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Research Article

A Course-Based Undergraduate Research Experience (CURE) using Ocean Plastic Microbes as a Framework that Is Impactful for Both In-Person and Online Course Modalities

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A course-based undergraduate research experience (CURE) is described, both in its original, field-based and in-person design, as well as its adaptation to online delivery during the COVID-19 pandemic. The CURE experience was centered around the topic of microbes attaching to ocean plastic debris, and included connecting nontraditional undergraduate students attending a primarily teaching institution to personnel of a research-intensive institution. The CURE was implemented in nonmajors and majors' general biology laboratory courses, as well as in an introductory microbiology lab course for health majors. Student perception of the CURE was assessed quantitatively through self-administered retrospective surveys, and qualitatively using open-ended survey questions and focus group interviews. Survey questions were grouped into four themes: (1) research at the research institution, (2) research at the teaching institution, (3) laboratory skills, and (4) interest in science. To assess impact of the CURE by modality, major and course level, theme scores were analyzed using ANOVAs ($\alpha = 0.05$). Changes in student perception of learning were measured by comparing the "before" and "after" survey scores in each theme. The main source of variation in the model was time, followed by theme and major, while modality had a negligible effect. Overall, there were increases in student perception of learning across all themes across modality, major, and course level; however, not all were statistically significant. Highest gains were observed among nonmajors, while those of the majors' upper division courses were the lowest. On the other hand, majors' overall scores were the highest. Health majors' survey gains were mostly between those of nonmajors and majors. Qualitative data contextualized the quantitative results. The online adaptation was a valuable alternative, especially for nonmajors, as it expanded the range of students reached, with results similar to the in-person alternative. Preliminary data show a positive effect of the CURE in student success majoring in biology.

1. Introduction

Low graduation rates and underrepresentation of minorities in STEM disciplines have been widely discussed in the last decades. In 2012, the President's Council of Advisors on Science and Technology, a group of distinguished scientists and engineers who provide advice to the President of the United States on science and technology matters, released a groundbreaking report that drew attention to the concerningly low graduation rate in STEM fields and emphasized the importance of enhancing STEM education at all levels [1]. Attrition of students from STEM careers can be attributed to multiple factors during students' educational journey [2], and minority students often feel a lack of belonging in academia [3]. Increased awareness of these issues has brought a surge of education research focused on improving STEM education, through the implementation and assessment of interventions that can promote student success, such as the AAU STEM

Initiative [4], focus on diversity and inclusive teaching [5, 6], mentoring [7, 8], and among others. In a recent article in *Science Magazine*, Dr. Jo Handelsman, a prominent researcher in the field of science education pointed at the slow pace of change in supporting students from historically excluded communities, who are "discouraged and often alienated by the climate and teaching methods commonly found in STEM classrooms" [9].

STEM educators face the challenging task of rethinking their teaching approaches to promote diversity while ensuring that students persist and succeed in their disciplines [10]. As students bring their unique background and experiences to the classroom, the onus is on the instructors to address "how to select the right tools for the job, how to use the tools, and what latitude there is for using a range of tools" [11].

1.1. Undergraduate Research Experiences. Access to authentic research experiences is considered an evidence-based high-impact educational practice [12] and proven to sustain student interest and boost retention in the sciences for all students [13]. Undergraduate research experiences may be particularly important for racial/ethnic minority students, who are underrepresented in higher education at the undergraduate level, in graduate school enrollment, and in terms of degree completion [14, 15]. Multiple barriers exist to involve students in research projects, particularly in community colleges and primarily teaching institutions [16, 17], making a strong case for "replacing standard laboratory courses with discovery-based research courses" [1, 18].

1.2. Course-Based Undergraduate Research Experience (CURE). CUREs are considered an effective approach to increase student interest and engagement in STEM disciplines and broaden participation by specifically benefitting underrepresented student populations [19–22]. CUREs usually contribute knowledge to a research question by having students collect and analyze data within the framework of courses. The research project can be set up as an individual course, or as modules within courses. Successful CURE frameworks include The Genomic Education Partnership [23], SEA-PHAGES [24], and Tiny Earth [25, 26]. Of particular interest in the case of using CUREs to engage historically underrepresented (HU) students in STEM is the well-documented fact that HU undergraduates in all disciplines tend to express altruistic work goals, such as jobs that offer the chance to help others [27]. Designing learning experiences that align with HU students' equity ethics through projects that can benefit both global and local communities is a promising approach to diversify STEM education [3].

Success of CUREs can be assessed in multiple ways, from institutional indicators such as persistence in and graduation from STEM programs, to more short-term measures such as surveys and qualitative data stemming from interviews or focus groups [28, 29].

1.3. Ocean Plastic CURE. This paper describes the implementation of a CURE at a private nonprofit Hispanic and Asian American Native American Pacific Islander-Serving university with a nontraditional student population and an accelerated academic schedule, in collaboration with a research-intensive institution. The CURE is based on the relevant topic of ocean plastic pollution, specifically early colonization of floating plastic types [30–33]. The hypothesis of the CURE was that a topic with both global and local significance would be impactful for students, increasing their perception of knowledge regarding plastic pollution research at the participating institutions, scientific skills, as well as their appreciation of science. In turn, this could result in increased retention in STEM programs and/or increased enrollment by nonmajors in STEM programs.

Started in 2018 as a fully in-person experience including a field trip to the research institution, the CURE was adapted to an online alternative due to the COVID-19 pandemic emergency. Pivoting to online courses was a global solution to the need for isolation and social distancing, which was particularly difficult for courses with hands-on components, such as laboratory and field trip courses [34–37].

Results showed that the CURE, both in-person and online, significantly increased student perception of knowledge in the science and research topics surveyed, as well as their appreciation of science. In addition, the online adaptation of the CURE resulted in a threefold increase of the number of students reached. Different gains were observed depending on major and courses, and qualitative data provided additional insights on the impact of the CURE.

2. Methods

2.1. Human Subjects Protocol. This project was exempted by the National University (NU) Institutional Review Board (IRB), document number IRB-FY17-18-527.

2.2. Description of the CURE. The CURE is centered around microbial populations attaching to floating plastic in coastal waters [38–41] and consists of content modules of variable complexity implemented in a number of laboratory courses. These ranged from nonmajors' general biology laboratory course to upper division majors' laboratory courses. CURE dimensions [20] and the associated activities and their delivery method are shown in Figure 1. Short-term outcomes of the CURE included increased student engagement and appreciation of science, while long-term outcomes targeted increased enrollment and retention in the BS Biology program.

