

Addressing Foodborne Illness in Côte d'Ivoire: Connecting the Classroom to the Community through a Nonmajors Course-Based Undergraduate Research Experience

Marie A. Smith,^a  Jeffrey T. Olimpo,^b Karen A. Santillan,^b and Jacqueline S. McLaughlin^c

^aDepartment of Science, Technology, Engineering, and Mathematics, International University of Grand-Bassam, Grand-Bassam, Côte d'Ivoire

^bDepartment of Biological Sciences, The University of Texas at El Paso, El Paso, Texas, USA

^cDepartment of Biology, The Pennsylvania State University, Lehigh Valley, Center Valley, Pennsylvania, USA

The integration of course-based undergraduate research experiences (CUREs) into science, technology, engineering, and mathematics (STEM) laboratory curricula has provided new avenues to engage students at all levels in discovery-based learning. Empirical research demonstrates that CUREs have the potential to foster students' development of scientific process and reasoning skills, attitudes, motivations, and persistence in STEM. Yet, these outcomes are largely reported for studies conducted in the United States, Canada, Europe, and Australia. It therefore remains unclear to what extent CUREs are impactful for students enrolled in alternate international university contexts. To address this concern, we conducted a quasi-experimental mixed methods study to investigate the impact of a one-semester food microbiology and public health (FMPH) CURE on nonmajors students' development of science identity, science communication and process skills, science community values, and science-society perceptions at a private institution in Côte d'Ivoire, West Africa. Content analysis of students' end-of-semester research poster products and thematic analysis of student responses to post-semester open-ended survey items revealed positive gains with respect to student learning and student perceptions of the relevancy of their research to diverse audiences. Paired t-test analyses of pre-/post-semester closed-ended survey responses likewise indicated significant gains in students' science identity and science community values development as well as their confidence in handling and treating foods to reduce the bacterial load on those foods. Collectively, these findings suggest that the FMPH CURE was a meaningful and relevant learning experience capable of promoting students' growth as scientists and scientifically-minded citizens.

KEYWORDS course-based undergraduate research experience, introductory biology, nonmajors, CURE, science identity, science process skills, civic engagement, community engagement, international education

INTRODUCTION

Course-based undergraduate research experiences (CUREs) have been championed as an accessible and inclusive means to augment student participation in the scientific process (1).

Address correspondence to Department of Science, Technology, Engineering, and Mathematics, International University of Grand-Bassam, Grand-Bassam, Côte d'Ivoire, or Department of Biological Sciences, The University of Texas at El Paso, El Paso, Texas, USA.
E-mail: smithma@coastalcarolina.edu or jtlimpo@utep.edu.

[The e-mail address for corresponding author Marie A. Smith was updated in the current version, posted on 10 July 2023.]

The authors declare no conflict of interest.

Received: 4 August 2021, Accepted: 15 December 2021,

Published: 31 January 2022

In contrast to traditional laboratories, which have often been described as prescriptive in nature, CUREs seek to engage students in working collaboratively and iteratively to examine hypotheses associated with novel questions of importance to the broader scientific and/or lay communities (2, 3). Empirical studies have increasingly demonstrated that such engagement leads to positive gains in students' researcher self-efficacy, science process skills development, attitudes, and persistence in STEM (4–9). More recently, these studies have likewise highlighted the contextual affordances found within CURE learning environments that mediate such outcomes (10, 11).

In considering the wealth of information that is now readily available regarding the diverse structures and impacts of CUREs, it is critical to note that this information primarily originates from efforts enacted by educators and education researchers in the United States (U.S.), Canada, and Australia (see earlier references and also [12, 13], as examples).

Notably, these experiences have been shown to have a positive influence on students with diverse demographic and educational backgrounds (e.g., [8, 9]). Studies describing the implementation of and/or outcomes associated with CUREs and discovery-based projects conducted in formal teaching laboratories in other countries are fewer, by comparison. Exemplars include a food science course in Vietnam, which seeks to resolve local stakeholder issues (14); a research topics course in Fiji (15); a course with the overarching goal of assessing folic acid concentrations in milk produced and marketed in the United Arab Emirates (16); a 10-week laboratory exercise in India centered on studying the effects of dehydration on rice (17); and a program in China in which students characterize an enzyme of choice (18). In the latter study, for instance, Li and colleagues (18) demonstrated that students who participated in the research-driven course exhibited greater gains in laboratory, presentation, and experimental design skills than did their peers enrolled in the traditional version of the laboratory course.

Regardless, it remains the case that few descriptions of CUREs involving student populations in international contexts (and the associated impact of these CUREs) have been reported in the literature. Furthermore, it is unclear whether those outcomes reported for students in international contexts are consistent with those reported in countries such as the U.S. To address these concerns, we adopted a quasi-experimental mixed methods design to explore the following questions:

1. What impact does participation in a place-based food microbiology and public health (FMPH) CURE have on nonmajors students' development of science identity, science communication and process skills, and science community values?
2. What perceptions do FMPH CURE students possess regarding the benefits associated with the FMPH CURE and the potential implications of their research findings for their local community in Côte d'Ivoire, West Africa?

