Preserving the positive student outcomes of CUREs through disruption: implications for rem...

Preserving the Positive Student Outcomes of CUREs Through Disruption: Implications for Remote Learning

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Introduction

Undergraduate research, a key component of many science, technology, engineering, and mathematics (STEM) programs at the college/university level, was challenging for faculty to transition to remote instruction during the Spring term of 2020. The COVID-19 crisis meant that laboratories and other research facilities were entirely shut down for months, with no opportunity to use these spaces for teaching or for socializing students into the culture of working in laboratories. Without this physical space, undergraduate students run the risk of missing out on both educational/technical experiences and the mentoring that accompanies being in these spaces alongside experienced undergraduates, graduate students, post-doctoral students, professional staff, and faculty.

Course-based undergraduate research experiences (CUREs) were similarly affected by the shutdown. CUREs are becoming a widely adopted model for increasing opportunities for undergraduate students to participate in research and are a high-impact practice with well-established benefits (Auchincloss et al., 2014; Kuh, 2008; Linn et al., 2015; Russell, 2007). CUREs are defined by five key elements: disciplinary practice, broadly relevant research, discovery of an unknown outcome, collaboration, and iteration (Auchincloss et al., 2014; Ballen et al., 2017). What distinguishes CUREs from other inquiry-based labs is that students pursue authentic, novel research questions with an unknown outcome and relevance outside of the classroom (Ballen et al., 2017). CUREs make research more inclusive by mitigating barriers to accessing traditional, mentored research experiences such as lack of information, perceived barriers of interacting with faculty, time, and financial constraints, as well as faculty biases in selection, which may disproportionately affect students from marginalized identities (Bangera et al., 2014). Emerging research on CUREs demonstrates that they can provide many of the same benefits as mentored research experiences, such as development of research skills, gains in self-efficacy and scientific identity, and ability to persist in science (Brownell et al., 2012; Brownell et al., 2015; Corwin et al., 2015; Flaherty et al., 2017; Lopatto et al., 2008). CUREs also appear to benefit faculty, allowing them to directly connect their research and teaching, leading to potential publications, and also resulting in a higher level of engagement and excitement about teaching (Shortlidge et al., 2016; Shortlidge et al., 2017).

Two potential key benefits of CUREs documented elsewhere are self-efficacy and science identity (Brownell et al., 2012; Cole et al., 2021; Cooper et al., 2020; Hanauer et al., 2017, Vater et al., 2019; Vater et al., 2021). Here, we focus on these specific outcomes because self-efficacy and science identity are tied to a student's decision to stay in the sciences, and thus both are critical for the retention of underrepresented groups in STEM (Chemers et al., 2011; Hanauer et al., 2016). Self-efficacy, or students' judgements of abilities to perform academic tasks (Bandura, 1977; Hofer et al., 1998), is important to cultivate in students because it is related to STEM course grades (Cavallo et al., 2004), achievement of core competencies—problem-solving skills, creativity, and cognitive flexibility—needed to be successful in STEM (Gecas, 1989), and academic goal setting and resiliency (Zimmerman et al., 2017). Science identity, according to Carlone & Johnson's (2007) definition, is composed of three, interrelated dimensions: competence, performance, and recognition, which interact with an individual's other identities (e.g., gender, racial, or ethnic). Development of science identity has been shown to be critical for women and underrepresented minorities to persist in STEM fields (Vincent-Ruz & Schunn, 2018) and positively impacts a student's likelihood of entering graduate school (Merolla & Serpe, 2013) or a STEM occupation (Stets et al., 2017).

In the move to remote instruction in Spring 2020, there were many challenges to continuing laboratory courses online, perhaps even more so for CUREs. Pivoting CUREs was challenging due to the lab context and the need to maintain the key elements of CUREs: discovery of an unknown outcome, relevance outside the classroom, collaboration, iteration, and use of authentic disciplinary practices (Auchincloss et al., 2014; Ballen et al., 2017). However, if models were developed in which the same benefits of CUREs were maintained in the online/remote setting, this could have positive implications. If student gains in partially remote CUREs are similar to those in a face-to-face context, this suggests a possible way to scale up CUREs with online instruction. Additionally, there may be implications for removing barriers to STEM completion more generally, a long-standing and significant educational challenge (Chen, 2013; Huang et al., 2020; Institute of Medicine, 2011; PCAST STEM Undergraduate Working Group, 2012; Riegle-Crumb et al., 2019). For example, the California State University System has used virtual software to address curricular bottlenecks that prevent students from fulfilling lab requirements (Rivard, 2013; see also Ardissone, 2019, for a similar initiative in the University of Florida system). If there are ways to effectively support instructors as they offer online CUREs, more strategic opportunities are opened up to enhance STEM pathways.