In summary, sterilized pieces of floating plastic ("samples")—high density polyethylene, low density polyethylene, and polypropylene (PP)—were pretreated using 70% ethanol washes and UV irradiation and deployed ~5 m under the water surface near the Ellen Browning Scripps Memorial pier by the Scripps Institute of Oceanography (SIO), San Diego, CA. Deployment times were at least 30 days. Results from student work have been published elsewhere [40, 41]. Plastic samples were collected and processed by students, which included swabbing and inoculating Marine Agar 2216 (Fisher Scientific) and ChromAgar Vibrio™ (ChromAgar, Paris, France) media. Student laboratory activities included observation of colonies and Gram staining (general biology), as well as isolation of DNA from the plastic, 16S metabarcoding, and Blast analysis to identify colonies (microbiology and molecular biology). All samples were processed in a BSL-2

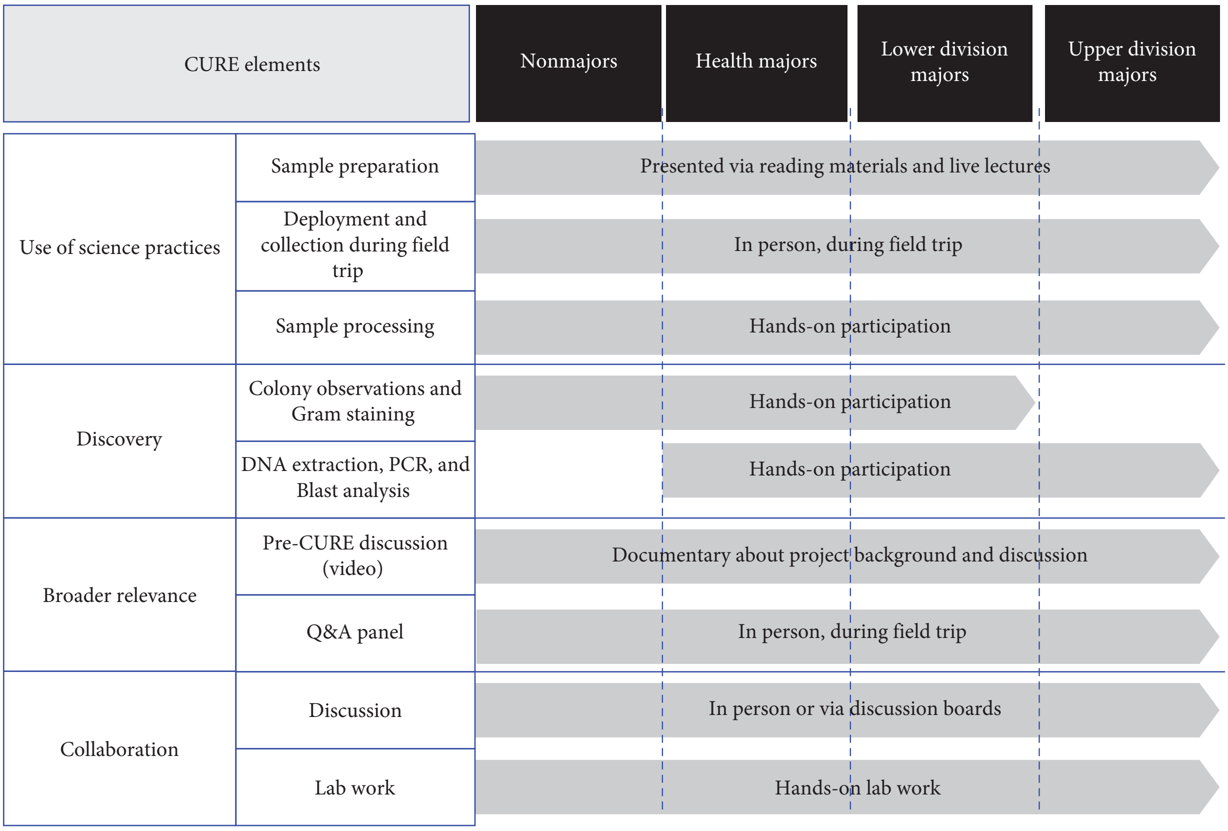


Figure 1: Overview of the activities included as part of the CURE. The figure refers to the original design, which was planned as mostly in-person activities. Created with BioRender (https://www.biorender.com).

level laboratory setting, following the ASM guidelines for Biosafety in Teaching Laboratories.

2.3. Student Activities during the CURE. For background information, students in all courses were required to watch the documentary "Into the Gyre" [42]. Laboratory activities were dependent on the type of course. An essential element in all courses was a field trip to the SIO, where students participated in deploying and/or collecting the plastic samples. Direct interactions with researchers were an important element of the CURE, achieved informally during the field trip, and in a more structured setting as a Question and Answer (Q&A) session afterward.

2.4. Courses. The CURE was implemented in a variety of in-person laboratory courses for which the CURE content was relevant. These courses were taught in an accelerated format of either 4 weeks or 8 weeks (if taught concurrently with lecture). In this setting, students do not take any other courses during this time. Each course consists of 45 hr of in-class time (corresponding to 10 sessions of 4.5 hr, twice a week in addition to two Saturdays). Due to the COVID-19 pandemic emergency, the CURE offerings were expanded to online sections of General Biology Lab courses (both nonmajors and majors). The CURE was additionally implemented in introductory microbiology courses (both online and in-person modalities).

BIO100A (nonmajors general biology laboratory) is a General Education (GE) course taken by nonscience majors. The course is offered in-person and online, both modalities including hands-on experimentation (in the laboratory or using household items, respectively). In this paper, BIO100A students will be referred as "nonmajors."

BIO169A (lower division majors general biology laboratory) is also a GE course but directed to biology majors and offered regularly in-person only. Content is focused on basic laboratory skills. One section was taught online during the COVID-19 pandemic emergency.

BIO407A (molecular biology laboratory) is an upper division in-person course taught concurrently with its lecture counterpart over 8 weeks.

In this paper, students from BIO169A and BIO407A courses will be referred to as "majors."

Both BIO193A and BIO203A are introductory microbiology lab courses taught concurrently with their lecture counterpart over 8 weeks. BIO203A is an in-person course, and its content is in accordance with the ASM Microbiology in Nursing and Allied Health (MINAH) curriculum guidelines (https://asm.org/Guideline/ASM-Microbiology-in-Nursing-and-Allied-Health-MIN). BIO193A is an online asynchronous course developed for certain programs that do not require hands-on laboratory experiences. Its content is in

Table 1: Schedule of the original in-person activities of the CURE and their online adaptations.

