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Investigating the Development of Team Science Skills and an Improved Understanding of Multidisciplinary Research through Parallel Courses in Biology, Geology, and Environmental Engineering

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Abstract

Collaborative teamwork is fundamental to successful research and is a desirable skill set for employers. Yet students receive little training in how to effectively work in teams. This article presents the preliminary design and implementation of course-based undergraduate research experiences (CUREs) in biology, geology, and environmental engineering in which student teams address questions related to their discipline while contributing to a shared research project. Team science training in communication, research planning, and conflict resolution was embedded into CURE classes at a regional R2 university. Although barriers to this approach were present, evidence in the form of writing prompt scores and team science products suggested student understanding of effective teams and the benefits of working with individuals within and across disciplines to solve complex problems increased.

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One of the National Science Foundation's "10 Big Ideas" is growing convergent research to foster the collaborations needed to solve complex global challenges such as climate change, "understanding the food, energy, water nexus," and "exploring the universe at all scales" (National Science Foundation n.d.). These collaborations often happen in small teams or larger scientific groups in which individuals work in an interdependent fashion with others. Training scientists to work productively with others, within and across disciplines, is therefore critical. The "science of team science" describes principles related to effective team management for convergent science and has concrete lessons for researchers. Unfortunately, there are few programs that teach team science to developing scientists (Love et al. 2022).

Addressing these complex global problems often requires information from multiple disciplines. The historical prominence of siloed disciplines and the resulting institutional barriers, such as assigning teaching credit and student credit hours to cross-listed courses, can make it difficult to provide opportunities for students to work across disciplines. Traditional disciplinary science provides students a sense of mastery and professional identity, however expertise and identity may not be sufficient to address the rapid changes in science and society (Lattuca 2001). An alternative to having each student become an adept interdisciplinary researcher who can leverage knowledge from diverse fields is to teach students to work in teams that have representatives from multiple disciplines. Working with individuals from a different discipline requires unique communication and critical thinking abilities. If institutions are to aid students with learning the competencies and skills needed to work effectively in teams across disciplines, one must know what these competencies encompass, how students might attain them through coursework, and how to measure whether students are indeed attaining the skills required (Hall et al. 2018; Love et al. 2022; Salas, Cooke, and Rosen 2008; Stokols et al. 2008; Wildman and Bedwell 2013). Therefore, tools were incorporated to teach students, the world's future scientists, how to work as a member of a multidisciplinary scientific team and evaluate their understanding and perceptions of teams.

Tying training in team science with linked undergraduate research experiences from diverse fields could be a particularly powerful way to prepare students to address the global challenges science increasingly faces. Participation in undergraduate research has been identified as a high-impact practice that can lead to increased persistence in science (Barlow and Villarejo 2004; Hurtado et al. 2008; Nagda et al. 1998); improved science process skills (Kardash 2000; Lopatto 2004); and increased entry into graduate school (Hathaway, Nagda, and Gregerman 2002). Embedding research within the curriculum through course-based undergraduate research experiences (CUREs) is a recognized strategy for increasing access to research (Allen et al. 2021a, 2021b; Bangera and Brownell 2014; National Research Council 2012).

This article presents the design and implementation of CUREs in which students from two (spring 2022) or three disciplines (spring 2021) worked together to address a shared research question. Students were enrolled in a CURE within their discipline (biology, environmental engineering, or geological sciences) and then the disciplinary CUREs collaborated to provide cross-disciplinary insights on their study system. Faculty and teaching assistants received training in team science, specific course elements were incorporated to facilitate teamwork among undergraduates, and students were assessed on their understanding of effective teams.

Research Questions

Research questions included:

1. What are the barriers to this model of collaboration across disciplines?
2. Can principles of team science communication, planning, and conflict resolution be introduced to courses through the creation of specific course elements?
3. Do students develop an understanding of collaboration across disciplines in research?

