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About the Journal

Science Education and Civic Engagement: An International Journal is an online, peer-reviewed journal. It publishes articles that examine how to use important civic issues as a context to engage students, stimulate their interest, and promote their success in mathematics and science. By exploring civic questions, we seek to empower students to become active participants in their learning, as well as engaged members of their communities. The journal publishes the following types of articles:

- ▶ **Book & Media Reports**
- ▶ **Point of View**
- ▶ **Project Reports**
- ▶ **Research**
- ▶ **Review**
- ▶ **Science Education & Public Policy**
- ▶ **Teaching & Learning**

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Contents

4 FROM THE EDITORS

- 5 SPECIAL SECTION**
TEACHING THROUGH WATER:
SCIENCE, COMMUNITY, AND CIVIC ENGAGEMENT
Davida S. Smyth

- 7 PROJECT REPORT**
The Influence of Effluent: A School and Community-Based
Course Experience in Nature-Based Water Solutions
Alexis D. Denn and Davida S. Smyth

- 14 PROJECT REPORT**
Educating the Educator: Using Agriculture to Build Science
Literacy and Civic Engagement
Christine Girtain and Jane Hunt

- 19 PROJECT REPORT**
Dark Waters: A Case Study
Jeena Joseph

- 24 RESEARCH ARTICLE**
Increasing Students' Scientific Self-Efficacy and Scientific Identity
Through Community-Engaged Microbiology
Kelly Casey Carroll and Lyndsey Blair

- 35 PROJECT REPORT**
The Regenerative Bioscience Open House:
A Promising Community-Engaged Outreach Initiative
Morgane E. Golan, Steven Stice, and Holly A. Kinder

- 49 RESEARCH PAPER**
Evaluating an Integrated Independent Study Model for Science-
Art Collaborations
Kyra R. Shaw, Kathleen Lu, Chloe Hansen, Cathy Chen, Emily Low, Mary
Campbell, Eve Milusich, Bryon F. Tuthill II, Isabela Velasquez, and Jessica Hua

- 69 RESEARCH PAPER**
Cultivating Changemakers: Global Health Education for Global
Citizenship
Katelyn Tenuto, Josie Trainor, and Alicia Wodika



SCIENCE EDUCATION
& CIVIC ENGAGEMENT
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From the Editors

Fall 2026 Issue

In this issue of *Science Education and Civic Engagement: An International Journal*, we are pleased to present three research articles, a project report, and a special section devoted to water. Together, these contributions reflect the many ways educators are connecting science learning to communities, civic questions, and the complex problems students encounter beyond the classroom.

Our special section, introduced by guest editor Davida Smyth of Texas A&M University-San Antonio, focuses on water, an issue that is simultaneously local and global. The three contributions demonstrate how educators can use the water systems and challenges within their own communities as living laboratories. The projects connect students and teachers with wastewater treatment, watersheds, PFAS contamination, and questions of equity and access, while asking learners not simply to acquire scientific knowledge but to use evidence, make decisions, and consider possible responses to real problems.

Our project report, by Morgane E. Golan, Steven L. Stice, and Holly A. Kinder of the University of Georgia, describes the Regenerative Bioscience Open House, an outreach initiative designed to connect secondary students and teachers with scientists working in an emerging biomedical field. Through hands-on experiences and direct interactions with researchers, the program seeks to make advanced science more accessible while supporting teachers, building relationships between schools and the university, and introducing students to possible STEM pathways. The authors also consider lessons learned from the program's initial implementation, including the continuing challenge of reaching students in rural communities.

Our three research articles examine different approaches to connecting scientific knowledge with broader communities and experiences. Kelly Casey Carroll and Lyndsey Blair of Bellarmine University investigate the impact of a community-engaged undergraduate microbiology course in which students partnered with Kentucky Watershed Watch to assess water quality and compare methods of detecting *E. coli*. Their findings suggest that community-engaged learning can strengthen students' scientific identities, self-efficacy,

and laboratory confidence while contributing to community-based environmental efforts.

