

Fostering Student to Student Collaboration Across Institutions in a Protein Centric CURE

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Abstract

Collaboration is an essential component of research because it allows scientists to share expertise and tackle difficult scientific questions. While many undergraduate science courses include inquiry-based or authentic research projects, opportunities for collaboration outside of the classroom are rarely provided. To address these limitations, we developed a set of course activities and assignments to implement student-to-student collaboration between institutions in a protein-centric CURE. The activities were tested in three courses: an upper-level biochemistry class at primarily undergraduate institution, genetics and an introductory biology class at a community college. A survey was created to assess students' perceptions of collaboration and the impact of the activities on their scientific and communication skills. The results indicated that an important component of students' experiences was the assignments designed to guide participants through the collaboration activities. The survey findings suggest that student-to-student collaboration improves science communication skills and motivates students to be more careful with experimental design and data collection.

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BACKGROUND

Scientific research is increasingly collaborative across institutions, driven by increased technical specialization and the capacity for virtual meetings (1, 2). The number of collaborative scientific papers between different institutions has grown substantially since the 1970s, often resulting in more impactful papers (3). To prepare students to join a workforce that expects cooperation, educators have been adding collaborative experiences to courses over the last few decades (4–6). Course Undergraduate Research Experiences (CUREs) are a well-established approach to introducing research practices to undergraduates, emphasizing collaboration as a key pillar, along with discovery, iteration, relevant work, and the use of scientific practice (7). Focusing on in classroom collaboration can increase students' sense of ownership of work (8, 9). A number of CUREs have been developed that link courses within the same department or school (4, 5). This approach involves having students from the same department or institution collaborate on a common or related course-based research projects.

Despite these advantages, few studies examined the benefits of cross-institutional collaboration among students from diverse academic backgrounds (3, 10–12). Our recent work, exposed students to collaboration with an outside faculty member from another institution (12) and showed such collaboration helped

students' ability to design experiments and caused positive shifts in attitudes towards sciences. Importantly, this study occurred in a diverse community of STEM disciplinary faculty from 2- and 4-year institutions across the country, illustrating that establishing collaboration in an undergraduate lab setting is feasible.

While instructors recognize the value of collaborations, organizing and developing activities to promote cross-institutional collaborations can be difficult and time-consuming for all parties involved (13–15). To address these limitations and promote student-to-student collaborations across diverse academic institutions, we developed a set of assignments and a survey that can be used to establish student-student collaborations. We investigated the impact of these activities on students' learning. The assignments and collaboration activities underwent three iterations of testing in a collaborative biochemistry CURE involving participants from a community college and a 4-year primarily undergraduate institution.

CROSS-INSTITUTIONAL STUDENT-STUDENT COLLABORATION: DESIGN AND IMPLEMENTATION

Course Details

Exercises and assignments described here were conducted by an introductory biology and a genetics class at a community

college (CC) and an upper-level biochemistry course at a primarily undergraduate institution (PUI) for three years. Students and faculty involved were members of the Malate Dehydrogenase (MDH) CURE community working on MDH research projects as part of their laboratory component (16), which covered fundamental biochemistry concepts such as protein structure and function, protein purification and gene expression techniques, literature searches, hypothesis development, experimental design, and scientific communication.

Instructors' Roles

Prior to beginning the project, instructors prepared for the collaborative activity by selecting the overall themes for students' research projects by choosing the region of the protein that would be studied through mutagenesis and enzyme assays, discussing the timeline for the student meetings, and coordinating at least two visits (virtual or in person) with the partner institution.

During the student-to student collaborative project, the instructors guide students through hypothesis development and experimental design assignments. They coordinate selection and pairing of student groups amongst participating classes based on the students' interests and research topics and, if students have difficulties contacting or communicating with the collaborative team, they reach out to participants to ensure timely responses and effective communication across institutions.