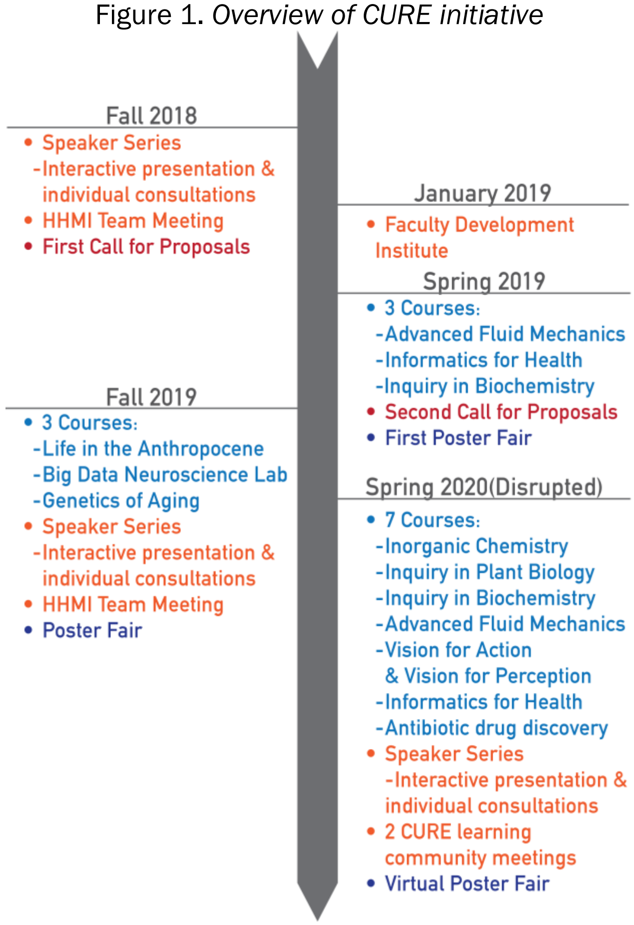
To navigate the challenges of moving CUREs to remote instruction, faculty need support and mentoring. Although other articles in this special issue may address the productive dimensions of CUREs and *student* mentoring, here, we describe faculty mentoring implemented during the transition to remote instruction. Through their engagement with ongoing CURE professional development activities, our faculty were already part of a learning community, a well-documented, effective educational development model (Steinert et al., 2006; Stes et al., 2010; Van Note Chism et al., 2012). Thus, during the transition to remote instruction, we leveraged this existing learning community to facilitate mutual mentoring during the course redesign process.

Recent studies have examined student outcomes in CUREs during the partially remote Spring 2020 semester (Broussard et al., 2021; Fey et al., 2020; Wang et al., 2020). Some have compared outcomes in a single CURE course between Spring 2020 and a prior, non-disrupted semester (Doctor et al., 2021; Mills et al., 2021). However, we are unaware of any other studies comparing student outcomes between in-person and partially remote semesters in a broad range of CURE courses. Given the paucity of published studies on fully remote or hybrid CUREs outside the context of COVID-19, this work provides important insights into preserving well-established psychosocial outcomes of CUREs in a partially remote context.

Institutional Context

For context, Brown University is a highly selective, private research university (R1). It enrolls approximately 7,000 undergraduates, with the majority (69%) entering the university intending to major in the life and/or physical sciences. By the time they graduate, over two-fifths of undergraduates have one or more concentrations in STEM. To increase the persistence and educational experience of students in STEM concentrations, in particular among students from underrepresented groups, the Brown CURE initiative (Figure 1) initiated a call for proposals for instructors to design and teach a CURE. All awardees attended a required, one-day CURE Faculty Institute that emphasized defining and aligning research and learning goals (Cooper et al., 2017), creating transparent, scaffolded assignments, and building community. Faculty already teaching CUREs also attended the workshop as facilitators or panelists. One faculty member was unable to attend and instead attended the CUREnet Institute, a 3-day institute designed to support faculty in the development of CUREs (https://serc.carleton.edu/curenet/about.html). Two instructors attended a CUREnet Institute in addition to participating in the one-day workshop at Brown. Faculty received ongoing support through additional workshops with outside facilitators (1-2 per semester), one-on-one consultations with Sheridan Center for Teaching and Learning staff, and early student feedback, also called "small group instructional diagnosis" elsewhere (Redmond & Clark, 1982) during the semester in which they were teaching. Faculty also received support during the disrupted semester through meeting as a learning community (Cox, 2013). In Spring 2020, the CURE learning community met twice in sessions led by fellow CURE faculty, sharing ideas about how they planned to pivot their course to remote instruction while maintaining essential learning outcomes. Sheridan Center for Teaching and Learning staff were key mentors/facilitators of the institute and early feedback, while a biology faculty member served in this role for the learning community.