Methods

Concurrent Research Project

The CUREs were offered at a large, regional university in the southeastern United States. There were two iterations of the collaboration across disciplines. Iteration 1 (spring 2021) had all three courses, and Iteration 2 (spring 2022) had the environmental engineering and geological sciences CUREs, with data from the prior year's biology CURE available to students. Issues related to teaching needs and instructor teaching loads caused the loss of the biology CURE from Iteration 2. The collaborative research project focused on Town Creek, an urban stream in Greenville, North Carolina, that was piped and buried in the 1930s. Recent efforts implemented by the city to reduce urban flooding and improve water quality included installing a large in-stream regenerative stormwater conveyance. This green stormwater infrastructure provided students with a local opportunity to evaluate an innovative approach to reducing water quality impairments along an urban stream. The research teams consisted of student-led teams from three different courses: Microbial Ecology (within biology), Groundwater Hydrology (within environmental engineering), and Hydrogeology and the Environment (within geological sciences). The overarching research focus for the cross-disciplinary collaboration was to evaluate how the microbial community and hydrology impacted the effectiveness of a regenerative stormwater conveyance as a sediment and nutrient treatment best management practice. All three courses were designed to align with the five components of a CURE—science practices, discovery, relevance, collaboration, and iteration—that have been previously recommended (Auchincloss et al. 2014; see Table 1).

Biology CURE Design

Although the microbial biology CURE had traditionally been taught in person, the course was online during Iteration 1 due to instructor preference during the COVID-19 pandemic (and was not taught during Iteration 2). The microbial ecology CURE offered an ecological and evolutionary perspective to examining processes that generate and maintain microbial biodiversity while also emphasizing how microbial traits influence the abundance and distribution of microbes in various environments and consequent ecosystem functions and services. The goal of the research projects was to examine how environmental factors influenced microbiome composition and function in the Town Creek system. Specifically, the research projects involved evaluation of environmental change effects on microorganisms and biogeochemical functions and analysis of environmental and microbial data using modern statistical approaches. Each team included three to four undergraduate students and at least one graduate student. The graduate students served as near-peer mentors to the undergraduate students on the team. As research questions were formulated, teams refined hypotheses based on instructor feedback. When the overarching research question and hypothesis were finalized, the instructor and TA encouraged each student to develop an individual subquestion to be answered with the data being generated.

Geological Sciences CURE Design

The geology CURE focused on understanding water movement, occurrence, and behavior at the earth's surface

TABLE 1. Course Elements Associated with Each CURE

	Microbial ecology (Biology)	Groundwater hydrology (Environmental engineering)	Hydrogeology and the environment (Geological sciences)
Student enrollment: 2021	12	13	5
Student enrollment: 2022	NA	9	13
Science practices	Hypothesis testing, experimental design, computational and statistical analysis using R programming, communication of project to peers and instructors	Field measurements of aquifer properties, calculating and modeling groundwater flow and interpreting results	Field and lab measurements of water quality, streamflow, groundwater inputs, and other hydrological parameters
Discovery	Visualization of water quality data through time to evaluate storm effects on ecosystem using R statistical environment	Field trips and data collection; model manipulation; visualization of groundwater flow and water quality data	Field activities on a weekly basis to monitor green stormwater infrastructure (all students)
Relevance	"How does the microbial community and hydrology interact to affect the function of a local urban regenerative stormwater conveyance system?"		
Collaboration	Students worked in teams of 3 to 4 undergraduates and 1 graduate student to formulate research questions. For the primary data, a designated group member with the help of a teaching assistant collected and processed samples for microbial sequencing.	Students worked in teams of 3 to 4 to formulate research questions and collect the primary data. The raw data from the geological sciences class was used by all teams. They coordinated which team was responsible for each set of data.	Students worked in a team of 5 to formulate a single research question. Instrumentation, samples, and data were shared among students within and between courses to accomplish tasks detailed in the student-designed research plan.
Iteration	Students completed computational tutorials and applied microbiome and water quality analyses in preparation for ongoing data collection, synthesis, and interpretation.	Teams altered their plans throughout the semester based on learning what data was available and what data could be easily collected.	Teams adapted their approach and instrumentation during the semester. Storm and rainfall events provided the opportunity for repeated measurements.