Selection of "Student Groups" to Support Learning Through Collaboration

During the three-year trial period, the participants in the collaborative CURE activities were students taking an intermediate Biochemistry course at a primarily undergraduate institution ($n = 28\text{--}32$ students per year), an Introductory Biology ($n = 18\text{--}24$ students per year), and a Genetics class at a community college ($n = 8\text{--}12$ students per year). Students were divided into groups of three within their classes based

on the criteria established by the instructors for forming laboratory teams. In the biochemistry class, for example, students completed a survey through the CATME Team Maker tool and were assigned to teams based on responses about leadership preferences, disciplines of interest, academic skills, and performance in prerequisite courses (17). Students in the community college courses were allowed to self-select into teams. Depending on enrollment, each class at the participating institutions had five to six teams. The instructors ensured that there were an equal number of groups for the collaborating courses, which sometimes resulted in the formation of groups of two or four students to obtain an equal number of teams. Prior to the first collaboration meeting, guidelines and norms for group work and collaborative interactions were set to ensure students had equitable responsibilities in terms of expectations and deliverables during the collaboration activities. In order to ensure equitable access to content and activities, students were encouraged to organize meetings in the mode most accessible to collaborative participants, whether virtual or face-to-face. For inter-institutional collaboration, instructors paired groups that were working on the same mutants or shared a common interest in studying a specific mutation type or enzyme parameter, such as specific activity, K_m , or substrate specificity. Students typically chose projects such as evaluating alternate substrates and potential inhibitors with wild type and mutant MDH enzymes, determining kinetic parameters, and examining the impact of different amino acid substitutions at the same position in the MDH catalytic loop.

Collaboration Meetings

Students taking part in the student-to-student collaboration were required to schedule two meetings, one close to midterm and another one towards the end of the semester. These two meetings were the minimum required for the activity to be considered collaborative. Students have the freedom to schedule more meetings if needed. Participants were given the option of meeting in person or virtually but all students decided on virtual meetings due to the availability of the scheduling options.

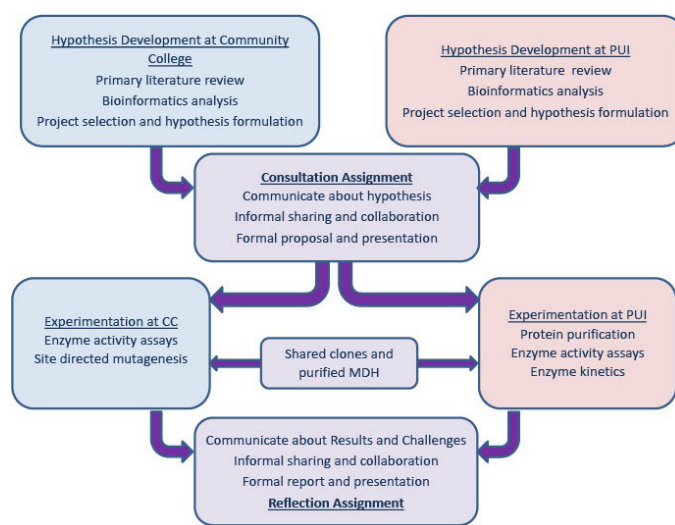


Figure 1. Framework for student-to-student collaboration. The framework, organization and activities conducted in the collaborative Malate Dehydrogenase (MDH) CURE.

Collaboration Activities

Throughout the three-years of testing, the collaborations involved a variety of activities including sharing research materials such as strains, genetic constructs, and purified proteins. For instance, during the first year of collaboration, students in the biochemistry class purified wild type and mutant proteins and shared with the students in the introductory biology class at the community college who performed activity assays. During the next two iterations of the collaborative project, students in the genetics classes at the community college constructed mutant enzymes that were shared with students in the PUI for protein purification and activity assays. Students also provided feedback on hypothesis development and methodology to their collaborators. Toward the end of the semester, the teams compared results and discussed the difficulties and challenges encountered during the project (Figure 1).

Collaboration Assignments

Prior to the first collaboration meeting, each team reads a review article and completes an assignment on the structure and function of malate dehydrogenase. The instructors assess the students' answers and guide them through a class discussion about the relevance of studying the effect of mutations on enzyme activity. Following the discussion, each laboratory team is instructed to start thinking about potential mutations and their impact on enzyme activity. Students use molecular visualization and bioinformatics tools to focus on a specific amino acid, analyze its properties, and develop a hypothesis about how changes at the chosen site will affect the activity of the enzyme (16). To support the hypothesis development part of the project, all teams complete the "Thinking about Your Hypothesis" worksheet (Supporting File S1) designed to help teams formulate hypotheses using a standard format that would guide their discussions during the collaborative meetings. Students at each participating institution then move to the first collaboration task, designated as "Consultation 1 (Supporting File S2)."