Time	In-person	Online
Week before the CURE	Watch documentary "Into the Gyre." Quiz in class or online	Watch documentary "Into the Gyre" and discuss in a discussion board
Week of the CURE	Field trip to SIO lectures by faculty. Processing of plastic samples (inoculation on Marine Agar and ChromAgar Vibrio plates). In-person Q&A	Watch recorded lectures by faculty, content assessed in weekly quiz. Review-related course material (ex. differential/selective media, bacterial cell structure, etc.) Watch footage from sample preparation/deployment/collection (videos and images). Online Q&A with breakout room discussion
Week after the CURE	Observation of plates, Gram staining of colonies. Majors: 16S PCR and Blast analysis for identification of colonies. Survey deployed online. Focus group signups	Watch videos and images of lab results (plates of colonies, staining results). For majors: Blast PCR sequences provided for identification of selected colonies. Survey deployed online. Focus group signups

accordance with most of the MINAH curriculum guidelines and includes virtual simulations and other online activities.

In this paper, BIO193A and BIO203A students will be referred to as "health majors."

Courses were taught by both the authors (A.M.B. and R.E.S.) and by other faculty (see Acknowledgments). Materials for instruction were provided in advance by the authors to guarantee uniformity. Authors (A.M.B., R.E.S., and J.S.B) coordinated and participated in crucial activities such as the field trip experience and Q&A session.

2.5. Online Adaptation. The CURE was implemented for in-person courses between December 2018 and February 2020. The activities included both the field trip and hands-on laboratory experiments. Starting March 2020, all in-person courses migrated online and field trip activities were halted. CURE activities were resumed in a virtual setting in November 2020. In July–August 2021, selected course sections returned to an in-person setting, and students completed lab experiments on plastic samples collected by the instructor. In parallel, other online sections participated virtually. Students watched video recordings of sample deployment and collection, as well as recordings of laboratory activities related to the project (inoculation of samples, observation of colonies, Gram staining, DNA extraction, PCR, gel electrophoresis). The Q&A panel was organized online using Zoom. Students from all participating courses and sections were invited, and after a general session students could choose breakout rooms for small-group discussions based on specific topics of interest. Table 1 shows the changes to the CURE to allow for online delivery.

2.6. Assessment of the CURE: Surveys. Student perception of learning was assessed through self-administered retrospective surveys that included standard multiple choice/selection questions, as well as open-ended text response questions. Surveys were deployed after the field experience (in a timeframe within 72 hr after the Q&A panel). The retrospective questions required the students to provide a response after the event (i.e., "after") and then to reflect back (i.e., "before") to their status (e.g., level of knowledge) prior to the event [43]. Students were asked to rate their knowledge, competence, or interest in questions focused on four themes: (1) research at SIO (SIO), (2) research at NU (Research), (3) laboratory skills (Skills), and (4) interest in science (Interest) (Table 2). The data collected from the surveys were delivered to Steuck & Associates (grant external evaluator), who de-identified and completed preliminary analyses.

2.7. Assessment of the CURE: Qualitative Data. Starting program year 2 (2018), the student survey included two 3-part questions and asked the students to write 1–2 sentences for each part. The purpose of the questions was to understand how the NU CURE program impacted student's personal and professional interests in the areas of biology, research, and ocean plastics. These questions are as follows:

(i) What worked? Describe up to three things that you liked and/or worked well in this course.

(ii) We are planning similar research experiences for other Biology courses. What are your recommendations?

Three sets of focus group interviews were carried out via Zoom between fall 2020 and summer 2021 by the external evaluation team ($n = 25$). Most students ($n = 21$) were from the nonmajors' group, together with one major and three health majors. These interviews focused mostly on the online experience in order to assess the fidelity of implementation of the CURE. Additional questions were asked to assess career interest and process improvement. Online focus group questions (Steuck & Associates, unpublished reports) included: "Tell us about the online experience. What kinds of activities did you participate in for the SIO ocean plastic research virtual experience? Would you have been more or less likely to attend if the experience was in-person? Do you feel like you would have the same benefits if the field trip was in-person instead of virtual? In what ways?" Career and interest focus group questions (Steuck & Associates, unpublished reports) included: Has your experience in this project changed your awareness of professional careers related to biology? How can your knowledge of biology support your future career decisions and goals? "Was there even a flicker of a moment when you thought about doing ocean plastics research?" Process improvement focus group questions (S&A, unpublished reports) included: "What worked well?" and "What can be improved?"

Table 2: Retrospective survey questions.

Topic	Q	Prompt
SIO	Q4	Rate your knowledge about the SIO Research Institution
	Q6	Rate your knowledge about the SIO research projects
	Q7	Rate your knowledge about the methods used by SIO researchers
	Q8	Rate your knowledge about STEM careers
Research at NU	Q9	Rate your knowledge of the plastic research project at NU
	Q11	Rate your competence in laboratory skills
	Q12	Rate your competence in problem solving
Laboratory skills (based on CLOs†)	Q14	Rate your competence in applying the scientific method, including drawing testable hypotheses from observations and data
	Q15	Rate your competence in techniques such as PCR and gel electrophoresis
	Q16	Rate your competence in compound and dissecting microscopy, including fixing and staining of specimens
	Q17	Rate your competence in classifying organisms according to basic principles of taxonomy, including the use of a taxonomic key
	Q18	Rate your competence in explaining the structure of prokaryotic cells, as well as differences between major groups of prokaryotes
Interest in science	Q20	Rate your ability to think like a scientist
	Q21	Rate your interest in performing scientific research
	Q22	Rate your appreciation of scientific research

Note: After the CURE experience, students were asked to rate the aspects below after and before the experience on a Likert scale from 1 (not knowledgeable at all) to 5 (extremely knowledgeable). Questions are numbered as they were in the survey, while those not included in the table refer to informed consent, prompts to move to the next section, consent to answer open ended questions, as well as request to future contact. †CLO, course learning objectives.

2.8. Statistical Analyses and Graphing. A χ^2 test was used to evaluate the demographic similarities between the total population and that of the survey responders. Only subpopulations with at least five participants were included. A Student t-test was used to compare the before and after scores of the 15 survey questions.

For some analyses, scores were binned according to the four themes of the survey: knowledge about SIO research, knowledge about research at NU, laboratory skills, and appreciation of science. Because datasets contained both paired responses (before and after survey scores of the same student) and grouping (modality, major, course) data, repeated measures ANOVA models ($p = 0.05$) were used to simultaneously test for effects over time and effects from other variables. For these analyses and visualizations, JMP (SAS, Cary, NC) and Prism 9 (GraphPad Software Inc., La Jolla, CA) softwares were used.