and subsurface, with an emphasis on groundwater, water quality, and the effects of human development on the hydrologic cycle. Lectures and in-person field events were held once per week on separate days. In-person activities were conducted at Town Creek and in a multiuser research lab. In-stream water quality data was collected weekly by the teams, and individual research questions were developed during the first month of the course. During the initial weekly site visits the students were encouraged to develop individual research questions associated with the team's goal of evaluating the effectiveness of the regenerative stormwater conveyance at treating sediment and nutrient inputs from the uptown area. During the second month the students developed a research outline that documented methods, data analysis, and a preliminary literature review on their topic. Data collection along the creek occurred for the first 10 weeks of the course, and the remainder of the course was focused on literature review, data synthesis, and manuscript, video, and presentation preparation.

Environmental Engineering CURE Design

The groundwater hydrology CURE had one lecture session and one lab session per week to study groundwater flow processes used in water resources engineering: aquifer withdrawals, water supply projections, groundwater recharge, subsurface flow, contaminant transport, and groundwater remediation. The research project was the primary focus of the lab sessions, which included data collection at the field site as needed. The team research questions were developed after the students learned about the site and data that had been collected previously. These questions often changed as the students learned more about the true data needs for some of the methods they found in literature and the challenges of collecting environmental data. Then the teams spent the remainder of the semester designing and carrying out experiments and monitoring, analyzing data, and presenting results. Most of the semester was spent designing the monitoring and analyzing the data. Each team received specific training for tasks relevant to their research question, whether it was conducting a slug test to measure hydraulic conductivity or manipulating and analyzing large data sets.

Cross-Disciplinary Structure

Students in the three courses met together twice during the semester for students to share information from their discipline. These meetings were facilitated by the fact that the courses had at least one day a week on which they had the same course meeting time. To facilitate sharing of data as well as video and photo files collected during the course and other previously collected data, maps, reports, and articles, a Microsoft Teams site was created that students in all three courses could access. In addition, Microsoft Teams was used for team meetings and communications, as well as communication among teams and courses.

The instructor of the geological sciences CURE introduced the field site for all three of the courses because he had the most experience at the site. The first joint course meeting was in early February (week 5 of the semester) and provided an opportunity to learn about the ongoing efforts to improve drainage and water quality in the Town Creek watershed through the implementation of green stormwater infrastructure and to discuss potential research questions and projects. A second meeting took place in April and served as an online research symposium in which students presented their project and current findings. This event provided an opportunity for cross-disciplinary questions using both live discussion and through a shared document in which groups could ask detailed questions directly to teams in another discipline. The teams then had time to respond to questions with findings from their own work. To provide additional opportunities for cross-course engagement, the biology instructor and graduate teaching assistant (GTA) hosted weekly Hack-a-Thon meetings, which were open office hours focused on data analysis. These meetings were open to all students participating in the three linked CUREs.

CURE Participants

Students registered for the CUREs based on major requirements and were not specifically selected to participate. The student demographics were well aligned with the study institution (see Table 2), including the student GPA, which ranged from 1.9 to 4.0. Over two iterations of the project, 52 undergraduate students participated, 18 in geology, 22 in environmental engineering, and 12 in microbial ecology (Iteration 1 only). Microbial ecology was colisted as a graduate course so there were also 7 graduate students who participated in the course.

TABLE 2. Demographics of CUREs and Study Institution

Demographic	CUREs (*N* = 52)	Institution
Female	25 (48%)	61%
PEER*	21 (40%)	27%
Pell eligible	24 (46%)	45%

Note: *PEER is defined as persons historically excluded due to their ethnicity or race and includes individuals who identify as Black, African-American, Hispanic, or Pacific Islander (Asai 2020).