Figure 1. *Overview of CURE initiative*



Note. Through our CURE initiative, we supported faculty in launching eight new or re-designed CURE courses. Faculty-focused events are colored orange/red, while student-facing courses and events are in blue.

Ten courses that ran in Spring 2019, Fall 2019, and Spring 2020 were included in this study (Table 1). Of these ten courses, three ran only in Fall 2019, four ran only in Spring 2020, and three ran in both Spring 2019 and Spring 2020. In this manuscript, we categorize courses that ran in Spring 2020 as "disrupted," and courses which ran in Spring and Fall 2019 as "non-disrupted." The disrupted semester included three new courses, three courses which ran in both Spring 2019 and Spring 2020, and one course which was developed prior to the CURE initiative but was only surveyed in Spring 2020. Most of the courses were newly designed or redesigned through our CURE Faculty Institute, but "Inquiry in Biochemistry…" and "Inquiry in Plant Biology…" were designed as CUREs prior to this initiative. The instructors ranged in career stage from postdocs to tenured faculty (evenly distributed across disrupted and non-disrupted semesters), and the disciplinary breadth of courses spanned biology, chemistry, engineering, neuroscience, and cognitive, linguistic, and psychological sciences. Two courses were taught by two authors of this manuscript (i.e., Cohen and Johnson).

Table 1. *Summary of CURE courses included in the study*

Course Name, Instructors & Description (^{N}new, ^{R}redesigned, *already existed)	**Number of students**	**Students' year in college**	**Semester(s) (^{D}Disrupted)**
BIOL 0600: Genetic Screening in Model Organisms^{N} Louis Lapierre & Joslyn Mills Bonal Using gene silencing (RNAi) in *C. elegans*, students identify genetic modifiers of proteins with roles in aging by reverse genetics.	11	2-3	Fall 2019
CLPS 1195: Life Under Water in the Anthropocene^{N} Ruth Colwill & Andrea Megela Simmons Students investigate the impact of anthropogenic stressors on development and behavior in *Danio rerio* and *Xenopus laevis.*	11	2-4	Fall 2019
NEUR 1630: Open-Source Big Data Neuroscience Lab^{N} Alexander Fleischmann Students develop strategies to mine open-source sequencing, imaging and connectivity data to address fundamental open questions in brain science.	10	2-4	Fall 2019
BIOL 0940G: Antibiotic Drug Discovery: Identifying Novel Soil Microbes to Combat Antibiotic Resistance^{N} Toni-Marie Achilli Students search soil bacteria for new antibiotics that can be used to treat infectious disease. Based on the Tiny Earth Initiative.	16	2 only	Spring 2020^{D}
CHEM 0500: Inorganic Chemistry^{R} Eric Victor Students synthesize metal nitrosyl complexes using a variety of new ligand platforms that have not been previously explored.	55	2-4	Spring 2020^{D}

BIOL 0440: Inquiry in Plant Biology: Analysis of Plant Growth, Reproduction, and Adaptive Responses* Alison DeLong & Mark Johnson Students use genetic tools to address novel questions about mechanisms that control plant growth and development.	11	1-3	Spring 2020[D]
CLPS 1591: Experimental Analysis of Vision for Action and Vision for Perception: Are There Separate Mechanisms?[N] Fulvio Domini Students design and implement VR experiments to test for the existence of two separate visual systems for perception and action.	9	1-3	Spring 2020[D]
BIOL 0285: Inquiry in Biochemistry: From Gene to Protein Function* Kristina Cohen Students use mutagenesis to test how a novel, single amino acid substitution affects enzyme kinetics.	13 (2019) 24 (2020)	2-4	Spring 2019 Spring 2020[D]
BIOL 1555/PHP 2561: Methods in Informatics and Data Science for Health[R] Elizabeth Chen & Neil Sarkar Students use data science and informatics approaches to address a biomedical or health challenge.	33 (2019) 27 (2020)	2-4	Spring 2019 Spring 2020[D]
ENGN 1860: Advanced Fluid Mechanics[R] Dan Harris Students use rapid prototyping methods to iteratively design and test a fluids-related device relevant to ongoing research activities at Brown.	20 (2019) 12 (2020)	2-4	Spring 2019 Spring 2020[D]

Note. The courses in the study included entirely new courses designed through the CURE initiative at Brown, pre-existing courses that were redesigned to include or expand on a research component of the course, and CURE courses launched prior to this initiative.