Figure 1 was created with Biorender (biorender.com, agreement KU255LCD98).

3. Findings

3.1. CURE Participation and Demographics. Between November 2018 and August 2021, a total of 442 students participated in the CURE as assessed by roster data. From those, 232 survey responses were collected (52.5% response rate).

Table 3 shows the demographic characteristics of the total student population as well as the survey responders. Student demographics were diverse, with Hispanics constituting the second-highest group. As it is typical for the university, military students constituted the majority (over 60%) of the student population and the average age was 31.

A χ^2 test did not reveal significant differences between the total and the survey-responder populations regarding gender, ethnicity, or military status ($p < 0.05$, data not shown). Therefore, the survey responder population can be considered representative of the total population.

Of the 232 survey responses received, 187 were considered valid (42.3% response rate). The invalidated responses were either sent by students who did not attend the course, dropped, did not complete required questions, or did not participate in the CURE activities.

Table 4 shows the number of total students and survey responders according to the course, major, and their modality. Overall, 320 students (72%) participated in the online CURE, versus 122 in-person (28%).

3.2. Students Rate Their Experience Higher After the CURE. Over the 3 years of the CURE experience, students had consistently rated their "after" CURE experience higher than the "before" experience in the 15 survey questions (Figure 2(a)). A paired t-test of the scores of all questions before and after for all students showed a significant difference ($p < .0001$, $t = 20$, $df = 14$).

The complexity of the data, due to planned (major, course, themes) and unplanned (modality) factors influencing the results required multiple analyses. Figure 2(b) shows the survey scores gains ("after" minus "before" response scores) binned by the four themes, averaged, and separated by modality (in-person and online) and major (majors, health majors, and nonmajors). To explore the different factors contributing to the gain, the binned scores were compared using a repeated measures ANOVA (Table 5). Before and after survey scores were binned according to four themes and averaged. Of all the

Table 3: Demographic characteristics of the total and survey-responder population ($n = 442$ and 232, respectively).

Demographic category	All (*N*, %)	Survey responders (*N*, %)
Ethnicity		
White	133 (30.1%)	77 (33.2%)
Asian	39 (8.8%)	23 (9.9%)
Unknown	54 (12.2%)	19 (8.2%)
Black or African American	59 (13.3%)	33 (14.2%)
Hispanic	122 (27.6%)	59 (25.4%)
Native Hawaiian/Pacific Island	5 (1.1%)	2 (0.9%)
Two or more races	28 (6.3%)	16 (6.9%)
American Indian/Alaskan Native	1 (0.2%)	0 (0%)
Nonresident alien	1 (0.2%)	0 (0%)
Elected not to respond	NA	3 (1.3%)
Gender		
Male	232 (52.5%)	123 (53%)
Female	194 (43.9%)	98 (42.2%)
Unknown	16 (3.6%)	11 (4.7%)
Military status		
Active military	148 (33.5%)	72 (31%)
Veteran	142 (32.1%)	84 (36.2%)
Reserve/Military dependent	12 (2.7%)	15 (6.5%)
Non military	140 (31.7%)	61 (26.3%)

Table 4: Student participation in the CURE and the survey by course and modality.

Group	Course name	Description	Modality	Number of students	Number of survey responders
Nonmajors	BIO100A	Nonmajors' general biology lab	Online	259	81
			In-person	73	53
Majors	BIO169A	Majors' general biology lab	Online†	14	3
			In-person	24	6
	BIO407A	Molecular biology lab	In-person	20	16
Health majors	BIO193A	Online introductory microbiology lab	Online	23	14
	BIO203A	Introductory microbiology lab	Online†	24	10
			In-person	5	4

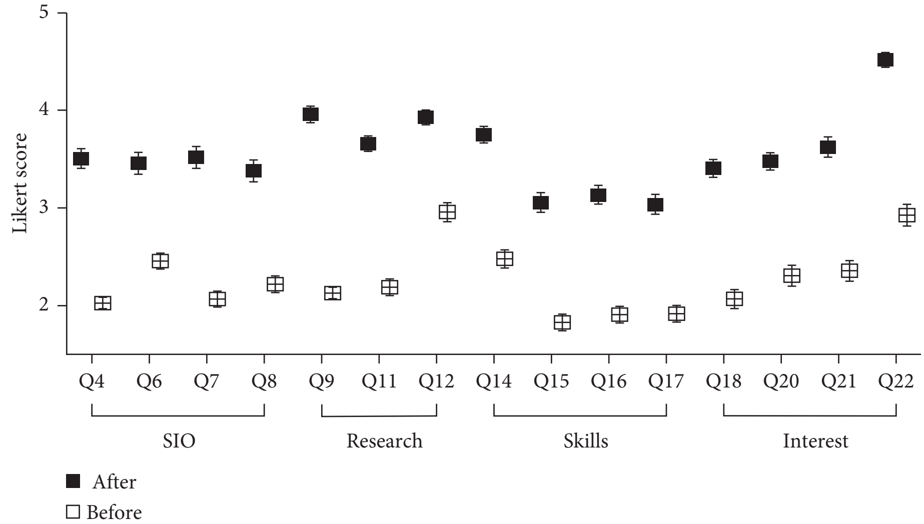
Note: The total number of survey responders correspond to the total valid survey responses ($n = 187$). †Pandemic adaptation only.

individual factors analyzed, the most significant was time (before vs. after), responsible for 35% of all variation (partial η^2 0.354), followed by theme and major, while modality had a negligible value (less than 1%). Significant interactions were also observed between all factors. In addition, item reliability (Cronbach's α) was 0.8786 for the whole set of variables.