Team Science Training

Each CURE had an instructor and graduate teaching assistant, for a total of three faculty and five GTAs over the two iterations. Two of the faculty participated in an intensive, two-day, interactive professional development course through the American Institute of Biological Sciences in partnership with M. Kathleen Joyce and Associates. This workshop was designed by experts on collaboration and teamwork to provide participants with the knowledge and skills required to become productive and effective members of scientific teams. The topics included:

- What interdisciplinary team science is, and why it matters
- Characteristics of strong, effective teams
- Characteristics of leadership
- Shared goals and objectives
- Facilitating discussions, meetings, agreements, consensus, and disagreement
- Dealing with conflict
- Making team decisions

To introduce team science to the teaching assistants, three 1- to 2-hour workshops were held, in which GTAs were taught principles of effective teams, conflict resolution, and strategies for helping students become a productive team. Team science workshops were provided to GTAs throughout the semester to help them promote the development of team competencies with their undergraduates through the incorporation of team-building activities and tools to enhance team communication and function. These formal workshops were supplemented with multiple sessions for instructors and GTAs to share their experiences and learn from each other. Team science training materials are available online (ECU Digital Market n.d.).

Each CURE had students organized into teams of three to five people. To facilitate the development of effective teams, GTAs were encouraged to lead team-building exercises early in the semester. The faculty or GTAs also presented students with information on team science and why it was important, and informed the students that one course objective for their CURE was the development of team competencies. In addition, teams were tasked with creating two tools, a communication plan and a research plan, that reflected the process that productive teams use (National Research Council 2015). During the first week

TABLE 3. Communication Plan Guidelines for Students

Elements	Low performing or less productive teams	High performing or more productive teams
General principles for effective, inclusive team communication	1 principle	4 or more principles
Mode of communication (text, Slack, teams, email, other)	Just identified	Multiple modes identified for specific purposes
Specify a frequency for communication and time to respond	Simple response, weekly or during class	Includes quality or details of communication expectation and specific time to respond
How will you handle conflicts that arise between team members?	Talk to teaching assistant or instructor	Multistage plan for addressing conflict within the group
Course or project-specific criteria	Not considered	Identifies an issue or issues specific to this course and/or project

TABLE 4. Research Plan Guidelines for Students

Elements	Low performing or less productive teams	High performing or more productive teams
Explained overall goal or question, with hypothesis	Goal simply stated	Goal and hypothesis articulated, with smaller goals articulated in plan updates
Defined research tasks	Tasks generically listed	Tasks of higher detail, assigned to team members, rotated among team members
Reflected on research tasks	Partial or unclear reflection or results	Complete and clear reflection and results
Included steps for the future	Unclear future steps or simply listed	Next steps complete and clear, with future direction for the following lab period and future lab periods
Updated regularly	Plan not updated/updated sporadically	Plan updated regularly for all elements of research plan

of the CURE, teams were tasked with developing a communication plan (CP), which they would amend as needed throughout the semester (see Table 3). This exercise made students think intentionally about the expectations they had for their team and acceptable communication behaviors (a known best practice from the science of team science).

The teams created an initial research plan (RP) once they had been introduced to the research goals for the CURE (see Table 4). This initial RP asked the teams to identify the overarching goal of the project to ensure that members of the team shared the same mental model of the research. Teams were instructed to look at their RP regularly (generally weekly) to add specific tasks as they began their research. For example, the RP included information on the necessary week-to-week work and the assignment of which team member was responsible for which task, by what date, to ensure that each student had a way to contribute meaningfully to the work and to aid in accountability (another known best practice from the science of team science).

Research Instruments

Scoring

Rubrics were developed to score the team communication and research plans. The rubric items were developed from the elements of an effective communication plan (Table 3) and the elements of an effective research plan (Table 4). To establish validity and reliability for the scoring, two researchers scored a subset of the communication plans. For the communication plans, the researcher scores resulted in a kappa of 0.77, indicating substantial agreement. For the research plans, the researcher scores resulted in a kappa of 0.92, indicating near perfect agreement.

