Engaging Undergraduate Students in Authentic Research in the Inorganic Chemistry Laboratory Course

Arpita Saha
Georgia Southern University

Leah Williams
Georgia Southern University

Author Biography

Dr. Arpita Saha is an Associate Professor in the Department of Chemistry & Biochemistry at Georgia Southern University (GSU). She conducts research in Bioinorganic Chemistry, Magnetic Materials, and Environmental Chemistry and teaches courses for freshmen to graduate students. She serves on the leadership committee for the College of Science and Mathematics' Diversity & Inclusion Collaborative, Alliance of Women in STEM, developing Freshmen Research Program at GSU. She organizes workshops on Inclusive Teaching Practices in the classroom and empowering underserved groups in STEM. She engages students in scholarly research pursuits via classroom teaching. Dr. Saha is the recipient of 2021 USG Hall of Fame Faculty Award.

Dr. Leah Williams has a doctorate in Chemistry Education with ten years of experience conducting STEM education research. Her research interests include student resource use, open-education resources (OERs), and course-based undergraduate research experiences (CUREs). She is a lecturer in the Department of Chemistry & Biochemistry at Georgia Southern University and teaches Principles of Chemistry, Survey of Chemistry, and Professional Science Communication.

Introduction

Several studies have established the positive benefits of engaging undergraduate (UG) students in authentic research experiences (Russell, Hancock, & McCullough, 2007; Williams & Reddish, 2018). UG students often participate in multi-semester research opportunities (capstone project/research credit) with a faculty member for which they must qualify/wait for an available spot in a research group. By integrating research into a one-semester teaching lab using Course-based Undergraduate Research Experiences (CUREs), we can remove this barrier to the research experience and provide students of all levels and interests the opportunity to participate in an authentic research program (Bangera & Brownell, 2014).

CURE studies have gained momentum already in the biological sciences and lower-level chemistry courses; however, the implementation is less prevalent in advanced-level chemistry courses (Williams & Reddish, 2018; Pagano, Jaworski, Lopatto, & Waterman, 2018). At GSU, we transformed the Inorganic Chemistry teaching laboratory into a CURE in Fall 2019 and found profound joy connecting teaching pedagogies with research gains. Dr. Saha created a discovery-based learning experience to engage the entire class in pursuing a common research question within the context of the course itself. The experience was quite gratifying as students were genuinely interested in the challenge and pursuit of research. To measure student understanding of the nature of the scientific research process after completing this course, Dr. Williams administered and analyzed a CURE survey previously published (Lopatto et al., 2008).

Goal of the activity

There are multiple benefits of redesigning a traditional lab course with fixed outcomes into a discovery-based lab course. For example, a CURE lab explicitly includes authentic research practices, discovery, collaboration, and iteration (Auchincloss et al., 2014) which often leads to potentially publishable research findings with UG students as coauthors. The goal of this activity was to provide all students, regardless of experience or background, an opportunity to engage in novel scientific research by participating in a CURE lab. We intended for students to gain experience with solving a research problem with potential to publish in an academic journal, synthesizing a variety of scientific data, and understanding the overall research process including grappling with failure.

Description of the activity

Dr. Saha designed and taught the thirteen-week-long laboratory course incorporating an authentic research experience. Students undertook several self-designed research projects to synthesize and characterize transition metal complexes for applications related to medicinal chemistry/material sciences. Each lab section consisted of eight groups of three students each.

During the first week, all students were trained to perform a literature search and underwent safety training. Students were guided to select research topics related to the course where they were assigned one ligand and all student groups designed different types of reaction schemes using different metals and experimental conditions to synthesize novel compounds. This group work provided an opportunity to collaborate intellectually and contribute to the research design and findings afterward.