We hypothesized that students participating in the FMPH CURE would demonstrate gains in science identity, science communication, and science process skills (e.g., identification of a measurable hypothesis; data analysis and interpretation). This assertion is congruent with previous research conducted in U.S. contexts (e.g., [10, 19, 20]). Additionally, earlier studies on student experiences in place-based/locally-contextualized CUREs (e.g., [11, 18]) note that participants reported positive perceptions of their engagement in the course, including development of research skills and greater awareness of how the findings of their independent projects could impact their community. We therefore anticipated similar outcomes in the context of the present research.

GUIDING FRAMEWORKS AND MODELS

We situate our research within Auchincloss and colleagues' (2) five-dimensional CURE framework, which postulates that

students who engage in CUREs employ scientific techniques and skills to address novel questions of broad importance to one or more communities outside the classroom. Within such learning environments, scientific investigations are conducted in a collaborative and iterative manner, reflecting the nature of science and further distinguishing CUREs from traditional laboratory experiences. In addition to informing the development of student learning objectives (SLOs) and activities associated with the CURE described herein (see *Course context*), Auchincloss and colleagues' framework – as well as subsequent perspectives on and considerations for creating and implementing nonmajors CUREs (21, 22) – was vital in allowing us to identify salient assessment measures that aligned with those SLOs and activities while remaining cognizant of underlying situational factors.

More acutely, current literature on place-based education was used as a lens through which to capitalize upon the aforementioned element of broader relevance; namely, to ensure that individual components of the FMPH CURE were scaffolded appropriately to facilitate classroom-community connections. Notably, place-based educational approaches afford students the opportunity to articulate the relationship between what they learn in their coursework and the application of those concepts in real-world contexts, leading to advancement in students' science identity development, affect, and persistence (see references 8–14, as cited in [23]). Accordingly, by intentionally integrating these frameworks and instructional models, our objective was to create a meaningful and relevant learning experience that would promote students' growth as scientists and scientifically-minded citizens.

METHODS

Course context

Recent metrics from the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) identify diarrheal diseases as the sixth leading cause of death in Côte d'Ivoire, with a sizeable fraction of these fatalities being attributed to poor sanitary practices leading to foodborne illness (24–28). Identifying mechanisms to address this crisis offers a novel platform to engage undergraduates in developing and conducting scientific investigations that are of direct relevance to their local communities. In an effort to capitalize upon these affordances, we created a course-specific CURE focused on food microbiology and public health that was designed to promote students' development of research-oriented skills and attitudes (see Table 1 for a complete list of student learning objectives for the course). Congruent with Auchincloss and colleagues' (2) framework, FMPH CURE student dyads or triads engaged both separately and as part of the larger class in iterative cycles of experimentation and data analysis to address the overarching question of how to decrease bacterial loads on food, with the intent of disseminating their findings to the campus community and to other external stakeholders. Foci pursued ranged from examination of the effects of antibacterial

TABLE I
FMPH CURE student learning goals and outcomes

Student learning objective ^a	Method(s) of assessment
1. Apply scientific techniques and practices (e.g., literature review; laboratory skills) to execute a student-designed, team-based research project	Student Poster Products, Open-Ended Response Prompts
2. Interpret data collected as a result of executing a student-designed, team-based research project and communicate those results to diverse audiences	Student Poster Products, Open-Ended Response Prompts
3. Demonstrate increased, positive attitudes with respect to one's role as a scientific researcher and scientifically-engaged citizen as well as with respect to scientific values, more broadly	Pre-/Post-Course Survey ^b
4. Value the role of science in society	Open-Ended Response Prompts

^aStudent learning objectives were developed based on Bloom's and Fink's Taxonomies of Learning (as described in [34, 35]).

^bComplete descriptions of each of the assessments listed in this table can be found in the "Methods" section.

agents such as potassium permanganate (KMnO₄) and sodium hypochlorite (NaClO) on the bacterial load found on meats and produce (e.g., lettuce) to characterization of the extent to which handling money (or not) impacts the bacterial load found on local bread products, among other examples. Collectively, execution of these projects necessitated that students prepare control and treatment samples, which were then inoculated on Plate Count Agar (PCA) using sterile technique. Plates were sealed and stored at 37°C for 24 h before analyses were performed. Within the context of the CURE, the instructor (M.A.S.) provided mentorship and coaching to students to facilitate advancement of research projects as well as to enculturate students to the daily work of scientists. With the exception of minor adjustments to course content based on student feedback, the curricular materials and instructional strategies employed across semesters were identical.