Move to Remote Instruction

Like many U.S. institutions of higher education faced with the COVID-19 pandemic, Brown University moved all its courses to a remote (i.e., synchronous instruction taught via Zoom) or online format (i.e., asynchronous instruction taught via multiple modalities including discussion boards, recorded videos, and simulations). In Brown's case, the Spring Term began on January 22 with face-to-face instruction. The university had a two-week break during March 14 - 29 for instructors to re-tool their courses, and remote courses resumed on March 30 for 5.5 more weeks of instruction. The two-week break included the scheduled Spring Recess; therefore, the disrupted term was one week shorter than a typical academic term.

In this paper, we compare specific outcomes for students in disrupted and non-disrupted terms. Because student characteristics might be one possible reason for dissimilar outcomes, in this section we examine the demographics, educational plans, and reported motivation to enroll in the CURE. For all these dimensions, we find no statistically significant difference.

Almost all the students enrolled in our CURE courses either had already declared or intended to declare a STEM concentration when they enrolled (100% disrupted cohort, 96% non-disrupted cohort). Across all courses, students self-selected to enroll in the CURE courses, and all of the courses were fully CUREs (i.e., they did not have a mix of CURE and traditional lab sections). There was no difference in the percentage of students who had declared or intended to declare a STEM concentration, comparing disrupted and non-disrupted cohorts ($\chi^2 = 2.344$, df = 1, $p = 0.1258$). The students in the disrupted cohort were not demographically different from the students in non-disrupted semesters (Appendix 1).

The two cohorts were also similar in their reported motivation for taking the CURE course. We used questions from the CURE Survey (Denofrio et al., 2007; Lopatto, 2004) to examine students' motivation for taking the course. They were administered pre-course. Students were given a list of possible reasons for taking the course and asked to rate their importance. In all semesters, the reasons with the highest frequency of "very important" or "moderately important" ratings were "interest in the subject matter" and "to learn lab techniques or other technical skills" (Appendix 2). We used chi-squared tests to compare between the disrupted and non-disrupted cohorts and determined that there was no significant difference between the two groups in terms of their reasons for taking the CURE course (Appendix 2). No student who completed both surveys enrolled in more than one CURE within a term, although one student enrolled in a CURE in more than one term and completed surveys for both courses.

Methods

To evaluate student outcomes of our CURE initiative, comparing disrupted and non-disrupted CUREs, our key research questions (RQ) are:

> *RQ1*: In what ways did faculty who taught in Spring 2020 describe making adjustments to their teaching to fulfill core CURE course objectives, while teaching in remote format?
>
> *RQ2*: Do the two groups of students similarly perceive essential elements of a CURE experience, as measured through the Laboratory Course Assessment Survey (LCAS)?
>
> *RQ3*: In terms of key student outcomes associated with CUREs, namely self-efficacy and science identity, do the two groups of students have statistically significant results?

To determine how faculty adapted their courses to remote learning in Spring 2020 (RQ1), we held two meetings of the CURE learning community: one occurred one week before remote learning began, during the planning phase (March 19th), and one occurred at the end of the third week of remote instruction (April 17th). In the first meeting, faculty members shared their plans for the transition to remote learning and had the opportunity to discuss their concerns and anticipated challenges with the group for support. Following this meeting, the proposed changes were summarized (by Wright) and the faculty reviewed the written summary to verify that their proposed changes were recorded correctly. In the second meeting, the group discussed how the transition was going and each instructor shared their successes and had the opportunity to discuss challenges with the group. This meeting was also recorded, and all faculty affirmed that they were continuing with the same adaptation plans.

To assess student outcomes, we administered pre- and post-course surveys each semester in which new and existing courses were supported (Spring 2019, Fall 2019, and Spring 2020). Our survey contained questions from validated survey instruments that have been used to evaluate CURE courses in the past. We administered the Laboratory Course Assessment Survey (LCAS) in full within the post-course survey to assess students' perceptions of the CURE's collaborative, discovery-based and relevant components, as well as iteration within our CUREs (Corwin et al., 2015). The collaboration scale ranks how often students engage in various collaborative behaviors from 1 (never) to 4 (weekly), whereas discovery and relevance and iteration are both measured on a scale from 1 (strongly disagree) to 6 (strongly agree; Corwin et al., 2015).