Kyra R. Shaw and colleagues explore an interdisciplinary independent study model that brought student artists into an ecology research laboratory to create works centered on wetland ecology. The resulting collaboration gave student artists opportunities to develop interdisciplinary skills while producing an exhibit that helped campus visitors learn about wetland wildlife and ecological research. The study offers a model for bringing science and art together in ways that benefit both participants and broader audiences.

Katelyn Tenuto, Josie Trainor, and Alicia Wodika of Illinois State University examine the role a global health general education course can play in developing students' civic attitudes, behaviors, and sense of themselves as global citizens. Their study found increases in civic attitudes and engagement behaviors and points to the importance of giving students both the confidence and the opportunities to translate concern about local and global issues into action.

Across these contributions, the settings and subjects vary widely, from microbiology and watershed monitoring to regenerative bioscience, wetland ecology and art, and global health. Yet a common thread emerges: science education is most meaningful when students have opportunities to connect what they learn with the world around them. Whether through research, creative collaboration, community partnerships, or civic engagement, these projects demonstrate how educators can help students move beyond acquiring knowledge to applying it in ways that matter.

We thank our authors for sharing their work and hope that the ideas presented in this issue will encourage readers to explore new possibilities for connecting science education and civic engagement in their own classrooms and communities.

Matt Fisher
Trace Jordan
Co-Editors-in-Chief
Marcy Dubroff
Managing Editor

Teaching Through Water: Science, Community, and Civic Engagement

Water is the most local of global problems, and we all face issues concerning water, from water scarcity to water security, from floods to drought, and from polluted water to remediated wastewater. In Texas, where I live and teach, conversations about water occur every day as our communities tackle the challenges of ongoing drought, protecting our precious aquifers, and the growing need to reuse water sources such as wastewater effluent.

This ongoing wicked problem presents an opportunity for those of us who teach through issues. We can engage with the topic of water and connect the issues we're encountering to the context of a biology, chemistry, or English literature class. I've long used water issues to "CURE" my teaching through classroom-based research involving local ponds, rivers, and wastewater plants. Sanitation and toilet design can spark discourse about pathogen transmission, antimicrobial contamination, and the inequities faced by those who lack access to safe sanitation. When done well, integrated projects and research experiences can generate meaningful data while helping to prepare career-ready students to tackle the concerns of the very communities they come from.

This special section offers a sample of how our educators are integrating water-related issues into their courses. Alexis Denn and Davida Smyth of Texas A&M University-San Antonio show how a partnership between a local wastewater treatment plant and a local high school can lead to data-rich, contextualized case studies. Their work demonstrates not only how nature-based solutions can encourage communities to engage with and embrace these

practices, but also how students themselves can become involved in generating the data.

Christine Girtain of the Jersey Shore STEM Ecosystem and Jane Hunt of Ashland University take us from engaging students to engaging teachers. Their paper shows how the "Nourish the Future" national initiative has been developed by teachers for teachers. It takes students on a journey from watershed processes to more complex analyses and investigations, examining human impacts, biological indicators, and chemical testing, and even prompting them to consider remediation plans. Importantly, students are asked what the evidence shows.

Jeena Joseph of Palo Alto College shows that integrating the film *Dark Waters* into the curriculum can help students engage with complex chemical concepts and the issues surrounding PFAS, the so-called "forever chemicals." Having students create research posters and participate in a short REU experience also affects students' perceptions of and engagement with chemistry.

All of these projects start locally and leverage real data from places that students and their teachers see every day, rather than far-away, hypothetical places they'll likely never visit. They ask students to decide, take responsibility, and do something: write a memo, develop a remediation plan, or advocate for a position. They build partnerships with real-world entities and utilities outside academia. Our authors span K–12, community college, and university settings, moving across the educational landscape. And they all consider issues of equity, access to clean water, who benefits from green infrastructure, and how agricultural advancements impact communities. These projects

epitomize the SENCER ideals by teaching through the issues of water.