Furthermore, a four-step pedagogical framework (29) was employed to scaffold students' development of scientific skills as they engaged in the research process. Early weeks in the semester were dedicated to learning essential techniques (e.g., reading primary literature; pipetting), whereas the middle third of the semester was devoted to experimentation and the last third to data analysis, interpretation, and communication (Appendix 1). Structured exercises (e.g., plant physiology and reproduction) were likewise integrated throughout the CURE, when feasible, to reinforce concepts discussed in the corresponding lecture portion of the course. J.S.M. mentored M.A.S. in the development of the CURE, and J.T.O. and K.A.S. worked collaboratively with M.A.S. to assess student outcomes (as described in greater length below). Overall, this structure allowed the authors to effectively monitor student progress in the CURE while simultaneously enhancing course quality to best meet students' needs.

Safety considerations

The FMPH CURE required culturing unknown organisms, sometimes involving foods likely to contain pathogenic organisms such as *Salmonella*. Plates were sealed after samples were prepared, or BSL-2 conditions were required. Training of students for BSL-1 and BSL-2 procedures occurred at the start of

the semester. Students were required to wear gloves and lab coats at all times and were also required to wear eye protection when working with liquids, as cutting and grinding of foods could cause splashing and eye irritation. Waste that contacted organisms was sterilized in an autoclave, and all tools/equipment were likewise sterilized before and after use with 60–75% ethanol and an open flame source. Care was taken to avoid potential fire hazards. Beakers, glass pipettes, and other glassware had the potential to break and become sharps hazards. All glass was disposed of properly in the glass bin, and the instructor (M.A.S.) was responsible for the proper disposal of all broken glass.

Participant recruitment and demographics

Participants (N = 20) were a convenience sample consisting of individuals voluntarily enrolled in a semester-long, introductory nonmajors biology CURE at a small, private university in francophone West Africa (see *Course context* above) in the Spring 2019 and Fall 2019 semesters (representing 67% of all eligible participants). The demography of this sample was equal percentages male and female, who predominantly self-identified as non-STEM majors (90%) (Table 2), and was similar to that of the two course sections from which data were obtained. In an effort to reduce selection bias, only those individuals who were enrolled in the CURE for the first time were included in our analyses. No other inclusion or exclusion criteria were employed. Comparison of student demographic information and pre-semester survey responses (see "Measurement" sections) revealed no significant qualitative differences between the Spring 2019 and Fall 2019 cohorts; thus, data obtained from these cohorts were aggregated prior to performing the analyses described below.

Measurement of science process and communication skills

Modified versions of the Association for American Colleges and Universities' (AAC&U) Inquiry and Written Communication VALUE rubrics (<https://www.aacu.org/value-rubrics>; Appendix 2) were employed to evaluate students' science process and

TABLE 2
FMPH CURE student demographic characteristics

Category	Participants (n) ^a
Gender	
Male	10
Female	10
Race/Ethnicity	
Black, African, or African American	20
Other Race or Ethnicity	0
First Generation Student Status	
Continuing generation	18
First generation	2
Major	
STEM	2
Non-STEM	18
Prior Research Experience	
Prior Experience	2
No Prior Experience	18

^aN = 20.

communication skills proficiency, as evidenced in end-of-semester CURE research poster submissions generated by each student dyad or triad ($n_{\text{posters}} = 9$). Submissions were blinded and scored by two individuals with expertise in discipline-based education research (K.A.S. and J.T.O.), with strong interrater reliability observed ($\kappa = 0.813$; $P < 0.001$). Scoring disputes were resolved via discussion between the two raters until consensus was achieved.

Measurement of science identity development, science community values, and student self-reported learning gains

To evaluate the impact of participation in the CURE on student affective and psychosocial outcomes, a 10-question, Likert-item survey was administered using a pre-/post-semester approach. Questionnaire items were derived from the Science Identity and Science Community Values scales of the Persistence in the Sciences (PITS) survey (30) as well as instructor-generated statements regarding students' self-reported attitudes toward learning and confidence in their learning gains. An *a priori* decision was made to remove two items from the Science Identity scale ("I feel like I belong in the field of science" and "I have a strong sense of belonging to the community of scientists") given that the majority of individuals within our sample self-identified as non-STEM majors (which confirmed pre-course student roster information obtained by M.A.S.) and, relatedly, previously observed discrepancies in how students interpreted those items. Potential responses to each item ranged from '1' (strongly disagree) to '5' (strongly agree), with all collected responses entered into SPSS (v.25; IBM) for future statistical analysis.

Characterization of student perceptions of the CURE

In addition to examining those cognitive and noncognitive outcomes identified above, we also sought to understand students' perceptions of their laboratory experience and its impact on their professional growth. In order to achieve this goal, two open-ended items were appended to the post-semester survey described in the preceding section. Specifically, these prompts were: "What scientific, professional, and/or technical skills do you believe you have gained as a result of taking part in this laboratory experience?" and "In what way(s) do you feel the research that you have done this semester will impact your local community?" Student responses were first blinded and then analyzed using a descriptive-interpretive approach (31, 32), in which thematic patterns were identified following iterative rounds of open and axial coding. More specifically, each response was coded by two individuals with expertise in discipline-based education research (K.A.S. and J.T.O.) using inductive coding methods (33). Strong interrater reliability was observed ($\kappa = 0.824$; $P < 0.001$), with all disputes resolved via discussion between the two raters until consensus was achieved.