To examine self-efficacy and science identity, we used two scales from Hanauer et al.'s (2016) Measure of College Student Persistence in the Sciences (PITS) survey. The self-efficacy scale asks students to rate their agreement with a series of statements concerning their confidence in their abilities to function as a scientist on a scale from 1 (strongly disagree) to 5 (strongly agree). The science identity scale asks students to rate their agreement on a series of statements concerning their sense of themself as a scientist who undertakes research activities on a scale from 1 (strongly disagree) to 5 (strongly agree). Both scales were used in their entirety and each individual student's response was calculated as the average of their responses to each item, as in Hanauer et al. (2017). We administered the questionnaires through Qualtrics and distributed them to students via direct email (see Table 2 for response rates). For questions that were administered pre- and post-course and utilized to examine change over the semester, we analyzed only students who completed both the pre- and post-course surveys. All data analyses were performed in *R* version 4.0.0 (R Core Team, 2020). The data were checked for normality using Shapiro-Wilk tests. None of the data were found to be normally distributed, so we used Kruskal-Wallis rank sum tests to compare means between disrupted and non-disrupted semesters. Given the range of variation in the courses included in the study, we tested for alternative variables that could account for differences between groups by checking for demographic equivalency (Appendix 1 & 2), as well as comparing new and repeat courses. We found no other variables to be of significant effect.

Brown University's Office of Institutional Research declared this project non-regulated, i.e., not meeting the federal definition of research because the data were collected for program evaluation. All surveys were optional and not attached to any course grade.

Table 2. *Survey response rates*

Cohort	**Response rate (completed post-course survey only)**	**Response rate (both pre- and post-course surveys completed)**
Not Disrupted (Spring 2019, Fall 2019)	64 out of 113 (56.6%)	55 out of 113 (48.7%)
Disrupted (Spring 2020)	99 out of 157 (63.1%)	80 out of 157 (60.0%)

Notes. Response rates are reported for students who responded to the post-course survey only as well as those who responded to both surveys. The LCAS was analyzed for all students who completed the post-course survey, however we only analyzed responses to the PITS survey questions for students who completed both the pre- and post-course surveys.

Key Findings
Below, we detail the key findings of our study in relation to our three research questions:

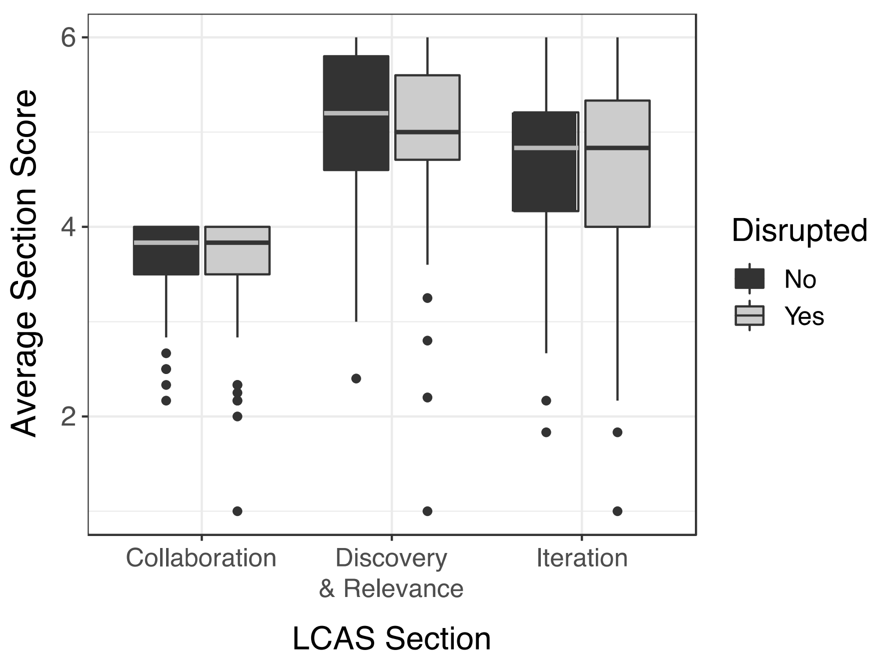
RQ1: In what ways did faculty who taught in Spring 2020 describe making adjustments to their teaching to fulfill core CURE course objectives, when asked to teach in remote format?
The nine instructors from seven courses who taught disrupted CUREs described four key categories of transitions that they made to their courses. Two faculty (Achilli & Victor) refocused the course to

data analysis. Using already collected data (by students in the case of Victor, by the instructor, in the case of Achilli), students were charged with tasks like computational modeling or developing predictive outcomes. Second, one instructor re-focused their course to engage with the primary literature. Cohen sought to build students' critical reading skills through use of the CREATE (consider, read, elucidate hypotheses, analyze and interpret the data, and think of the next experiment) framework, which builds scientific literacy by analyzing three sequential papers from the same research lab (Hoskins et al., 2007). A third pivot involved asking students to design a research proposal, a tack taken by Domini and Harris. Finally, for Chen & Sarkar's bioinformatics CURE, aside from shifting their meetings from in-person to online, no changes were necessary for the research project or course structure because many parts of the course were already online, using tools such as Slack and Google Docs. For more information about how the instructors changed their courses, please see this web resource: https://www.brown.edu/sheridan/hhmi-sheridan-cure-initiative-adapting-cures-remote-instruction.