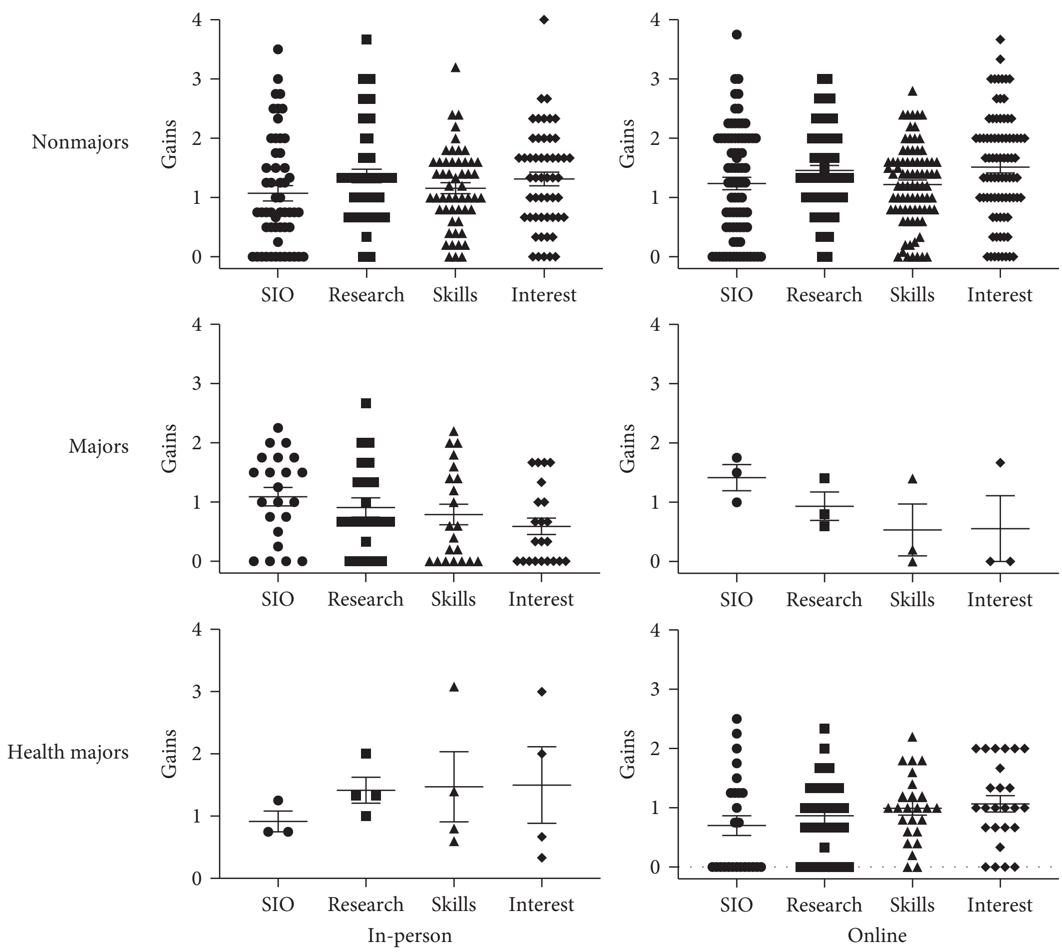
The analysis with the binned scores showed that overall, "after" scores were higher than "before" scores, and "before" scores for online students were lower than those for in-person, but the "after" scores were not different, resulting in higher gains for online students. Pairwise comparisons by themes within majors showed highest gains for nonmajors, where the "after" scores for all themes were significantly higher than the "before" scores ($p < 0.0001$ for all themes). Health majors had significantly higher "after" scores in Research ($p = 0.0054$), Skills ($p = 0.0009$), and Interest ($p = 0.0003$), but not for SIO. Majors showed significant gains for SIO ($p = 0.0004$), Research ($p = 0.0103$), and Skills ($p = 0.00403$), but not Interest.

A similar analysis was run using an average score of the 15 questions comparing modalities. A two-way repeated measures ANOVA with Bonferroni's multiple comparisons showed significant difference between "before" and "after" scores for both in-person and online students ($p < .001$), as well as between in-person and online students before the CURE experience ($p = .008$). However, no significant difference was observed between the scores of in-person and online students after the CURE experience.

As modality was found not to be a significant source of variation, it was removed as a factor in further analyses. Next, the gains of each major by themes were compared using a 2-way ANOVA with Tukey's post hoc test for multiple comparisons. Figure 3 shows the survey gains across majors and themes. Nonmajors had significantly higher gains compared to majors in all aspects but knowledge of SIO research. Health majors had gains similar to nonmajors in interest and skills, but significantly lower in the case of SIO knowledge ($p = 0.0177$) and research ($p = 0.0095$).



(a)



(b)

Figure 2: (a) "Before" and "after" survey scores (mean and SEM) of the individual survey questions for all students. (b) Scatter plot of survey score gains (mean and SEM) binned by themes (SIO, Research, Skills, and Interest) for the three majors in online and in-person modalities. Gain was calculated as "after" score minus "before" score.

Table 5: MANOVA analysis of survey scores comparing the three groups of majors.

Test	Value	Exact F	NumDF	DenDF	Prob > F	Partial η^2
All between	0.2625633	8.2422	23	722	<0.0001	0.2079604
Modality	0.0091197	6.5844	1	722	0.0105	0.0090373
Theme	0.0386692	9.3064	3	722	<0.0001	0.0372296
Major	0.0246105	8.8844	2	722	0.0002	0.0240194
All within	0.0948256	2.9767	23	722	<0.0001	0.0866125
Time	0.5484818	396.0038	1	722	<0.0001	0.3542061
Time × modality	0.0000816	0.0589	1	722	0.047	0.0000816
Time × theme	0.0004729	0.1138	3	722	0.9520	0.0004726
Time × major	0.0123893	4.4725	2	722	0.0117	0.0122376

Note: Before and after survey scores were binned according to four themes and averaged. Of all the individual factors analyzed, the most significant was time (before vs. after), responsible for 35% of all variation (partial η^2 0.354), followed by theme and major, while modality had a negligible value (less than 1%). Significant interactions were also observed. NumDF, number of degrees of freedom; DenDF, number of degrees of freedom associated with the model errors; Prob > F, p-value associated with the F statistic of a given effect and test statistic.