RESULTS

Students demonstrate proficiency in science process and communication skills

As a culminating event in the FMPH CURE, student teams were required to create and present a scientific poster describing their investigations. Content analysis of these poster products revealed that teams exhibited high levels of proficiency in such areas as identifying a researchable topic, drawing conclusions, and using language appropriate for a scientific audience (Table 3; as measured via an adapted version of the AAC&U Inquiry and Written Communication VALUE rubrics). In contrast, teams demonstrated greater difficulty in discussing the limitations and implications of their work. It is important to note, however, that lower levels of proficiency on this rubric dimension emerged not from a team's inability to identify appropriate limitations and implications, but rather a lack of intentional discussion regarding the relevancy of those items to the larger research process. Course notes obtained from M.A.S. indicate that this observation is possibly due to less instructional emphasis being placed on these aspects of the scientific process relative to other aspects (e.g., data interpretation; science communication).

Students exhibit positive shifts in affective and psychosocial outcomes

Participant responses to the pre-/post-semester questionnaire were analyzed using a series of paired *t*-tests with Bonferroni correction. Results indicated a statistically significant increase in students' perceptions of the importance of

TABLE 3
Student performance on end-of-semester poster presentations

Scoring criterion ^a	Avg score (SEM)	Mode	Minimum score	Maximum score
Topic Selection	3.00 (0.00)	3.00	3.00	3.00
Existing Knowledge, Research, and/or Views	2.78 (0.15)	3.00	2.00	3.00
Design Process	2.56 (0.18)	3.00	2.00	3.00
Analysis	2.67 (0.17)	3.00	2.00	3.00
Conclusions	2.78 (0.15)	3.00	2.00	3.00
Limitations and Implications	2.11 (0.26)	2.00	1.00	3.00
Context/Purpose for Writing	2.89 (0.11)	3.00	2.00	3.00
Syntax/Mechanics	2.44 (0.18)	2.00	2.00	3.00

^aScoring criteria were adapted from the AAC&U Inquiry and Written Communication VALUE rubrics (<https://www.aacu.org/value-rubrics>; Appendix 2) and were applied to all poster submissions ($n = 9$).

discussing new theories and ideas between scientists ($P = 0.004$; Table 4) as well as the extent to which they found the daily work of a scientist to be appealing ($P = 0.012$). Furthermore, significant, positive shifts in students' self-reported confidence in both choosing foods less likely to contain a lot of bacteria and treating foods to prevent bacterial growth were observed ($P = 0.007$ and $P = 0.005$, respectively). From a descriptive standpoint, while the remaining comparisons were not found to be statistically significant, positive shifts in student responses were observed for all relevant survey items.

Student perceptions of the FMPH CURE

Reflective of Auchincloss and colleagues' (2) framework, we sought to better understand the extent to which

participation in the FMPH CURE impacted students' growth as scientists, particularly as it related to gains in scientific, professional, and/or technical skills. Furthermore, given the place-based nature of the course, we were curious to learn more about students' perceptions of the possible connections between the investigations that they conducted during the CURE and the impact of the resultant outcomes on their local community. Qualitative analysis of student responses to open-ended prompts on the end-of-semester survey suggested that the CURE had a positive impact on participants' development of experimental design skills (65% of respondents; $n = 13$), attitudes toward and ability to effectively engage in collaboration (35% of respondents; $n = 7$), and knowledge and/or awareness of foodborne illnesses (25% of respondents; $n = 5$), among other outcomes (Table 5). With regard to the latter observation, students

TABLE 4
Pre-/post-semester comparisons of student survey responses

Item	Pre-score M (SEM)	Post-score M (SEM)	P value
Science Community Values ^a			
I think it is valuable to conduct research that builds the world's scientific knowledge.	4.60 (0.14)	4.75 (0.12)	0.330
I think discussing new ideas between scientists is important.	4.35 (0.13)	4.80 (0.09)	0.004
I think that scientific research can solve many of today's problems.	4.40 (0.20)	4.65 (0.11)	0.262
I feel that discovering something new in the sciences is thrilling.	4.00 (0.16)	4.35 (0.17)	0.049
Science Identity ^b			
The daily work of a scientist is appealing to me.	3.00 (0.23)	3.70 (0.22)	0.012
I derive great personal satisfaction from working on a team that is doing important research.	4.15 (0.17)	4.40 (0.13)	0.234
I have come to think of myself as a "scientist."	2.85 (0.25)	2.95 (0.23)	0.541
Student Attitudes Toward Learning and Confidence in Learning Gains ^b			
I am interested in learning about how to prevent bacterial growth on various types of food.	3.85 (0.26)	4.40 (0.20)	0.037
I am confident that I can choose foods less likely to contain a lot of bacteria.	3.65 (0.26)	4.35 (0.17)	0.007
I am confident that I can treat foods to prevent bacterial growth.	3.30 (0.27)	4.05 (0.21)	0.005

^aAdjusted $\alpha = 0.0125$ following Bonferroni correction.