Writing Prompt

Tripp and Shortlidge (2019) developed the Interdisciplinary Science Rubric (IDSR) to score student responses to a writing prompt that explicitly required students to identify disciplinary experts needed for a project. This rubric had 4 subscales: Objective, Disciplinary Grounding, Integration, and Broader Impact. Each item was assigned a score between 0 and 3, in which a 0 was considered naive, 1 was novice, 2 was intermediate, and 3 was mastery. A modified version of one of the suggested writing prompts (Figure 1) was used to determine student understanding of the characteristics of effective teams and the value of working with people from other disciplines to solve problems. High-quality responses to this prompt included an explicit discussion of the role each discipline played and how to facilitate collaboration between experts from different disciplines (Tripp and Shortlidge 2019). Students in the environmental engineering (2021 and 2022) and the geological sciences (2022) CUREs were asked to complete the writing assignment as part of their final exam. Students had an incentive to take the assignment seriously as it was worth 40 percent of their final exam grade. A subset of the responses to these prompts (five from engineering and five from geology) were scored by two researchers applying the IDSR rubric (Tripp and Shortlidge 2020). A kappa score of 0.85 was achieved, indicating substantial agreement between researchers. One researcher then scored the remaining student responses. A Kruskal-Wallis test was used to determine if there were significant differences in the scores among subscales. The scores for the two courses from which there was writing prompt data were examined separately. There was no writing prompt data from the biology CURE, because this prompt underwent pilot testing in 2021 only in the environmental engineering course. It was then expanded in 2022, when the biology CURE was not offered.

Discussion

What are the barriers to this model of cross-disciplinary collaboration?

This model of linking CUREs in three different disciplines provided a model for students to have meaningful interaction with students who had different areas of expertise than they did. The joint meetings of the CUREs were facilitated by the fact that the courses had at least one day a week on which they had the same course meeting time. Scheduling this one hour weekly proved more difficult than anticipated due to instructor course load, space availability, and schedule conflicts for majors in each discipline. In addition, all three CURE instructors directed programs within their discipline, and the biology instructor directed the interdisciplinary graduate program. These administrative duties came with some teaching release time that impacted the frequency with which they could offer their CURE. This resulted in biology not being included in the second iteration.

The cross talk between students in different courses that was facilitated by a shared document and by midterm presentations was highly beneficial but would have benefited from additional opportunities for in-person discussions (see Figure 2). Therefore, future iterations will also incorporate more explicit in-person opportunities for students to meet with their colleagues from the other CUREs.

In the two iterations of these CUREs, faculty struggled to find a balance between allowing the students to identify their own project and providing guidance. All three courses devoted the first four weeks to disciplinary content instruction. In microbial ecology the first month was spent learning foundational topics and links to ecosystem processes that humans value as services. The geology and environmental engineering CUREs were used to lay a foundation for the research with instruction that developed a basic understanding of groundwater and its influence on streams while also providing opportunities for hands-on research. The content helped students develop a research question, but this delayed starting the research until well into the semester. Future iterations of the project will identify a single project as the focus for all three classes.

Can the principles of team science communication, planning, and conflict resolution be added to CUREs through specific course elements?

Students in all course sections successfully created communication and research plans on their teams. The communication and research plan scores for each team are presented in Table 5. Using a median split, CP scores were divided into low and high scores. Table 6 provides examples of the low and high scores for each criterion. Although there is a range of scores for each criterion, the students and the instructors embraced this element of team science fully. Students reported that the CP was critical to their work, and faculty reported that issues of team dysfunction were minimal compared to prior semesters.

Teams met regularly and updated research plans to adjust short-term goals and team member responsibilities and used a shared document for ongoing notes, questions, and updates on progress. During this time, students had access to computational tutorials to learn how to manipulate data and to conduct analyses on environmental and microbial data. The beginning of each lab session was used to remind students of where they were in the research process and discuss potential for data sharing. Their periodic updates to this RP provided an opportunity for students to reflect on where they were in the research process, what they needed to do next (even if it differed from what they had previously anticipated), and how each team member could meaningfully contribute to the research.