Assignments

Consultation 1

A few weeks prior to this assignment, students have a mini lecture and a discussion on hypothesis development with the course instructors. This exercise is designed to provide guidance on how to write a good hypothesis, not for instructors to revise or evaluate students' hypotheses.

The first collaboration assignment (Supporting File S2) was designed to get students to know their cross-institutional collaborators while learning about their hypotheses and experimental designs. Students were instructed to set up a meeting with their peers and answer some informal questions to learn more about their backgrounds and research interests. As part of this first assignment, they gave brief presentations during which they discussed their hypotheses and requested feedback. Students are given guided questions and suggestions on what to include on the slides of their first presentation to help them with the first consultation assignment (Supporting File S3). This part of the collaboration involves students critiquing each other's hypotheses while providing suggestions for improvement. Students frequently revise or rewrite their

hypotheses in response to input from collaborators; however, revising hypotheses is not required. Faculty members are not involved in these group discussions or the students' conversations. Following the first consultation, students can finalize their hypotheses and discuss them with the instructors before they carry out the initial set of experiments at their home institutions. They collect data and interpret their results to prepare for the next collaboration meeting, which usually happens six weeks after the first consultation.

Collaboration Reflection

The second collaboration assignment, titled "Collaboration Reflection," focuses on communicating and discussing the projects' outcomes as well as reflecting on the benefits of collaboration (Supporting File S4). In their independent classes, students work on a final presentation and a written report describing the research results, limitations, and future work. During the second collaboration meeting, the teams informally present their results and discuss whether or not the hypotheses were supported or refuted by the data collected. They are also encouraged to discuss the challenges and limitations of the research and reflect on how collaborating with another team of students helped improve their communication skills and understanding of the research project.

Students' Perceptions of Inter-Institutional Collaboration

A survey gathered information about students' perceptions of the impact of their collaboration during the CURE (Supporting File S5). On a scale of 0–3, participants rated how collaboration impacted various aspects of their course experience (Table 1). In accordance with Federal Regulations for review of research protocols, the Institutional Review Boards of the participating institutions, determined that the survey protocol used in this study qualified for an Exempt Determination, under federal guidelines 45 CFR Part 46.101(b), Category #1.

Forty-eight students responded to the survey during the fall semester of 2022. Out of the 48 participants, 24 were from the Biochemistry class at the PUI, and 24 were from the Community College (6 from Genetics and 18 from Introductory Biology). A large majority (76%) thought the assignments were critical or important in organizing the students' meetings and collaborative exercises. 62% indicated that collaboration was critical or important in encouraging them to be cautious with experimental design and data collection. Students reported that collaboration had an impact on their scientific communication skills, with 56% indicating that this aspect of collaboration was critically important or important to their learning experience (Table 1).

Working with peers from a different institution, according to 79%, had some impact on how satisfied they were with the courses they were taking, had some bearing on their motivation to "keep better records of experimental procedures" (75%) and their ability to "learn biochemistry concepts related to the project" (80%) and thought these aspects of the project were important to their academic experience (Table 1).

Participants were also asked whether collaborating with students from another institution gave them a sense of

Table 1. Lesson timeline.

Survey Question*	Critically Important (3)	Important (2)	Somewhat Important (1)	Not Important (0)
How do you think that collaboration with a different institution helped you improve your scientific communication skills?	10%	46%	38%	6%
How did collaborating with students from another institution affect your understanding of biochemistry concepts relevant to your research project?	13%	15%	52%	20%
Did working with students from another institution encourage you to be more cautious in your experiments and data collection?	35%	27%	24%	14%
How did the collaboration assignments assigned by your instructors assist you in organizing meetings with student collaborators from other institutions?	27%	49%	20%	4%
Do you think that collaboration helped you keep better records (notebooks, notes) of your experimental procedures and data collection?	17%	18%	40%	25%
How do you think that collaboration with a different institution affected your satisfaction with the course?	8%	25%	46%	21%

* The total number of students that participated in the survey during the fall semester of 2022 was 48 ($N = 48$). $n = 24$ for the PUI Biochemistry class, $n = 6$ for Genetics, and $n = 18$ for the Introductory Biology course at the Community College.