^bAdjusted $\alpha = 0.0167$ following Bonferroni correction.

TABLE 5

Student responses to the question: “What scientific, professional, and/or technical skills do you believe you have gained as a result of taking part in this laboratory experience?”

Theme	Number of responses (%) ^a	Sample student response
Increased Awareness of Foodborne Illness	5 (25%)	“I think it will be about paying more attention to bacteria in foods. I will be more cautious when buying street foods.”
Collaboration/Teamwork	7 (35%)	“I have firstly learned to really work in teams; this is something that I did not really like before.”
Data Analytics and Dissemination	3 (15%)	“I have learned to analyze and discuss the result of the experiment.”
Laboratory Safety	1 (5%)	“... everything should be sterilized, we should be well dress[ed], and we need to follow the protocol.”
Experimental Design/Techniques	13 (65%)	“I learned more about the scientific method. In fact, before taking this lab experience, I was not really aware of how scientists were proceeding from the formulation of the hypothesis to the results of [the] experiment.”
Scientific Reasoning	1 (5%)	“I have developed my scientific acumen.”
Troubleshooting/Learning from Failure	1 (5%)	“... I was able to gain skills like... learning from failures.”
Patience with the Pace of Scientific Research	1 (5%)	“I have become patient... ”

^aN = 20; student responses were coded into multiple categories, as appropriate.

likewise reported that the findings of their investigations could serve to increase their *community's* understanding of and ability to respond to foodborne diseases (Table 6). For instance, one respondent stated that “[they] hope that by doing this research, we (their project team) can spread knowledge and change the way people work – make them adopt new habits to increase safety of food.” Interestingly, several students ($n = 8$) acknowledged that their own behaviors with regard to purchasing street foods were altered as a result of conducting research as part of the FMPH CURE, suggesting that improving street vendors’ sanitation practices would increase the likelihood of sales for those vendors, at least among the study sample. Such responses highlight the place-based focus of the course and the broader impacts of the FMPH CURE curriculum.

DISCUSSION

Empirical studies have increasingly documented the positive impact of engagement in CUREs on students’ attitudes and motivations, science process skills development, and persistence in STEM (4–9). To a lesser degree, research has likewise focused on the contextual factors mediating such outcomes in CURE learning spaces, including the role of course structure as well as student and instructor behaviors (10, 11). While this is the case, a limited number of studies (e.g., 14–18) have examined student outcomes and the mechanisms for effective implementation of a course-specific CURE with

regard to an international student population in an international university environment.

In this article, we sought to address this concern by employing both quantitative and qualitative approaches to examine student learning and professional development in the context of a place-based food microbiology CURE in francophone West Africa. Results indicate that students acquired proficiency in developing a researchable question, conducting their investigations, and drawing conclusions (as evidenced by evaluation of end-of-semester poster products; Table 3). These data were supported by qualitative responses provided by participants on the end-of-semester open-ended survey prompts (Table 5). Furthermore, positive shifts on select factors related to science community values and science identity were observed, including student perceptions of the importance of discussing new theories and ideas between scientists (Table 4). Lastly, participants reported that they gained confidence in their understanding of food safety (e.g., confidence in treating foods to prevent bacterial growth) and believed that their research could likewise inform the members of their community about the risks associated with foodborne illness and potential preventative measures that could be employed to limit outbreaks.

These outcomes are consistent with previous, related reports in the literature (14–18). Similarly, Olimpo et al. (11) demonstrated that student engagement in a place-based, health disparities CURE at a large, Hispanic-Serving Institution yielded significant gains in participants’ researcher self-efficacy and sense of project ownership. The authors furthermore argued that “students [in the CURE] valued the need for increasing community

TABLE 6

Student responses to the question: "In what way(s) do you feel the research that you have done this semester will impact your local community?"

Theme	Number of responses (%) ^a	Sample student response
Increasing Awareness of Foodborne Illness	13 (65%)	"The project that we have done has a big impact on our community. In [the] Ivory Coast, meat is always sitting outside, and a lot of street restaurant owners do not wash or hand[le] the meat well. It leads to diseases, especially when paired with vegetables. So, I hope that by doing this research, we can spread knowledge. . ."
Dissemination of New Sanitation Methods	8 (40%)	". . . change the way people work, make them adopt new habits to increase safety of food."
Changes in Personal Behavior ^b	8 (40%)	"I will apply my knowledge in my day-to-day life, meaning I will pay attention to my eating habits, the kinds of foods I usually eat, and be really cautious when it comes to food."
Enhance Knowledge of How to "Do" Science	1 (5%)	"I would bring my knowledge [to] my communities on diverse experiments [that we have] done in class."