All eight groups were able to perform experiments, however, given the novel nature of each reaction, their outcomes were varied. These experiences taught them that research is unpredictable, requires critical thinking and troubleshooting. All students were given the opportunity to critically reflect on their data and that of their peers (via Google Drive) during the initial and final presentation weeks. These practices helped students to write a final comprehensive report. An outline of the thirteen-week laboratory course sequence is shown in Table 1.

Table 1. An outline of 13 weeks of the Inorganic CURE lab

Week	**Event**
Week 1	Course logistics & semester plan, safety training, pre-implementation survey
Week 2	Compound plans due; NMR Tutorial
Week 3-4	Synthesis of novel coordination complexes
Week 5-6	Training on instruments: FTIR & UV-Vis spectroscopy, CHN Elemental and Thermogravimetric Analysis
Week 7	Novel compound characterization
Week 8	Initial report due; Present data and analysis
Week 9	Iteration - Repeat synthesis of novel compounds
Week 10-11	Iteration - Characterization of products
Week 12	Oral presentations of data and analysis
Week 13	Final report due, post-implementation survey

The CURE design presented two specific challenges for an upper-level Inorganic Course:

- Each synthesis demanded a unique experimental design that needed to be compatible with assigned laboratory hours.
- All students were required to be trained in specific spectroscopic and solid-state instrumentation techniques which again require careful time management.

Both challenges were addressed via coordinating action plans specific to each group every week before the assigned lab time and running parallel training sessions with help of a teaching assistant and instrumentation specialist. Some groups were excited when they isolated pure crystals and some groups were disheartened for not getting pure products. However, students understood the importance of failure in the research process and learned how to transform that information into a positive experience. Several students approached the instructor asking for additional hours to collect products, take microscopic images of the crystals, or perform additional characterization techniques such as X-ray Diffraction Analysis (XRD). Some groups were able to synthesize novel products and the data will be published in due course in a scientific journal. Some representative pictures submitted by students are shown in Figures 1 and 2.

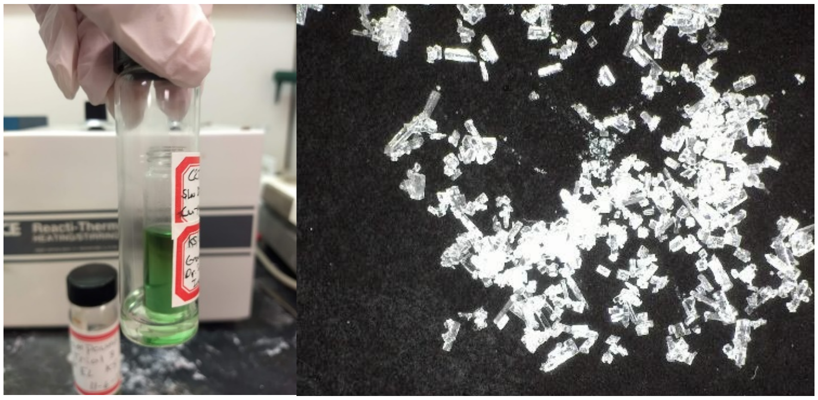

Figure 1. Crystallization and microscopic images of a novel product submitted at the CURE Lab

Figure 2. Crystallization and microscopic images of novel product submitted at the CURE Lab

Reflection

We measured the potential impacts of participating in a CURE on students' understanding of the nature of scientific research. Dr. Williams administered the survey online via Qualtrics at the beginning and the end of the semester as a pre/post-implementation survey. The survey includes questions about the participant's research experience as well as Likert-type items to determine students' perceptions about the CURE and their role in the course.

Of the twenty students that responded to both surveys, 40% never conducted scientific research and 75% planned to attend graduate school (primarily STEM/health-related) after graduation. Over 75% of students also indicated that "getting hands-on research experience" and "learning about science and the research process" were important factors in deciding to take this course.

Based on this information, the CURE course provided opportunities for many UG students to engage in authentic research practices that may not have otherwise done so. The pre-implementation survey (Figure 3) indicated that the majority our students had little to no experience with some features of CUREs such as working on projects "entirely of student design", "in which students have some input into the research", or "where no one knows the outcome" (75%, 50%, and 50% respectively).