RQ2: Do the two groups of students similarly perceive essential elements of a CURE experience, as measured through the Laboratory Course Assessment Survey (LCAS)?

Although most instructors described significant changes in learning activities, the LCAS survey suggested that the disrupted CUREs still maintained foundational aspects of CURE objectives, from the perspective of students. The LCAS assesses four CURE dimensions through three survey indices: collaboration, discovery & relevance, and iteration (Corwin et al., 2015). When we compare students' LCAS responses from non-disrupted semesters (Spring & Fall 2019) to responses from Spring 2020 (disrupted), there is no significant change in any of the subsection scores (Figure 2; Kruskal-Wallis rank sum test, $p > 0.05$ for all comparisons, see Appendix 3, N(disrupted) = 95, N(non-disrupted) = 60).

Figure 2. *Perceived CURE course elements by course type*



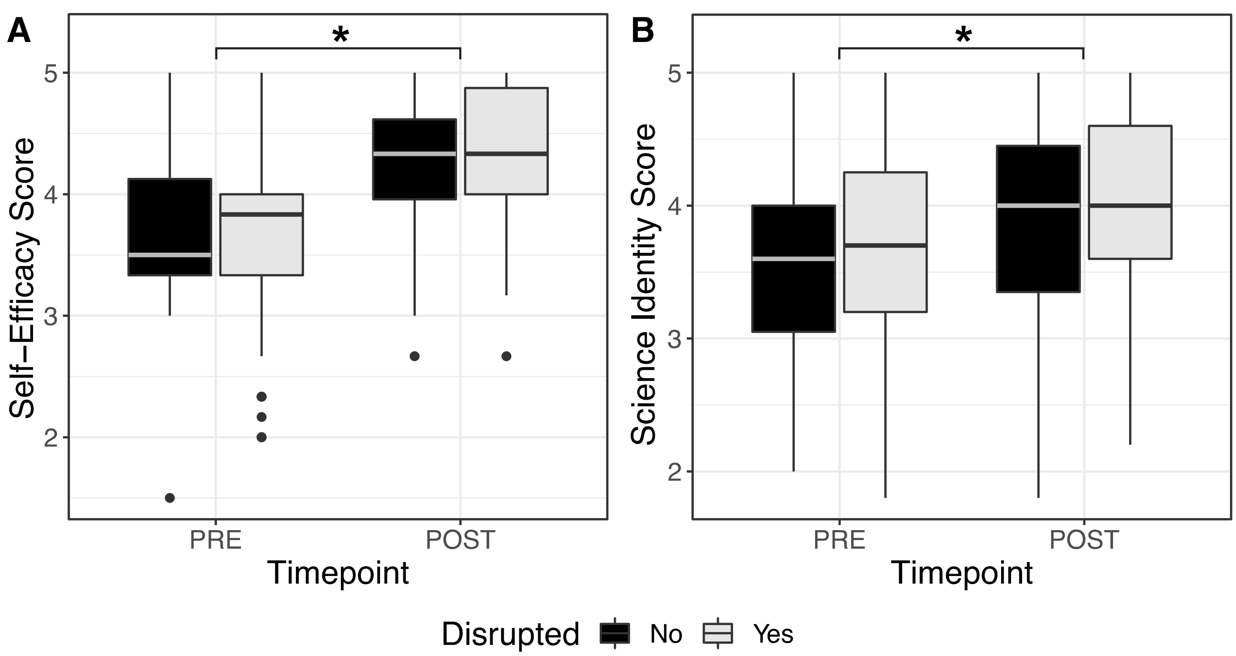
Notes. Perceived CURE course elements were not affected by the transition to remote learning, N(disrupted) = 95, N(non-disrupted) = 60. Boxplots follow standard Tukey representations: boxes represent the 25-75% interquartile range and median (center line) with outliers indicated by points.

RQ3: In terms of key student outcomes associated with CUREs – namely self-efficacy and science identity – do the two groups of students differ?