^a*N* = 20; student responses were coded into multiple categories, as appropriate.

^bNote that statements in this coding category reflected participants' views regarding how they would change their own behaviors (rather than those of community members), though these statements often described interactions the participants would have with other individuals in their community.

awareness of public health issues in the region, [which] could be accomplished both through practical means (e.g., increased communication) and professional means (e.g., students pursuing careers with a civic engagement focus)" (pp. 19, 21).

There are several limitations inherent of our study. First, while we present data from multiple instantiations of the FMPH CURE, our collective sample size is small, and all student cohorts were taught by the same instructor. While this is not uncommon of studies in the field (e.g., 20), and while retaining the same instructor can reduce confounding, we caution against overgeneralization of the results presented herein. More broadly, it therefore remains unclear to what extent the course is scalable for implementation in multiple sections per semester (should the need arise) as well as what form(s) of professional development would be necessary in the event that the CURE was facilitated by more than one individual. We suggest these as areas for future research, particularly with regard to developing a better understanding of the impact of the CURE on diverse student and faculty populations.

Additionally, restrictions in course scheduling precluded inclusion of a comparison group. Thus, we find it important to reemphasize that our intent was to explore the direct influence of the FMPH CURE on cognitive and noncognitive student outcomes rather than generate claims regarding the efficacy of the CURE relative to one or more other laboratory-based experiences. While such comparisons are prevalent within the literature, we contend that future work in this area is needed, as less remains known about the benefits and barriers associated with nonmajors CUREs (21). Relatedly, given the place-based nature of the FMPH CURE, future studies are warranted regarding student outcomes in CUREs that incorporate a community engagement component versus those

that do not. Collectively, these findings will provide valuable insight into effective mechanisms for increasing access to and inclusion of international students in research-intensive experiences in the STEM classroom and beyond.

CONCLUDING THOUGHTS: CONSIDERATIONS FOR DEVELOPING INTERNATIONAL CURES

We contend that facilitating CUREs in an international context presents unique challenges and affordances relative to instruction in the United States. For instance, material resources in the geographical area where M.A.S. taught were greatly limited, resulting in a lack of equipment available for use during students' independent research projects and the need for students to generate hardcopy deliverables rather than digital media (e.g., creation of posters on poster paper rather than electronically). However, anecdotal observations suggested that these challenges demanded greater planning and collaboration between students and between students and the instructor, which was viewed favorably.

More broadly, despite the fact that most students at the institution at which this research occurred hail from the immediate urban area of Abidjan, Côte d'Ivoire, in francophone West Africa, their educational backgrounds, level of English proficiency, and prior experiences with science vary widely. These attributes, M.A.S. notes, were poorly addressed in the traditional laboratory curriculum, where students had few opportunities to engage in the scientific process or receive actionable feedback on their efforts in that regard. Additionally, there was a clear need for increased practice drawing conclusions based on data. Comparatively, the FMPH CURE was intentionally designed to provide a structured, iterative, and collegial environment that acknowledged both the students' perspectives and

backgrounds as well as the research-/pedagogically-oriented goals of the course.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.1 MB.

ACKNOWLEDGMENTS

We thank the FMPH CURE students for their willingness to voluntarily participate in this research as well as members of the campus community and public who attended end-of-semester poster presentations delivered by said students. We also wish to thank Andrea Rediske for her feedback on earlier versions of this article.

This research was approved by The University of Texas at El Paso's Institutional Review Board (IRB) under protocol number 789648.