We found large reported gains with these last two features in post-implementation survey (70% and 60% respectively, Figure 4). 70% of students also reported much/extensive gains in "working in small groups".

These highlight important aspects of a CURE – discovery and collaboration. When asked about the potential benefits of participating in a CURE, 55% of our students reported large/very large gains in "tolerance for obstacles", 75% in "understanding the research process", and 60% in "understanding how scientists work on real problems" (Figure 5).

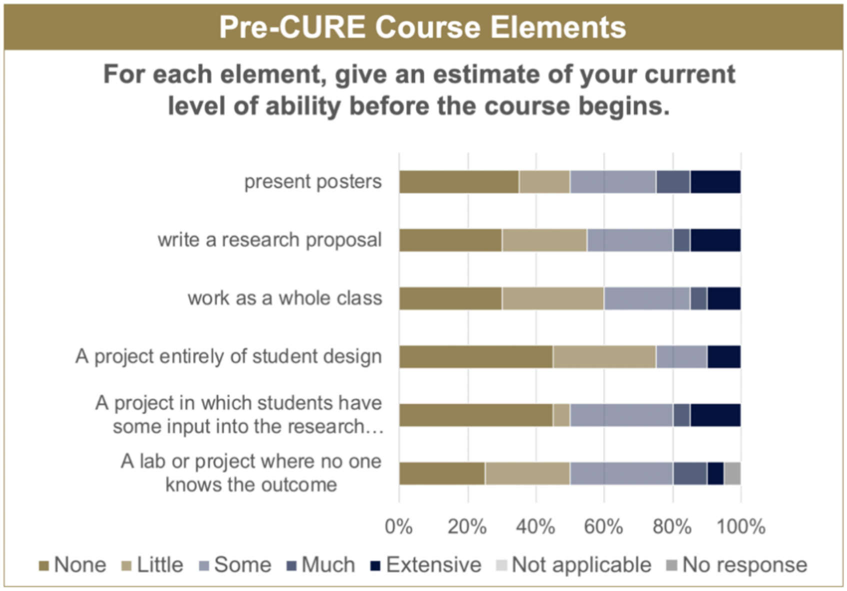

Figure 3. Student reported experience with various course aspects prior to participating in the CURE lab. Only aspects where 50% or more of students reported little to no experience are shown here.