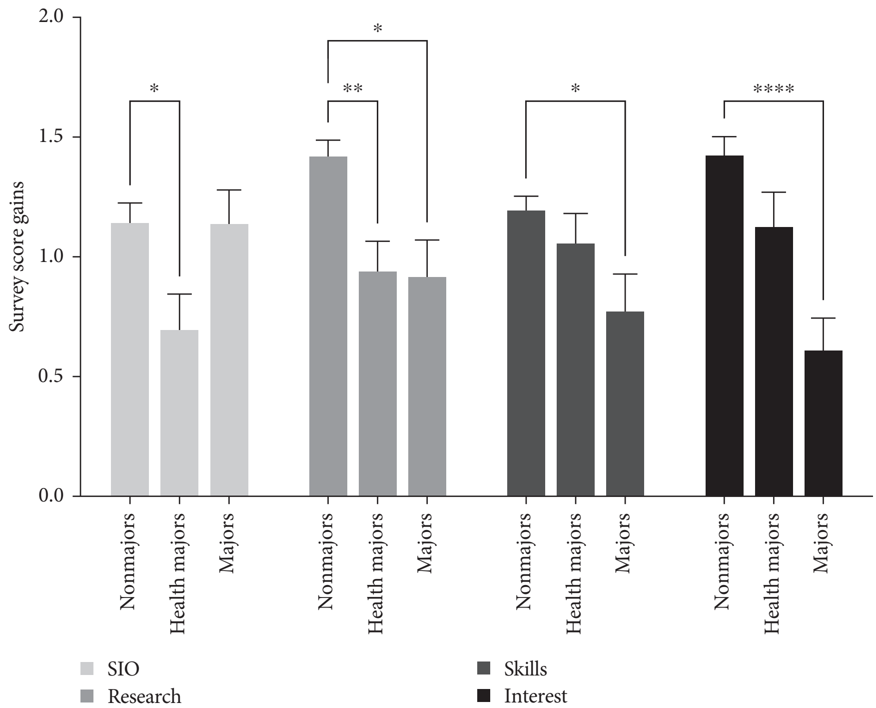


Figure 3: Survey score gains (mean and SEM) by themes and majors. Significant differences were observed for SIO knowledge between nonmajors and health majors ($p = 0.0177$), for Research between nonmajors and health majors ($p = 0.0095$) and nonmajors and majors ($p = 0.0109$), for Skills between nonmajors and majors ($p = 0.0417$), and for Interest between nonmajors and majors ($p < 0.0001$). $^{*}p \leq 0.05$, $^{**}p \leq 0.01$, and $^{***}p \leq 0.001$.

3.3. Course-Level Results. The nonmajors student population, while heterogeneous in respect to their majors, was all derived from one course (BIO100A). Health majors were also derived from one-course type (introductory microbiology, either online, or in-person). Majors, on the other hand, included both lower and upper division courses (BIO169A, general biology and BIO407A, molecular biology, respectively). Therefore, it was decided to compare student survey gains by courses. As modality was not considered a significant contributor to variation, the BIO193A and BIO203A courses (online and in-person microbiology courses in health majors) were consolidated as one group (labeled HM). A two-way ANOVA showed Course as the only significant factor ($p < 0.0001$, Table 6). Figure 4(a) shows a heatmap of the "before" and "after" survey scores by the courses analyzed in Table 6. Majors in general had higher "before" scores compared to nonmajors and health majors. Gains, therefore, were more pronounced for nonmajors and health majors. As shown in Figure 4(b), there was no significant difference in gains between the lower division (BIO169A) and upper division (BIO407A) majors courses. Interestingly, the highest gains within the SIO theme were observed for the lower division majors. As noted before, highest gains corresponded to nonmajors in all themes but SIO, significantly higher than health majors for both SIO

Table 6: Two-way ANOVA of survey score gains compared at the course level.

ANOVA table	SS	DF	MS	F (DFn, DFd)	P-value
Interaction	9.628	9	1.070	F (9, 724) = 1.679	$p = 0.0901$
Course	22.25	3	7.416	F (3, 724) = 11.64	$p < 0.0001$
Themes	0.7315	3	0.2438	F (3, 724) = 0.3828	$p = 0.7654$
Residual	9.628	9	1.070		

Note: The course factor was the only significant contribution to variation. SS, sum of squares; DF, degrees of freedom; MS, mean square.

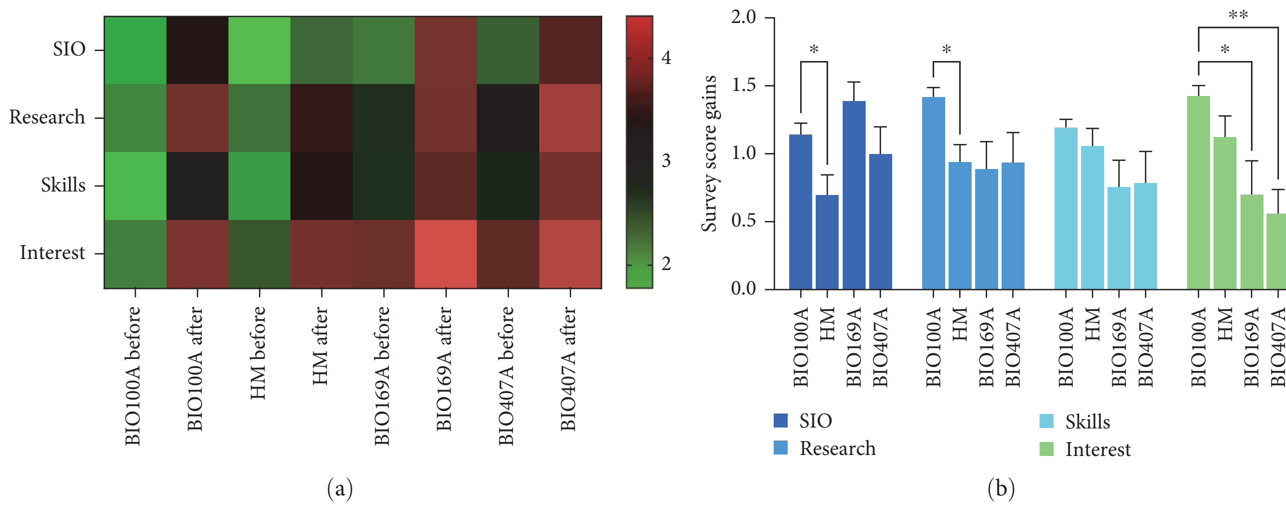


Figure 4: (a) before and after survey scores by courses. Both lower division (BIO169A) and upper division (BIO407A) majors students had higher before scores compared to non-majors and health majors. (b) Survey score gains by courses. Nonmajors had significantly higher gains compared to health majors for both SIO ($p = 0.033$) and Research ($p = 0.0207$), and significantly higher gains for Interest compared to both lower division ($p = 0.0437$) and upper division ($p = 0.0012$) majors. $^{*}p \leq 0.05$ and $^{**}p \leq 0.01$.

($p = 0.033$) and Research ($p = 0.0207$), and significantly higher for Interest compared to both lower division ($p = 0.0437$) and upper division ($p = 0.0012$) majors.