Student affective outcomes remained consistent across all semesters. Students showed increases in both self-efficacy and science identity during the semester in which they enrolled in our CURE courses and these positive outcomes were maintained in the disrupted semester. Students in all semesters showed a significant increase in self-efficacy from the pre-course to the post-course survey (Figure 3A; Kruskal-Wallis rank sum test: χ^2 = 49.423, df = 1, p < 0.001, N = 120). We found no significant differences in self-efficacy scores between the disrupted and non-disrupted semesters when comparing at either time point (Pre: Kruskal-Wallis rank sum test: χ^2 = 0.066433, df = 1, p = 0.7966; Post: χ^2 = 1.4808, df = 1, p = 0.2237, N(disrupted = 80, N(non-disrupted) = 40).

The items related to science identity followed the same pattern that we observed for self-efficacy. First, there was a significant increase in science identity item scores between the pre-course and post-course survey in all semesters (Figure 3B; Kruskal-Wallis rank sum test: χ^2 = 10.898, df = 1, p < 0.001, N = 120). Second, we saw no significant difference between the disrupted versus non-disrupted semesters when comparing within each timepoint (Pre: Kruskal-Wallis rank sum test: χ^2 = 1.0413, df = 1, p = 0.3075; Post: χ^2 = 0.91795, df = 1, p = 0.338, N(disrupted = 80, N(non-disrupted) = 40).

Figure 3. *Outcomes of self-efficacy and science identity by course type*



Notes. Positive outcomes in self-efficacy and science identity were not negatively impacted by the transition to remote learning.A) Average self-efficacy score; B) Average science identity score. Survey items were from Hanauer et al. (2016). N(disrupted) = 80; N(not disrupted) = 40. Boxplots follow standard Tukey representations: boxes represent the 25-75% interquartile range and median (center line) with outliers indicated by points. *Significant difference from Kruskal-Wallis rank sum test at p<0.01.

Discussion

Here, we compare the results of seven CURE courses at Brown University, disrupted by an abrupt, mid-semester transition to remote instruction in Spring 2020, with six CUREs that were taught face-to-face in Spring and Fall 2019. For RQ1, we find that most instructors made changes to their course with the pivot to remote instruction, namely switching key assessments from synthesis and presentation of research results to data analysis, scientific literacy, or research proposals. One course's instructors described very minimal changes. For RQ2, we find that despite these alterations, there was no significant difference in students' observed estimation that remote courses maintained key elements of CURES – collaboration, discovery/relevance, and iteration. Finally, for RQ3, there was also no significant difference in students' gains in self-efficacy and science identity, comparing fully face-to-face and disrupted classes. In both contexts, students' responses indicated significant improvements in self-efficacy and science identity.

Together, these three findings suggest that partially remote CUREs can be as effective as face-to-face CUREs. One possible explanation for these findings is the anchoring of these courses in sound faculty development practice. The ongoing professional development which our CURE faculty engaged in established a learning community, which met at least once per term, and multiple times during Spring 2020. Faculty learning communities, like the one established here, are a highly effective strategy for impactful faculty development, with documented effects on teaching beliefs and behaviors (Steinert et al., 2006; Stes et al., 2010; Van Note Chism et al., 2012). Particularly in STEM, faculty learning communities are an effective way to support instructors in development of new teaching ideas and practices and sustain that support during times of challenge (Borrego & Henderson, 2014; Henderson et al., 2011), like the COVID-19 pandemic.

While we hope that global pandemics are not a frequent instructional challenge in the future, remote and hybrid CUREs have potential benefits outside of this exceptional situation such as reducing curricular bottlenecks or accommodating students with work or family constraints that impede them from attending in-person laboratory courses. Ardissone et al. (2019) found that a compressed "bootcamp" lab format was as effective as a full semester microbiology lab and was accessed by a greater diversity of students. Thus, the idea of a short, in-person data collection period, followed by online learning, may be a model for leveraging the benefits of CUREs to students enrolled in online or hybrid degree programs. Our study provides some initial support for this hybrid model, although more research is needed to tease apart the differences between in-person, hybrid, and fully remote CUREs. Another limitation of the study is that a very high proportion of students in this study (96-100%) had already declared or intended to declare a STEM concentration and that all the students self-enrolled in the CURE courses. While not all students necessarily knew what a CURE course was, they chose to enroll in a STEM course with a research component. It may be that this level of interest/skill was somehow important to students' motivation or resilience in experiencing equally high outcomes from disrupted CUREs. If most students who enroll in remote or hybrid CUREs are not STEM majors and have less motivation or interest in the subject matter, then our results may not be generalizable to the non-major population. Indeed, Ballen et al. (2017) put forth alternative learning goals for non-majors in CUREs and argued that CUREs for non-majors should be a topic of focus in future research. Another future area warranting investigation would be the faculty benefits of remote or hybrid CUREs. One of the most important faculty benefits to teaching CUREs is connecting their teaching to their research (Shortlidge et al., 2016). While some faculty research programs may include computer-based research amenable to an online CURE, it is possible that the faculty benefit of CUREs would shift for researchers whose research is not easily adapted to the online interface.