REFERENCES

- Bangera G, Brownell SE. 2014. Course-based undergraduate research experiences can make scientific research more inclusive. *CBE Life Sci Educ* 13:602–606. <https://doi.org/10.1187/cbe.14-06-0099>.
- Auchincloss LC, Laursen SL, Branchaw JL, Eagan K, Graham M, Hanauer DI, Lawrie G, McLinn CM, Pelaez N, Rowland S, Towns M, Trautmann NM, Varma-Nelson P, Weston TJ, Dolan EL. 2014. Assessment of course-based undergraduate research experiences: a meeting report. *CBE Life Sci Educ* 13:29–40. <https://doi.org/10.1187/cbe.14-01-0004>.
- Spell RM, Guinan JA, Miller KR, Beck CW. 2014. Redefining authentic research experiences in introductory biology laboratories and barriers to their implementation. *CBE Life Sci Educ* 13:102–110. <https://doi.org/10.1187/cbe.13-08-0169>.
- D'Arcy CE, Martinez A, Khan AM, Olimpo JT. 2019. Cognitive and non-cognitive outcomes associated with student engagement in a novel brain chemoarchitecture mapping course-based undergraduate research experience. *J Undergrad Neurosci Educ* 18:A15.
- Jordan TC, Burnett SH, Carson S, Caruso SM, Clase K, DeJong RJ, Dennehy JJ, Denver DR, Dunbar D, Elgin SCR, Findley AM, Gissendanner CR, Golebiewska UP, Guild N, Hartzog GA, Grillo WH, Hollowell GP, Hughes LE, Johnson A, King RA, Lewis LO, Li W, Rosenzweig F, Rubin MR, Saha MS, Sandoz J, Shaffer CD, Taylor B, Temple L, Vazquez E, Ware VC, Barker LP, Bradley KVV, Jacobs-Sera D, Pope WH, Russell DA, Cresawn SG, Lopatto D, Bailey CP, Hatfull GF. 2014. A broadly implementable research course in phage discovery and genomics for first-year undergraduate students. *mBio* 5:e01051-13–e01013. <https://doi.org/10.1128/mBio.01051-13>.
- Kirkpatrick C, Schuchardt A, Baltz D, Cotner S. 2019. Computer-based and bench-based undergraduate research experiences produce similar attitudinal outcomes. *CBE Life Sci Educ* 18:ar10. <https://doi.org/10.1187/cbe.18-07-0112>.
- Olimpo JT, Fisher GR, DeChenne-Peters SE. 2016. Development and evaluation of the Tigriopus course-based undergraduate research experience: impacts on students' content knowledge, attitudes, and motivation in a majors introductory biology course. *LSE* 15:ar72. <https://doi.org/10.1187/cbe.15-11-0228>.
- Rodenbusch SE, Hernandez PR, Simmons SL, Dolan EL. 2016. Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees. *LSE* 15:ar20. <https://doi.org/10.1187/cbe.16-03-0117>.
- Shaffer CD, Alvarez CJ, Bednarski AE, Dunbar D, Goodman AL, Reinke C, Rosenwald AG, Wolyniak MJ, Bailey C, Barnard D, Bazinet C, Beach DL, Bedard JE, Bhalla S, Braverman J, Burg M, Chandrasekaran V, Chung H-M, Clase K, Dejong RJ, Diangelo JR, Du C, Eckdahl TT, Eisler H, Emerson JA, Frary A, Frohlich D, Gosser Y, Govind S, Haberman A, Hark AT, Hauser C, Hoogewerf A, Hoopes LLM, Howell CE, Johnson D, Jones CJ, Kadlec L, Kaehler M, Silver Key SC, Kleinschmit A, Kokan NP, Kopp O, Kuleck G, Leatherman J, Lopilato J, Mackinnon C, Martinez-Cruzado JC, McNeil G, Mel S, et al. 2014. A course-based research experience: how benefits change with increased investment in instructional time. *CBE Life Sci Educ* 13:111–130. <https://doi.org/10.1187/cbe-13-08-0152>.
- Esparza D, Wagler AE, Olimpo JT. 2020. Characterization of instructor and student behaviors in CURE and Non-CURE learning environments: impacts on student motivation, science identity development, and perceptions of the laboratory experience. *CBE Life Sci Educ* 19:ar10. <https://doi.org/10.1187/cbe.19-04-0082>.
- Olimpo JT, Apodaca J, Hernandez A, Paat YF. 2019. Disease and the environment: a health disparities CURE incorporating civic engagement education. *Sci Educ Civic Engage Int J*. <https://new.seceij.net/articletype/disease-and-the-environment/>.
- Pedwell RK, Fraser JA, Wang JT, Clegg JK, Chartres JD, Rowland SL. 2018. The beer and biofuels laboratory: a report on implementing and supporting a large, interdisciplinary, yeast-focused course-based undergraduate research experience. *Biochem Mol Biol Educ* 46:213–222. <https://doi.org/10.1002/bmb.21111>.
- Sangster SL, Loy KL, Mills SD, Lawson KL. 2016. Engaging first-year university students in research: promise, potentials, and pitfalls. *cjsotl-rcacea* 7. <https://doi.org/10.5206/cjsotl-rcacea.2016.1.3>.
- LeGrand K, Yamashita L, Trexler CJ, Vu TLA, Young GM. 2017. Developing food science core competencies in Vietnam: the role of experience and problem solving in an industry-based undergraduate research course. *J Food Sci Educ* 16:118–130. <https://doi.org/10.1111/1541-4329.12123>.
- Chand RR, Kaur M, Singh P. 2019. Reformatations and promoting active learning via course based research [CBR] at the University of Fiji. *Asian J Dist Educ* 13:20–31.
- Alneyadi A, Shah I, Ashraf SS. 2019. An innovative bioanalytical research project course to train undergraduate students on liquid chromatography–mass spectrometry. *Biochem Mol Biol Educ* 47:228–238. <https://doi.org/10.1002/bmb.21225>.
- Bhushan GD. 2020. A systemic approach to understand plants' responses under abiotic stress: a laboratory exercise for undergraduate biology majors. *J Biol Educ* 54:262–270. <https://doi.org/10.1080/00219266.2019.1569085>.

