------------------------------------------|----------------------------------------|---------------------------|
| Typical comments                                    | “Using iPods in the lab to communicate with and visualize my partner’s work during lab is incredibly helpful. I feel as though this system works very well to connect lab partners working from different locations. I find maintaining my virtual lab notebook to be very helpful for organizing my data in a clear, accessible format that I can access at any time.” (FRI Student) | “I think that executing the experiment with the remote students over zoom was a good attempt as we were able to converse about what was happening in lab without their physical presence. They were also engaged throughout the process in asking questions about the steps.” (FRI UGPM) | “Even though I took classes online, my experience was not greatly affected. I was paired up with another student and he used an iPod to show me the whole process of each lab expt. I also had the opportunity to direct him to conduct experiments according to the instructions I said, and then he would point out my mistakes and reminded me what steps can be done better.” (FRI Student) | “We made it outside in the beautiful weather and the hotspot worked for livestreaming the campus watershed tour.” (RE) | “Students seem to be appreciating the in-person/remote lab format and are really thinking about how to get the most out of it... Demonstrating how to load a gel is so much better with an iPod-eye view and I never want to demo it with people looking over my shoulder again.” (RE) |
| Photos                                              | Remote student observing expt and recording information into ELN. | Hands-free mobile iPod use. | Stationary use of iPod with camera focused on experiment. | Water sample collection in the field while remote students view the process. | RE demonstrating lab technique with in-person and remote students viewing via Zoom or projector screen. |

April 2022 Volume 23 Issue 1
10.1128/jmbe.00225-21
and dynamic use of technology, we also compiled a series of recommendations and troubleshooting suggestions to help alleviate technical issues (Appendix 2 in the supplemental material).

Since teamwork and collaboration are central to CUREs and particularly important for students participating remotely, we used data collected from the collaboration category questions in the Corwin et al. Laboratory Course Assessment Survey (LCAS) (16). LCAS is a validated survey which measures students’ perceptions about their experience relative to categories of research-course design which science education research has shown to relate closely to students’ engagement and retention in STEM majors. In terms of students’ perception of their exposure to collaborative activities, the mean for collaboration for our students was above 95%, whereas the means for the reference data were below 90% of the possible range (Table 2). Even in a hybrid environment with reduced in-lab time and remote lab components, we were able to provide students with an environment conducive to building teamwork and collaboration skills.

Although students prefer in-person lab experiences, our strategy can increase CURE and research access to students, educators, and institutions beyond COVID-19. While students could benefit from this strategy in future remote situations due to sickness, geography, or severe weather, there are ways that this model could be built into the curriculum to provide long-lasting benefits. Whenever a portion of students are participating remotely, instrument and supply costs can be reduced due to lower numbers of in-person students. Community colleges and primarily undergraduate institutions (PUIs) with limited research resources and/or instrumentation can collaborate with high-research activity-institutions rich in resources to provide students more research and mentorship access through remote experiences. These types of partnerships could also lead to the formation of bridge programs, which have been shown

![Graph showing student responses on the end-of-semester survey to the question “Based on all of your lab experiences, rank these lab learning methods according to your preferences for future lab experiences, with 1 being the method you would prefer the most,” n = 95.](image)

**TABLE 2**

| Student group | Mean | SD | n | % of possible range |
|---------------|------|----|---|-------------------|
| Traditional (LCAS ref) | 20.87 | 4.0 | 68 | 87.0% |
| CURE (LCAS ref) | 21.11 | 3.2 | 73 | 88.0% |
| FRI Spring 2021 | 23.50 | 1.5 | 96 | 97.9% |

aTraditional students (LCAS ref): data from students who took a traditional-type laboratory course (n = 68). CURE students (LCAS ref): data from students who took a CURE-type course (n = 73). SE is not shown because data did not meet the assumption of homogeneity of variance. For Collaboration, there were six questions (e.g., “In this course, I was encouraged to provide constructive criticism to classmates”), with choices of “never” = 1, “one or two times” = 2, “monthly” = 3, and “weekly” = 4, for a possible mean range of 6-24. Calculations as per Corwin et al. (16).
to increase STEM retention of at-risk students by preparing them for their next steps, whether their next degree program or a summer research experience (17). This method could also give educators, both K-12 and higher-ed, the opportunity to receive remote training on CURE implementation and more.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.1 MB.

ACKNOWLEDGMENTS

This study was made possible by resources provided by the Office of the Executive Vice President for Academic Affairs and Provost. We thank our FRI team, including the REs Jonathan Schmitkons and Christina Baer, and numerous Affairs and Provost. We thank our FRI team, including the REs Jonathan Schmitkons and Christina Baer, and numerous WGPs for their technology implementation and discussion. We also thank Nancy Stamp for manuscript feedback and Binghamton’s IT department for technical assistance.

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