Our authors have shown that living laboratories are everywhere around us. They are the local creek or pond, the community garden that our grandparents tend, and the local farmers' market. I hope the work presented in this special section will spark excitement and encourage our readers to find the living laboratories on their campuses and in their communities, and to share what they learn with us in future issues.

Davida Smyth

Chair of Natural Sciences

Director for Research Development and Administration

Professor of Biology

Texas A&M University-San Antonio

TEACHING THROUGH WATER

The Influence of Effluent: A School and Community- Based Course Experience

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Abstract

Nature-based solutions (NBS), such as constructed wetlands, leverage natural processes to address societal challenges, including the return of effluent to communities. Despite scientific support, public acceptance of NBS remains limited, and rural communities are rarely included in conversations. We developed paired case studies grounded in real data, in partnership with a rural wastewater treatment plant. Our goal was to help undergraduate and secondary school students bridge the gap between their knowledge of water reuse and their willingness to adopt it. Infusing case studies with original field data allowed us to advance a genuine research question about

the constructed wetland and to immerse the students in an authentic local problem. Our data suggest measurable gains in knowledge, where gains could be made, and a trend towards acceptance of water reuse. This pilot project shows the promise of a course-based case study approach to help build public trust in nature-based solutions in Texas and beyond.

Introduction

Water scarcity poses an increasing but unevenly distributed challenge to communities across Texas and beyond. This issue is further exacerbated by the misuse of these resources and by personal, agricultural, and industrial practices that contaminate our limited supplies and hinder existing conservation efforts (Leijnse et al., 2024; Schumacher, 2025). It is now critical that we diversify our dwindling supplies through the development of alternative water sources, which include treated wastewater effluent. We are increasingly returning treated water to rivers, streams, and aquifers that serve as freshwater sources for surrounding communities (Texas Water Development Board, n.d.). One method for remediating this treated wastewater is to create artificial wetlands at the point of release into freshwater bodies, as is being done in rivers, at the City of Castroville WWTP (Ayaz, 2008) and elsewhere. While each of these methods of recycling treated water has substantial merits, each one also provides a pathway for biological and pharmaceutical micropollutants to cycle back into these communities. Despite potential consequences and the lack of studies on this topic, the reuse of treated non-potable effluent is one of the most promising methods for addressing the growing challenge of water sustainability (Reznik et al., 2019). Using a constructed wetland is among the Nature-Based Solutions (NBS), the next frontier in environmental management, leveraging natural processes to address water quality as it is reintroduced for community use. Along with constructed wetlands, these practices may make it possible to harvest rainwater or water from industrial processes. As a result, communities around the globe are looking towards NBS as both a primary and a secondary means of water remediation.

Despite growing support for NBS, these practices have only recently begun to capture the interest of the public and of what researchers refer to as "stakeholders," with co-benefits as the primary motivators of support (Giordano et al., 2020). The term "stakeholders" can be broadly defined as individuals or bodies that impact or are impacted by the design, implementation, or performance of NBS (De Trift et al., 2026). Without clearer lines drawn between these NBS approaches and improved public health and increased financial opportunities, it

may take longer to inspire the same confidence and support in communities where traditional, grey infrastructure dominates the landscape of environmental engineering practices. A key issue with implementation is a lack of knowledge and education regarding the role of NBS and alternative water sources in such communities where grey infrastructure dominates. So-called stakeholders are concerned with the viability of NBS options in terms of cost-effectiveness and reliability compared with traditionally engineered options (Seddon et al., 2020).

The Local Context

Many governing and conservation bodies have implemented grants, fines, incentives, and signage to educate the public, but when funds are misused, these efforts may falter (Gibson et al., 2023). Locally, the San Antonio River Authority (SARA) has a dedicated education team that provides curricula, river camps, pre-made presentations, and hands-on experiences to motivate people of all ages to engage meaningfully with community waterways. In a similar vein, the San Antonio Water System (SAWS) has specialized education programs aimed at establishing a water-literate community through youth engagement. Both educational and community-forward engagement have been shown to increase public acceptance, outperforming passive education in many other areas of research (genome editing, renewable energy projects, biotechnology), so why not in the context of water resources (Abdulkareem et al 2024; Etchegary et al., 2015; Jimenez et al., 2022; Pathiranage et al., 2024)?