The research plans were intended to be living documents, updated regularly with details on tasks completed, task assignments, results, reflections, and future plans. However, the documentation of research or project activity was not always robust, generally due to time limitations. Most of the elements in these initial iterations of the research

FIGURE 1. Writing Prompt Completed by Students in Engineering (2021, 2022) and Geology (2022)

Background: A coastal town in Louisiana would like to clean up a contaminated waterfront area and make it a park with a large portion dedicated to community vegetable gardens. The site has a long history of contamination due to industrial run-off and to make matters worse it is now also contaminated with light, sweet crude oil from the BP oil spill. To begin the clean-up process they analyzed soil samples from various locations in the park and along the shoreline. Not only did they find that soil samples still have a great deal of the oil from the spill, but also substantial amounts of alkyl halides. Committee members who have been hired to oversee the project would like to apply "green" methods for cleaning up the site and by reducing the concentrations and/or the toxicity of chemical compounds and restoring natural conditions.

Your Assignment: The city hires you, a lead environmental scientist with a PhD in microbiology, to craft a long-term plan for cleaning up the site. Craft a plan for the city and be sure to be specific regarding the science used to address the problems. Also be sure to include how you will approach your task and who should be involved (e.g., tools, techniques, procedures, individuals, groups).

What information will be needed to develop your plan? What team will you need to effectively carry out your plan? Craft your essay as a proposal to the city, outlining your program and the team that will help you best accomplish the task. **Make sure to use the RUBRIC below when writing your essay!!**

FIGURE 2. Example of Exchange Posted on Document Shared by the Three CUREs

Question from Microbial Ecology: There's obviously a meaningful difference of microbial diversity between areas with differing soil moisture, but will it be a measurable difference in water level between our plots at such a small spatial scale?

Answer from Environmental Engineering: We will be able to see a measurable difference in water level between the plots near the ditch and the plots away from the ditch. We should have graphs showing this after Wednesday, April 7.

plans were scored present or absent, except the criteria of defined research tasks and discussed next steps and future directions**.** These items were scored based on three levels: complete/clear, partial/unclear, and none. Below are exemplars scored as complete/clear:

- Defined research tasks: Identify which contaminants will be analyzed; observe water usage rates at different times; observe steam levels for baseflow/stormflow; identify soil capacity to move water; know levels of groundwater; observe seasonal changes in stream and groundwater levels. [Engineering]
- Discussed next steps and future directions: This data will help us create a contour map that will estimate the water table and show which way the water is flowing and how much of a difference there is in water table height. [Engineering]

Additional time allocation by the instructors would allow teams to create more detailed research plans. Emphasizing reflection by the teams on where they were in the research process and what their next steps should be would be particularly beneficial. The creation of the research plans were successful, however, in formalizing research goals and allowing students to intentionally plan a role for each team member.

Do students develop an understanding of collaboration across disciplines in research?

The mean scores and standard deviation for the ISDR writing prompt are presented in Table 7. The disciplinary grounding and objective subscores were significantly higher for engineering than the broader impact and integration subscores ($X^2 = 50.7$, $p < .0001$; see Table 5). The objective and disciplinary grounding average scores were between intermediate and mastery levels, and the broader impact and integration average scores were between novice and intermediate for engineering. For geology, the objective scores were significantly higher than the integration scores ($X^2 = 21.0$, $p = .001$; see Table 5). The objective, disciplinary grounding, and broader impacts average scores were between novice and intermediate in this course, and the integration average score was between naive and novice.