belonging. In total, 60% indicated that working on the same project with students from a different institution gave them a sense of belonging. One student commented, *"It was cool to talk to people of different environments who are studying similar things to me,"* while another participant noted, *"It allowed my group to bounce ideas off of another group, and thus we were able to edit our thoughts concerning our research project."*

The survey also revealed which aspects of inter-institutional collaboration students considered to be the most positive or beneficial, including: practicing asking and answering questions, getting feedback, brainstorming, helping each other in times of confusion, sharing different perspectives, meeting new people, and networking. In their comments, a student stated, *"The most positive aspect was being able to see what another group is doing with their mutant MDH strains and seeing if their hypotheses were supported or not."* Other participants noted that a beneficial aspect was *"hearing the feedback each time from both sides, everyone was respectful, and we all had a genuine interest in each other's projects."* Many stated that having different perspectives or angles on the project they were doing was a positive aspect of collaborating. *"I enjoyed hearing the perspective of students more focused on biology rather than chemistry than I am used to."* Finally, when asked whether collaboration should be done in other courses, 75% of students answered "yes" and reiterated the benefits of these activities. One student commented, *"I think collaborations with other schools could be a really cool way to become part of a scientific community and get more feedback on our work,"* while another stated, *"I think it was a very cool aspect and made it feel like working in a professional field."*

LESSONS LEARNED AND RECOMMENDATIONS FOR IMPROVEMENT

After three years of conducting the student-to-student collaboration, we gained many helpful insights with each

iteration. For example, it is critical to compare course syllabi to ensure that all participants have adequate time to learn about the project's background and work on hypothesis development prior to the first meeting. Additionally, instructors should schedule class time for student meetings; ideally, classes should be offered on the same day and at the same time to encourage meetings and communication across teams. Meeting outside of class hours was difficult and frustrating for a few collaborative groups. Finally, instructors should follow up on the status of the collaboration and team meetings. Students may neglect to meet and believe it is sufficient to exchange emails or text messages instead. Instructors must establish clear expectations for meetings and collaboration tasks.

We recommend that instructors who are implementing collaboration into their CUREs consider the duration of the CURE and the collaboration activities among the participating courses. Some classes do brief (modular) CUREs, while others conduct a research project throughout the semester. To make collaboration meetings and activities interesting and fruitful, the scheduling of the collaboration activities must be coordinated with the course's syllabus. If collaborative teams are meeting virtually, we recommend that students record the meetings. The recordings can be used as an artifact to assess collaborative and communication skills. These could also be used to assess students' virtual meeting etiquette, which is defined as set of guidelines that individuals must follow during a virtual meeting with co-workers or collaborators.

We also solicited student feedback on how to improve inter-institutional collaboration. One of the main takeaways from the responses was that the collaborative courses should all have the same meeting times to make scheduling and classroom visits easier. Some students expressed disappointment when their collaborative team skipped a meeting or did not participate as actively in the research discussions. Many expressed interests in meeting more frequently throughout the semester to collaborate on experiments and calculations. This inter-

institutional collaboration was conducted among students from various institutions (PUI vs. CC) and academic levels (First years/Sophomores vs. Juniors/Seniors). Some participants stated that they would have preferred to collaborate with a class at the same or higher academic level. Others, enjoyed sharing information with and teaching their junior peers.

CUREs make it possible to bring authentic research experiences to large populations of undergraduates with diverse backgrounds and there is a need to continually enhance this model (7, 9). Collaboration is essential in the current research environment and therefore should be incorporated into CUREs to provide our students with the most realistic research experience. Technological advances and increased familiarity with meeting virtually, make student collaboration feasible for any undergraduate institution. This report outlines a roadmap for instituting student-to-student collaboration across different institutions and provides evidence that these assignments increased gains in organization, preparation and communication of the participating students. Future studies should focus on how to best organize these collaborations to optimize student motivation/engagement in the project while assessing what aspects of the collaboration (How many times should the students meet? how much should the faculty be involved?) are most critical to the experience.

SUPPORTING MATERIALS

- S1. Student-to-Student Collaboration in CURES – Hypothesis Worksheet
- S2. Student-to-Student Collaboration in CURES – Assignment 1_Consultation
- S3. Student-to-Student Collaboration in CURES – Hypothesis Discussion Guide
- S4. Student-to-Student Collaboration in CURES – Assignment 2_Collaboration Reflection
- S5. Student-to-Student Collaboration in CURES – Collaboration Survey

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