Our goal was to help students from a local secondary school and undergraduates undertaking a biology degree to engage with NBS through case studies and to understand the vital role of informed decision-making in determining whether a community would accept or reject water reuse. We partnered with the Castroville Wastewater Treatment Plant and developed a pair of case studies, along with a knowledge and attitude survey, to test whether a narrative-style, local, data-driven case study could help them move towards engagement with and acceptance of water reuse and the benefits of NBS.

Box 1. Research Questions Guiding the Project

- What is the existing acceptance of NBS across varied contexts? Which models of community engagement are most strongly associated with public acceptance of NBS in these varied contexts?
- Can exposure to a case study that embeds local data increase acceptance and understanding of NBS?
- How does effluent release impact parameters in a local water body with a wetland? Does proximity to the wetland reduce the impact? Is the impact sustained as the distance increases from the wetland?
- To what extent does involvement in a case-study "research experience" improve students' engagement with and appreciation of nature-based solutions?

Materials and Methods

The project combined an original field-based data collection effort with a course-based curriculum. This meant that the data being analyzed in the classroom were the same data being generated to answer our research questions about the wetland's capacity to remediate the wastewater plant effluent. Samples were collected monthly from three sites along a constructed wetland that receives effluent from the Castroville plant, as well as upstream and downstream sites on the Medina River, from February to July, 2026 (Figure 1). Samples were analyzed for nitrate and for phosphates using a portable spectrophotometer, and DNA extracted from the samples was sequenced to characterize the wetland's microbial community (by Plas-midsaurus). These data showed a modest but consistent decline in nitrates as the effluent moved along the wetland, and a detectable presence of DNA from taxa associated with antibiotic resistance in the effluent, which became the backbone of the data in the case studies rather than a hypothetical scenario typical of existing case studies. The research was thus used to construct two linked case studies for use in both K-12 and undergraduate settings. The first case study is a narrative-based one: the students follow a fictionalized resident of a small Texas town as she attends a city council meeting and hears from a variety of

FIGURE 1. Sites for Collection of Water Samples



stakeholders, including the plant operator and a panel of concerned citizens, each with a different stake in whether or not the town's treated wastewater effluent should be used to irrigate the city's park. The second case study was more data-driven, with the students playing the role of consultants employed by the same town council. They must interpret real data on nitrate and phosphate concentrations, as well as *Escherichia coli* (*E. coli*) counts. They would compare the upstream and downstream locations and consider policy options before making a recommendation in the form of a memo. At either end were pre- and post-tests that measured knowledge, engagement, and attitudes. This two-set case study design would enable us to determine whether combining a story with a data-driven experience would have a greater impact than either alone.

This project formed the basis of the first author's master's thesis research. The materials were piloted with undergraduate students at Texas A&M University-San Antonio, under IRB oversight, and modified versions were administered to K-12 students, with effectiveness being self-reported by their classroom teacher. A further

subset of seven students tested the material over the summer as part of an NSF Research Experiences for Undergraduates (REU) program, where participants conducted research at a constructed wetland in a local water body, adding real field-based experience to the case study they completed.

Box 2. Case Study and Field-Based Activities by Participating Students

- Reading and discussing a narrative case study depicting a community considering the fate of its treated wastewater
- Interpreting real data on phosphate and nitrate concentrations along with numbers of *E. coli* from a partner wastewater treatment plant
- Comparing upstream and downstream water quality data compared with that of the constructed wetland
- Drafting a written memo making a recommendation to the fictional city council that would make mention of the data
- Monthly field collection of water samples at three wetland sites as well as the upstream and downstream controls
- Water analysis in the lab for nitrate and phosphate concentrations using a portable spectrophotometer
- Nucleic acid extraction and sequencing (done by a company) to characterize the wetland microbial community
- Completion of a paired pre- and post-test instrument that measures knowledge, attitudes, and engagement