3.4. Student Open-Ended Comments and Focus Groups. These results were gathered from the annual reports of the grant external evaluator (Steuck & Associates, unpublished reports). Due to IRB privacy rules, the grant PIs did not have access to the raw data and relied on consolidated and deidentified summaries. Between August 2019 and February 2020, 42 students submitted answers to the two open-ended questions in the survey. Of those, 31 were nonmajors, 7 lower division majors, and 4 upper division majors.

Regarding the question of what worked well, among the nonmajors, a majority of the comments focused on three primary components: the high quality of the instructors, the field trip experience, and the lab work. Many students noted that the field trip was a unique experience that added excitement to the course while also allowing them to better understand field research and the broader context of plastic pollution. In addition, the lab experiments were highlighted by many students as impactful, noting that they provided opportunities for hands-on learning, and that they were grounded in real-world problems and context. The undergraduate lower division biology majors mentioned the field trip, lab exercises, and learning from the scientists working in the field as aspects they felt worked well. Notably, the students felt the CURE helped reinforce scientific concepts they had learned in class, and half of the students mentioned that the experience increased their interest in participating in and/or learning about research. The undergraduate upper division biology majors emphasized the same benefits as the lower division biology majors, further highlighting the benefits of the CURE lab experiments, the on-site field trip, and the interactions with the RI scientists.

Regarding the question of what can be improved, nonmajors had few suggestions, but some pointed to the logistics of the field trip, need for more advance information, and particularly to focus less on career paths during the discussion. The undergraduate lower division biology majors suggested improvements in three key areas: streamlining the field trip, expanding the lab experience, and giving the students the chance to write and publish findings. The undergraduate upper division biology majors had fewer suggestions for improvement and rather emphasized the importance of the CURE experience overall, stressing the need for hands-on involvement in research experiences.

After the transition to the online CURE experience, 43 students completed the open-ended questions, resulting in 195 comments. As the courses were online and included other virtual lab components besides the CURE, some of the comments addressed those components or technical issues

Table 7: Example quotes from open-ended questions (2019–2021).

Question	Student answer	Student major and level
What worked? Describe up to three things that you liked and/or worked well in this course	"I really liked that we got to be involved in examining the overall big picture of the plastic problem. / I tried to hide my enthusiasm as I have been following and studying the plastics problem for a while on my own. I loved that we got to see the process and learned the history of the research facility. I also loved getting out of the classroom/lab and apply what we have been learning out in the real world"	NM, in-person
	"The field trip worked well because it gave me the student, to actually meet scientists in the field and see what kind of things they really do, not just from a power point presentation"	LDM, in-person
	"Actually going to the site where the project was actively ongoing and talking to the Scientist working on the project and conversing with them and seeing how excited they were in the explaining of all aspects of the project with us knowing what level students we were. I found that this is what drove home the process of field work and the passion that can only be displayed firsthand"	UDM, in-person
	"I liked getting to meet the people who were involved in the project and hearing their perspective. I liked the advice given by all the panel members on how to get involved and seek out opportunities in the scientific field. I liked learning about the project itself and hope it will have a big impact on the future of the plastics industry"	LDM, virtual.
We are planning similar research experiences for other Biology courses. What are your recommendations?	"I believe for a school like NU, having the professors/doctors/research coordinators brief us on their career paths, seemed unnecessary. For a traditional college where most students are 18 and fresh out of high school, it would be a worthy experience. The research project should be geared more to generating awareness of the projects, not how to conduct personal goals. I found myself feeling as though that portion was targeted toward an audience that National does not often cater to"	NM, in-person
	"The research experience was invaluable. I think they should be marketed better and more emphasis placed on the research experience"	UDM, in-person
	"I liked getting to meet the people who were involved in the project and hearing their perspective"	LDM, virtual

NM, nonmajors; LDM, lower division majors; UDM, upper division majors.

unrelated to the CURE. Most specific comments related to the topic of what worked were in relationship to their knowledge of ocean plastic research. The majority of the comments came from nonmajors, and only one lower division major submitted answers. Overall, students valued the experience and referred positively to the knowledge gained about plastic research and meeting with experts in smaller groups during the panel. Table 7 includes representative quotes from the open-ended comments.

Between November 2020 and August 2021, a total of 25 students participated in focus group interviews (one biology major, three health majors, and the rest nonmajors).

Regarding their careers and interests, all students commented that they learned about new professional careers, that they did not know about prior to this biology course, such as being a research scientist. All students interviewed expressed certainty in their chosen career paths and despite learning new information about research careers, they did not feel inclined to consider changing their major. On the other hand, the majority of the students interviewed agreed that the course changed their personal behaviors to be more environmentally conscious and/or reinforced good behaviors.

Their recommendations for the CURE often overlapped with issues experienced in the online modality in general. Specific suggestions included making the ocean plastic project a centerpiece of the course, to incorporate service-learning opportunities, and to bring guest speakers.

While most students valued online courses and understood the reasons of moving the CURE to a virtual delivery, most students expressed they wished they could attend in-person.

4. Discussion

The COVID-19 pandemic emergency upended life and particularly education worldwide. The sudden pivot to online delivery brought many challenges but also revealed technological opportunities that are advantageous and will remain intact even after the return to in-person education [44–46].

The CURE described in the paper was designed for in-person courses, with a field trip experience and direct interactions with researchers. In this modality, less than 100 students participated, and 79 survey responses were collected across all courses. While we could see consistent gains as measured by survey questions and positive feedback in open-ended questions, the potential to reach larger populations was limited. One clear impact of the online adaptation was its expansion. At the end of the third year, the implementation of the CURE in a larger number of online nonmajors sections resulted in an increase of participant and survey responders to 442 and 187, respectively, a more than threefold increase. In fact, the pandemic has produced a number of "virtual field trip" alternatives that can make field studies a more accessible and inclusive discipline [35, 36, 47].

The 15-question retrospective survey used provided detailed insights about the different aspects that were most impacted as part of the CURE. The survey questions reflected student perception of their knowledge of research and competence in skills, as well as interest in science. Evaluating student learning can be difficult [48] and due to the wide heterogeneity of courses and implementation, it was not possible to devise an overarching assessment.

In order to analyze the impact of the intervention, survey scores were binned into the four themes of the questions and explore the effect of time, course modality (in-person vs. online), and student population (majors and courses) through sequential ANOVA analyses. An initial Manova revealed the largest impact to the factor time (with after scores being significantly higher than before scores), followed by major and themes. Modality only had a negligible effect on the variation. While students in the online sections had lower "before" scores, they "caught up" to the in-person students in the "after" scores.