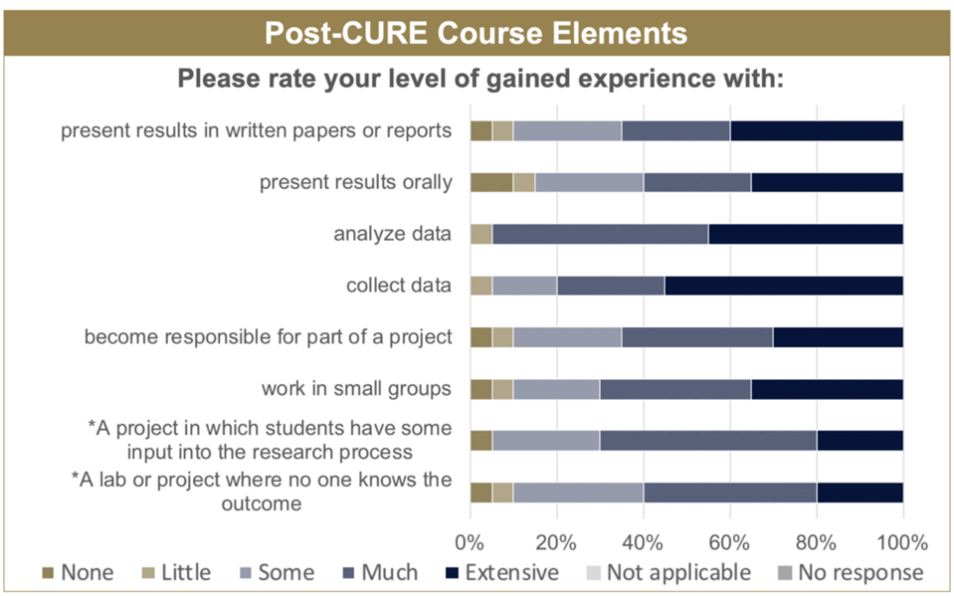

Figure 4. Student reported experience with various course aspects after to participating in the CURE lab. Only aspects where 50% or more of students reported much or extensive gain are shown here.

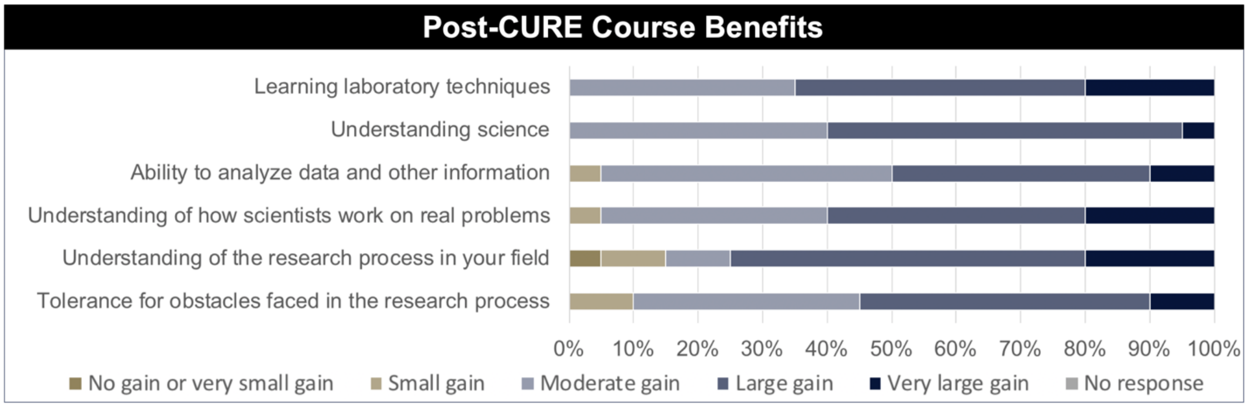

Figure 5. Student reported post-CURE potential course benefits. Only benefits where 50% or more of students reported large or very large gain are shown here.

Overall, this advanced-level CURE lab enabled students to conduct mini-research projects, train in several laboratory techniques and analytical instruments, and practice scientific writing and presentation skills. Despite challenges, developing a CURE lab was a gratifying experience. Students self-reported that they included this CURE experience in their resume as an authentic research experience! Others found the CURE lab to be far more enriching than a traditional lab, stating *"The free-form style of the CURE labs was more intellectually engaging than some of the more structured, guided labs"*.

References

Auchincloss, L. C., et al. (2014). Assessment of course-based undergraduate research experiences: a meeting report. CBE—Life Sciences Education, 13(1), 29-40.

Bangera, G., & Brownell, S. E. (2014). Course-based undergraduate research experiences can make scientific research more inclusive. CBE—Life Sciences Education, 13(4), 602-606.

Lopatto, David, et al. (2008). Genomics education partnership. Science, 322(5902), 684-685.

Pagano, J. K., Jaworski, J., Lopatto, D., Waterman, R. (2018). An Inorganic Chemistry Laboratory Course as Research, Journal of Chemical Education, 95, 1520−1525.

Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research experiences. Science, 316(5824), 548-549.

Williams, L. C., & Reddish, M. J. (2018). Integrating Primary Research into the Teaching Lab: Benefits and Impacts of a One-Semester CURE for Physical Chemistry. Journal of Chemical Education, 95(6), 928-938.