Both case studies and associated materials are available for download as resources in the QUBES hub available here: <https://qubeshub.org/publications/6186/1>

Results and Discussion

How Students Were Evaluated

To ensure that the students participated honestly and to the best of their ability, our pre- and post-tests were ungraded, and we emphasized to the students that this

was an assessment and study of their level of understanding as part of the research study. To us, honest answers were more valuable than expected ones. We actively discouraged them from "googling" the answers (this would be a concern for future at-home implementations). The instrument was designed to measure three dimensions:

- Knowledge – five multiple-choice items and two open-response questions scored against a four-level rubric
- Attitudes – twelve statements rated on a Likert scale
- Engagement – four open-ended reflection questions, with responses in the student's own words

We used a Wilcoxon signed-rank test to analyze the knowledge and attitude items. As the sample size was small, we conducted a sensitivity analysis by excluding two respondents who were flagged for unusually strong reversals between pre- and post-test attitude scores. Students' identities were not collected. Responses were coded prior to analysis. Participation was voluntary, and consent was obtained under the PIs' IRB protocol. For K-12 students, where a full quantitative instrument was not appropriate, effectiveness was assessed qualitatively through the teacher's self-reflection.

Student Success, Limitations and Reflections

Knowledge scores on the open-ended questions improved from the pre-test to the post-test for nearly all respondents (Figure 2). We also noted that item-level accuracy on the multiple-choice questions rose where there was room to grow. The most encouraging finding concerned public acceptance. At the outset of our project, during case study 1, most students were undecided about whether the town should use treated effluent to irrigate the city's park.

We observed more mixed results in our examination of attitudes (Figure 3). Most of the students already held favorable views towards resource conservation before the pre-test (not unexpected, given the course and their majors). There was a high ceiling of acceptance that limited how much movement was possible. However, two respondents showed a sharp negative swing in attitude

FIGURE 2. Individual Change in Open-Response Scores

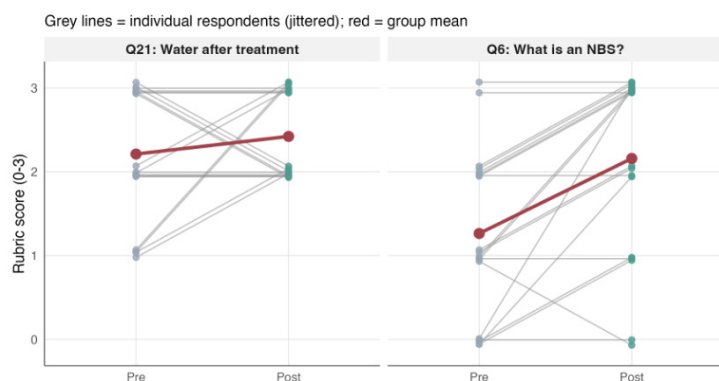
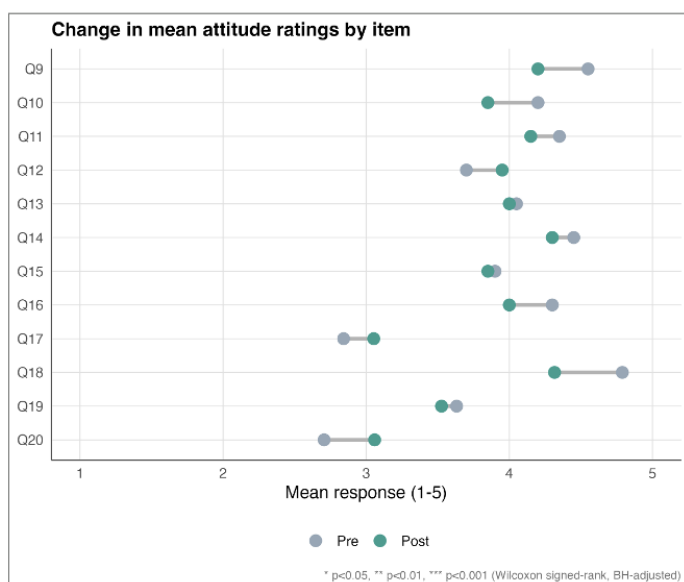