Subsequent ANOVA analyses of survey gains in dependence of major, themes, and courses, showed the highest impact in nonmajors, especially the theme Interest in Science. This is partly attributable to the fact that majors have higher before scores compared to nonmajors. Research has shown that majors' study approaches and previous knowledge is different from nonmajors, aspects to be considered when designing science courses [16, 49, 50].

In open-ended comments from the surveys and focus group interviews students expressed they gained knowledge regarding plastic pollution, the process of science, and scientific research as a career option. In addition, many commented on heightened awareness of everyday actions to protect the environment, and interest in activities relevant to their communities. However, nonmajors did not consider a career change to STEM disciplines, which can be partly explained by the particular student population targeted in this CURE: nontraditional and adult learners.

In the United States, data indicate that the number of nontraditional students surpasses that of traditional students [51]. While there is no one definition of what a nontraditional student is, they are characterized as older, often having jobs and with a higher minority representation [52]. In contrast, traditional students tend to be full-time students who are 18–24 years of age [53]. NU student population had an average age of 32 (results not shown). Active learning may be particularly beneficial for adult learners [54, 55], as studies have shown that adult learners come to the classroom with their life experiences, which provide both a rich supply of resources and possible misconceptions for the learning process [56]. Former and active-duty US Navy students interviewed reported previous knowledge and/or concerns about handling of plastic debris on ships (Steuck & Associates report, unpublished).

The majors' group was smaller compared to the nonmajors, and in addition, included two very different courses: a lower division general biology laboratory and an upper division molecular biology laboratory course. Majors in general, and particularly the upper division students, had higher "before" scores, resulting in small gains particularly in Interest and Skills. Majors overall appreciated the direct interaction with scientists, and the opportunity to do hands-on research. Due to program requirements, the upper division courses were always taught in-person, although during the pandemic, they did not participate in the in-person field trip.

While it is too early to fully analyze the long-term impact of the CURE, it is noteworthy that of the biology majors who took BIO169A (lower division general biology lab) the year before the implementation of the CURE, 72% discontinued or changed majors, while in the following three cohorts with the CURE, this number dropped to 45%, 25%, and 17% respectively (results not shown). Of the 11 students who participated in both the lower and upper division CURE, 55% have graduated, and 27% were still active in the program.

An additional challenge of the implementation of the CURE was the accelerated course timeline, which required condensing the material into a maximum of 3 weeks exposure. The majority of nontraditional students and millennials prefer flexible formats that allow them to juggle multiple responsibilities [57], which may explain the popularity of intensive course formats. The one course per month format evaluated in this project is particularly beneficial for military students, which can schedule their classes around deployment and training schedules. Studies have shown that accelerated programs can be as successful and rigorous as their traditional counterparts [58–62]. However, this requires careful course design and adequate deployment of the content [63–65]. The original in-person CURE design placed a large portion of content and activities on the in-person half-day field trip experience. While survey results consistently showed gains after the CURE, some open-ended comments referred to the experience to be disconnected from the rest of the course material. The online pivot forced not only the substitution of in-person events to online delivery but also allowed for a more gradual introduction of the same content through recorded lectures that students could watch in their own time. More structured instruction has been shown to benefit certain demographic populations such as Blacks/African-Americans, Hispanics, or first-generation college students [66–68]. Another aspect that was improved with student feedback was the Q&A panel with researchers. The virtual setting (via Zoom) allowed not only more student and research participants but also small group discussions based on student interest. That way the discussion could be more tailored to a particular student group. For example, nonmajors expressed more interest in societal and community action than in changing majors, while majors received more information regarding laboratory technology and STEM careers.

It became clear from the early results of the CURE that NU nontraditional nonmajors students were not interested in a career change to STEM. In fact, many of the nonmajors took the biology course as one of their last courses due to their apprehension of sciences (Steuck & Associates report, unpublished). The increased appreciation of science and knowledge about ocean plastic pollution, together with a potential for changes in behavior are encouraging and by itself a worthy goal moving forward with the project. The inclusion of health majors was a step to explore additional student populations who could benefit from being exposed to a STEM research experience. Many HU students do not apply to STEM programs due to their lack of knowledge about the process and the long-term advantages of such careers [7, 19]. In addition, as health professions tend to have a higher representation of females while exhibiting lower wages than males [69], redirecting allied health students toward STEM careers may help counteract the overall lower representation of females in STEM disciplines [70, 71]. Preliminary data showed the health majors' survey results to be intermediate between nonmajors and majors. In one section, taught in-person, the instructor applied the Tiny Earth [26] approach to isolate antibiotic-producing microbes from the plastic samples collected. Connecting the research aspect to a global health issue was highly motivating for students, although in the focus groups they expressed they were committed to their career goals (Steuck and Associates report, unpublished). It is planned to adapt the CURE to all microbiology courses at NU, with an increased emphasis on health and medical aspects in order for it to be more attractive to health majors.

Overall, survey results of the CURE were highly encouraging, especially the fact that an online adaptation increased the reach of the CURE while maintaining the gains, especially across nonmajors. On the other hand, focus group interviews showed that in-person students had a much higher engagement with the CURE, and many online students expressed the desire to participate in-person, especially in the field trip experience, given the option (results not shown).

The online CURE experience illustrates both the potential of expanding access to research activities by using virtual activities, and students' desire for experimenting it in-person. In the future, the range of virtual opportunities will be expanded for nonscience majors, while maintaining in-person opportunities for majors, either as part of CUREs or by involving students in more structured research opportunities.

Data Availability

Aggregated numerical data of survey responses are available from corresponding author on reasonable request.

Additional Points

Study Limitations. This study has several limitations. The 52.5% survey response rate may be reflective of a subpopulation of students who are either more engaged or more in need of the extra credit reward. The focus group participation was limited overall. Statistical analyses of the survey scores proved challenging, considering the large number of variables (time, major, modality, themes, and courses). In addition, there was also imbalance in student populations. Nonmajors constituted 75% and 72% of the total and the survey responder population, respectively. Some populations, such as the online majors group, were small compared to others. A particular limitation may be the removal of modality as a factor in some of the analyses. Results should be re-evaluated in the future with more comparable data groups. On the other hand, parallel analyses using an average score of all 15 survey questions yielded similar results to the binned analysis, supporting the validity of the conclusions. In addition, the effect of individual instructor and student engagement cannot be discounted, especially in the online setting. The original in-person setting guaranteed that all students would be exposed to the same experience by participating the field trip. In the online adaptation, while the same materials and assessments were posted for all courses and sections, the focus group interviews revealed that instructor engagement and promotion of the virtual field trip were uneven.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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