TABLE 5. Communication Plan (CP) and Research Plan (RP) Scores

Course	Team	CP score 24 pts	CP score %	RP score 14 pts	RP score %
First Iteration					
Microbial ecology	1	18	75%	9	64%
	2	19	79%	10	71%
	3	19	79%	9	64%
	4	14	58%	11	79%
Environmental engineering	1	13	54%	6	43%
	2	9	38%	10	71%
	3	9	38%	6	43%
Geology	1	15	63%	5	36%
Second Iteration					
Environmental engineering	1	17	71%	9	64%
	2	17	71%	6	43%
	3	15	63%	8	57%
Geology	1	15	63%	5	36%
	2	19	79%	8	57%
	3	8	33%	8	57%

The "green" restoration used in the writing prompt was not taught explicitly in either class but was implicit in the Town Creek project. The students were expected to find information for these processes on their own. Without explicit prompting by the instructor, students fared best on the objective and disciplinary grounding scores, overall. Integration was the lowest score, with some students neglecting it altogether. Future work will determine if increased levels of in-person collaboration between students in different CUREs will lead to higher integration scores.

Components of the integration of team science into these CUREs had direct relevance to the Objective, Disciplinary Grounding, and Integration subscales of the writing prompt rubric. For example, the research plans the students created were intended to help clarify the purpose and approach the team would use for their research. As the Objective subscale had one of the higher scores on the rubric, this tool may have helped show students how teams come to a shared understanding of their proximate and ultimate tasks. These scores could still be improved with a greater emphasis on using the research plan for these purposes.

Limitations

This manuscript presents the initial design and implementation of a model for course-based undergraduate research across disciplines. Although the evidence to date supports the continued refinement of this model and further integration of team science into the CUREs, there are a number of limitations to the findings. The first iteration took place in the spring of 2021 as the university was returning to in-person instruction. Faculty used a blend of virtual instruction time and in-person fieldwork. The joint meetings for the students across CUREs were conducted online, so opportunities for social interaction were limited. The second iteration in the spring of 2022 had fully in-person instruction, however the microbial ecology course was not offered that semester and only data from the prior year's microbial ecology class was available to the geology and engineering students. Finally, there were no comparison groups because these courses were each taught only in one section per year. The CUREs with the integration of team science were the only sections for each of these courses.

Implications

Overall, this project investigated a preliminary model for exposing students to research across disciplines using three CUREs that all focused on a complex, real-world environmental problem. The general emphasis on team science and interactions between the three CUREs was intended to produce improved understanding of the value

TABLE 6. Communication Plan Scores (*N* = 14)

Criteria	Low-scoring exemplars	Lower	Upper	High-scoring exemplars
Principles for effective, inclusive teams	Take notes and be open minded. [Biology] A platform for the team to share and be able to join meetings on, participation from each group member, and the development of a detailed schedule of when tasks should be completed. [Engineering]	0 - 5	5 - 7	Clarity: Team members will discuss the project in a clear and effective manner. Timeliness: Team members will respond to electronic communications in a timely manner. Respectfulness: Team members will communicate in a respectful manner. [Engineering]
Communication modes	Microsoft Teams (chat and video messaging). [Biology] The main modes of communication will be email, text, and Teams. [Engineering]	2 - 4	3 - 5	Microsoft Teams will be the primary method of sharing data among the groups; however, all group members are in a group chat for quick communication by text. Emails will also be sent for more pertinent discussion or communication with [instructor]. [Geology]
Communication frequency	Group will meet once a week. [Engineering] We will communicate on an as-needed basis. [Geology]	0 - 3	1 - 4	We should respond within 24-48 hours for any questions. Let the group know that you are unavailable, if possible, within 24 hours. This group will meet every Thursday from 2-3pm. [Biology]
Conflict resolution	We will talk it out and if that doesn't work, we will talk to the instructor. [Engineering]	3- 6	3 - 5	Discuss the issue, develop solutions, choose a solution to alleviate the conflict. Address conflicts within the group first with respectful communication as outlined above, worst case scenario communication with [instructor] as a mediator. [Engineering]
Course or project-specific criteria		0	0 - 1	Our group will be sharing resources, individual and team work as well as class data in a Microsoft Teams group. [Engineering]
TOTAL		8 – 15	17 – 19	

of teams and having input from diverse team members, ideas related to the Disciplinary Grounding and Integration subscales of the writing prompt rubric. The students did not appear to fully internalize these ideas, especially related to integration. The novice or naive responses in disciplinary grounding by the geology students may have impacted their integration scores. As integration is a high-level cognitive task, it is not surprising that students would need additional time and support to improve. From the joint CURE meetings and shared documents, it is clear that students were sharing data and that their final project relied on data from the other disciplinary courses. Future iterations of these CUREs will provide additional emphasis on the cross-disciplinary structure and in-person interactions between courses to determine whether it helps students improve their integration.