18. Li B, Jia X, Chi Y, Liu X, Jia B. 2020. Project-based learning in a collaborative group can enhance student skill and ability in the biochemical laboratory: a case study. *J Biol Educ* 54:404–418. <https://doi.org/10.1080/00219266.2019.1600570>.
19. Mader CM, Beck CW, Grillo WH, Hollowell GP, Hennington BS, Staub NL, Delesalle VA, Lello D, Merritt RB, Griffin GD, Bradford C. 2017. Multi-institutional, multidisciplinary study of the impact of course-based research experiences. *J Micro Biol Educ* 18. <https://doi.org/10.1128/jmbe.v18i2.1317>.
20. Peteroy-Kelly MA, Marcello MR, Crispo E, Buraei Z, Strahs D, Isaacson M, Jaworski L, Lopatto D, Zuzga D. 2017. Participation in a year-long CURE embedded into major core genetics and cellular and molecular biology laboratory courses results in gains in foundational biological concepts and experimental design skills by novice undergraduate researchers. *J Micro Biol Educ* 18. <https://doi.org/10.1128/jmbe.v18i1.1226>.
21. Ballen CJ, Blum JE, Brownell S, Hebert S, Hewlett J, Klein JR, McDonald EA, Monti DL, Nold SC, Slemmons KE, Soneral PAG, Cotner S. 2017. A call to develop course-based undergraduate research experiences (CUREs) for nonmajors courses. *LSE 16:mr2*. <https://doi.org/10.1187/cbe.16-12-0352>.
22. Cooper KM, Soneral PA, Brownell SE. 2017. Define your goals before you design a CURE: a call to use backward design in planning course-based undergraduate research experiences. *J Micro Biol Educ* 18. <https://doi.org/10.1128/jmbe.v18i2.1287>.
23. Fisher GR, Esparza D, Olimpo JT. 2019. Place-based case studies: a new approach to an effective teaching practice. *J Micro Biol Educ* 20. <https://doi.org/10.1128/jmbe.v20i1.1611>.
24. Centers of Disease Control and Prevention. 2021. Global health - Côte d'Ivoire. Retrieved August 2, 2021, from <https://www.cdc.gov/globalhealth/countries/cote-d-ivoire/default.htm>.
25. Alfred KK, Jean-Paul BK, Hermann CVV, Mirelle BA, Marcellin DK. 2019. Assessment of safety risks associated with pork meat sold on the market in Abidjan city (Côte d'Ivoire) using surveys and microbial testing. *Heliyon* 5:e02172. <https://doi.org/10.1016/j.heliyon.2019.e02172>.
26. Traore SG, Bonfoh B, Krabi R, Odermatt P, Utzinger J, Rose KN, Tanner M, Frey J, Quilici ML, Koussémon M. 2012. Risk of Vibrio transmission linked to the consumption of crustaceans in coastal towns of Côte d'Ivoire. *J Food Prot* 75:1004–1011. <https://doi.org/10.4315/0362-028X.JFP-11-472>.
27. World Health Organization. 2021. *Communicable disease epidemiological profile: Côte d'Ivoire*. Retrieved August 2, 2021, from https://apps.who.int/iris/bitstream/handle/10665/70300/WHO_HSE_GAR_DCE_2010.3_eng.pdf;jsessionid=E031F877A5D650A65779F0475E5BEAA5?sequence=1.
28. Toe E, Dadié A, Dako E, Loukou G. 2017. Bacteriological quality and risk factors for contamination of raw mixed vegetable salads served in collective catering in Abidjan (Ivory Coast). *AiM* 07:405–419. <https://doi.org/10.4236/aim.2017.76033>.
29. McLaughlin JS, Favre DE, Weinstein SE, Goedhart CM. 2017. The impact of a four-step laboratory pedagogical framework on biology students' perceptions of laboratory skills, knowledge, and interest in research. *J Coll Sci Teach* 47:83–91.
30. Hanauer DI, Graham MJ, Hatfull GF. 2016. A measure of college student persistence in the sciences (PITS). *LSE 15:ar54*. <https://doi.org/10.1187/cbe.15-09-0185>.
31. Elliott R, Timulak L. 2020. *Essentials of descriptive-interpretive qualitative research: a generic approach*. American Psychological Association.
32. Tesch R. 2013. *Qualitative research: analysis types and software tools*. In *Qualitative research: analysis types and software tools*. <https://doi.org/10.4324/9781315067339>.
33. Corbin J, Strauss A. 2015. *Basics of Qualitative Research* (4th ed). SAGE Publications.
34. Krathwohl DR. 2002. A revision of Bloom's taxonomy: an overview. *Theory Pract* 41:212–218. https://doi.org/10.1207/s15430421tip4104_2.
35. Fallahi C. 2011. Using Fink's taxonomy in course design. *APS Observer* 24. <https://www.psychologicalscience.org/observer/using-finks-taxonomy-in-course-design>.