CUREs are an established approach for scaling up the benefits of one-to-one faculty-to-student mentoring experiences to broaden participation in STEM (Auchincloss et al., 2014; Hensel, 2018; Kuh, 2008; Linn et al., 2015; Russell et al., 2007). Here, based on the documented equivalence of experiences and outcomes, we also propose that partially or fully online CUREs may also be a promising strategy to further this outreach. For example, in a nationwide survey of students with physical disabilities, a quarter (25%) reported challenges with simply getting to the lab entrance, while high proportions reported physical barriers to setting up laboratory experiments (66%) or operating laboratory equipment (61%) (Jeannis et al., 2020). While online or hybrid CUREs may also have unique accessibility concerns, it is likely that they could address physical barriers to lab experiences. Similarly, based on the experiences of large state systems, fully online CUREs may help resolve physical curricular bottlenecks, decreasing time to degree (Ardissone et al., 2019; Rivard, 2013). We recommend broader exploration on how hybrid and fully online CUREs can be a promising strategy for allowing a wider range of students to pursue STEM fields than would be possible with only physical laboratory settings.

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Appendix 1. ***Demographic comparison of student cohorts***

Demographic Category (self-reported)	**Non-disrupted cohorts**	**Disrupted cohorts**	**Significantly Different? (χ^2)**
First-Generation College Student	19.0%	19.2%	No χ^2 = 2.67e-31, df = 1, p = 1.000
Hispanic or Latinx	11.3%	13.5%	No χ^2 = 0.0291, df = 1, p = 0.865
Black or African American	6.25%	3.03%	No χ^2 = 0.354, df = 1, p = 0.552
Asian	34.4%	50.5%	No χ^2 = 3.4731, df = 1, p = 0.0624
Gender identities: Female, non-binary/third gender, and trans* (combined)	67.2%	55.7%	No χ^2 = 1.63, df = 1, p = 0.202

Note. Students in the disrupted semester (Spring 2020) were demographically similar to the cohorts which did not experience disruption (Spring & Fall 2019).

Appendix 2. *Self-reported reasons students enrolled in CUREs*

Reason for taking the class	Non-disrupted cohorts (% Moderately or very important)	Disrupted cohort (% Moderately or very important)	Significantly Different? (χ^2)
To fill a requirement for my concentration	69.1%	76.9%	No $\chi^2 = 0.923$, df = 1, p = 0.337
I need it for graduate or professional school	41.9%	54.2%	No $\chi^2 = 1.90$, df = 1, p = 0.168
I need it for my desired employment after college	60.0%	58.3%	No $\chi^2 = 0.00317$, df = 1, p = 0.955
Interest in the subject matter	97.0%	88.9%	No $\chi^2 = 2.77$, df = 1, p = 0.0961
To learn lab techniques or other technical skills	90.7%	85.2%	No $\chi^2 = 0.692$, df = 1, p = 0.405
To learn about science/engineering and the research process	88.2%	87.0%	No $\chi^2 = 0$, df = 1, p = 1.000
To get hands-on research experience	87.0%	83.3%	No $\chi^2 = 0.193$, df = 1, p = 0.660
It fit in my schedule	71.0%	66.7%	No $\chi^2 = 0.194$, df = 1, p = 0.659
The course and/or instructor has a good reputation	76.5%	79.4%	No $\chi^2 = 0.0762$, df = 1, p = 0.782

Notes. Students in disrupted and non-disrupted semesters reported similar reasons for taking a CURE course. Students were asked to rate on a scale of importance (very important, moderately important, not important, not applicable) potential reasons they might have had for taking a CURE course (from Dinofrio et al., 2007). The percentage of students rating an item as important (very or moderately) did not differ significantly between the disrupted cohort and non-disrupted cohort for any of the question items.

Appendix 3. *Kruskal-Wallis rank sum tests for LCAS*

Comparison **(N(disrupted) = 95, N(non-disrupted) = 60)**	**Kruskal-Wallis χ^2**	**df**	***p***
LCAS total score: disrupted vs. non-disrupted	0.17262	1	0.6778
Collaboration total: disrupted vs. non-disrupted	0.021804	1	0.8826
Iteration total: disrupted vs. non-disrupted	1.2461	1	0.2643
Discovery/Relevance total: disrupted vs non-disrupted	1.1948	1	0.2744