Learning how to conduct science on a team is essential, as students are entering a world in which large-scale societal, health, and environmental challenges await (Love et al. 2021). Developing plans for communication and teamwork are not typically addressed in traditional undergraduate lab courses. By encouraging CURE students to develop written plans about how to communicate with each other and how to accomplish research goals with their teams, key elements of team science were embedded into the CURE experience.

At the undergraduate level, students majoring in science and the related STEM disciplines rarely participate in authentic research activities as part of a science team. At the graduate level, some students participate in science teams and groups, but continue to receive little or no guidance or instruction on how to be the effective member of a team. The integration of team-based research opportunities into academic programs may help students develop a deeper conceptual understanding of topics and methods for solving problems within and across disciplines, while simultaneously gaining skills that support inclusion of different perspectives and capabilities for teamwork.

TABLE 7. Scores on Student Responses to Writing Prompt

		Environmental engineering *N* = 21		Geology *N* = 10	
Category	IDSR rubric criteria	Mean	SD	Mean	SD
Objective	1.1 Purpose: What is the problem and task? Provide background information to introduce and frame the problem/task.	2.10	0.77	1.90	0.83
	1.2 Approach: How will you approach the problem/task? Formulate a plan that clearly outlines your approach (steps/procedures).	2.17	0.81	2.30	0.64
	1.3 Credibility: What sources will you include? Use peer-reviewed articles and/or other supporting information that are relevant to the problem/task.	2.36	0.91	1.50	0.67
	Average objective score	**2.21**	**0.65**	**1.90**	**0.62**
Disciplinary grounding	2.1 Disciplines/experts: What disciplines and/or experts will be involved? Include two or more disciplines and/or experts in your approach to the problem/task.	2.81	0.39	1.70	1.42
	2.2 Disciplinary reasoning: Why are you including each discipline and/or expert? Meaningfully explain the reasoning behind the use of each discipline and/or expert.	2.17	0.92	1.30	1.27
	2.3 Methods and tools: What methods will each discipline and/or expert use? Include techniques/procedures/tools from contributing disciplines and/or experts.	1.98	1.05	0.60	0.92
	Average disciplinary grounding score	**2.32**	**0.69**	**1.20**	**1.11**
Integration	3.1 Leveraging disciplines/experts: How will each contributing discipline and/or expert build off each other to effectively address the problem/task in a way that one contributor cannot? Specifically address how each discipline's and/or expert's contribution (knowledge/methods) will be useful for the other disciplines and/or experts.	1.24	0.92	0.50	0.92
	3.2 Collaboration: How will you foster successful partnerships? Include and explain two or more ways to build community and respect among different disciplinary team members (e.g., establishing common ground and language, overcoming different perspectives, etc.).	0.90	1.06	0.40	0.92
	Average integration score	**1.07**	**0.93**	**0.45**	**0.91**
Broader impact	4.1 Societal impact: How does your proposed solution impact society? Include why your solution is locally and more broadly relevant to society and what/who will be affected (e.g., economics, politics, social, health, etc.).	1.62	0.84	1.30	1.00
	4.2 Limitations: What are the potential limitations to your plan and how will you overcome these barriers? Forecast possible limitations of your plan and provide resolutions.	1.02	1.05	0.90	0.94
	Average broader impact score	**1.32**	**0.86**	**1.10**	**0.92**
	Mean score out of 3 possible points	**1.73**	**0.61**	**1.16**	**0.71**

Data Availability

The data are not publicly available.

IRB Statement

This is an exempt study, UMCIRB: 20-000808.

COI Statement

The authors have no conflict of interest to declare.

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