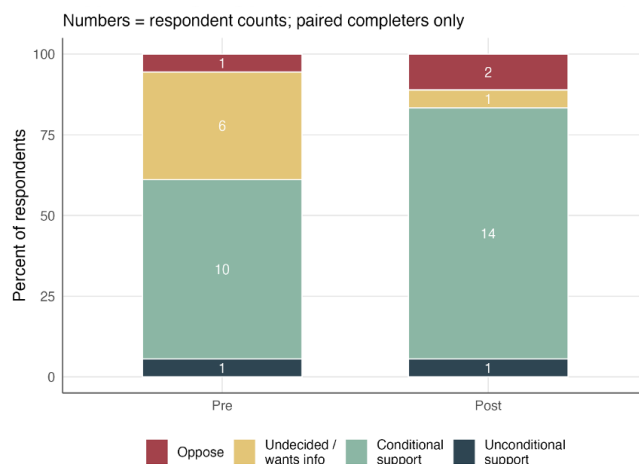
FIGURE 3. Barbell Chart of Change in Mean Attitudes by Item



scores. We suspect this may reflect a misreading of the scale or even a form of disengagement from the post-test, rather than a true reversal of attitude. Given this, the authors recognize the need to re-do and expand our pilot sampling beyond upper-level biology majors. Having completed both case studies, the gap among undecided students almost closed, with four individuals moving into conditional support and only one moving towards opposition (Figure 4).

One major limitation we identified early in the pilot was time. This practical barrier was owing to the limited time available in a single lab session. Conducting both the case studies and the pre- and post-tests takes time away from classroom activities. When time was short, the

FIGURE 4. Support for Irrigating Public Spaces with Treated Wastewater (Q22)



post-test was administered instead of the second case study. In future iterations, we will move the data-driven case study to an at-home, out-of-class assignment to be completed before class time. We also recognize that we need to consider the audience, a range of majors, and to include freshmen to seniors.

The need for greater implementation is evidenced by the course- and grade-level-based variation in K-12 students' ceiling of knowledge. 10th-grade students in an environmental systems class reported no knowledge of NBS at the outset of the pre-test, though they were often successful in selecting the definition when given multiple-choice options. 12th-grade students in a dual-credit biology course were able to correctly identify NBS in multiple-choice questions and offered robust short-answer responses. As previously discussed, time constraints prevented the implementation of the second case study. One of the greatest successes of our project was the connections that we made with the director of the Castroville Wastewater Plant. He was willing to share real, plant-specific data and discuss the issues. This real-world, locally sourced data likely had a much greater impact than a hypothetical scenario from elsewhere, and we now have an ongoing community-engaged project with real impact to build upon.

Box 3. Key Findings from the Pilot

- Nitrate concentrations declined significantly as the effluent moved through the constructed wetland (p values ranging from 0 to 0.042 across sites).
- Phosphate concentrations were more varied by date but remained consistently higher at the wetland sites than at the upstream and downstream control sites.
- *Burholderiaceae*, a taxon associated with antibiotic resistance, was the most abundant group we identified through sequencing water collected from the wetland.
- Knowledge responses measured with the rubric showed improvement from pre-test to post-test for all but one respondent.
- The number of students undecided about reusing water effluent for park irrigation decreased after using both case studies, with most moving towards unconditional support.

Summary and Future Directions

NBS like constructed wetlands are a proven tool for water remediation, mitigating the presence of nutrients, antibiotic resistance genes, and other water contamination concerns. We recognize that the efficacy of wetlands must be observed over a prolonged period to determine how well they withstand other factors, such as climate change and changes in pollutant types and concentrations. We must also consider equity in their construction and distribution. Educated and affluent communities are seeing the most direct benefits now, and the potential for these solutions to become class-specific looms. This is counterintuitive given the cost-efficiency of these designs, and resistance to NBS could be overcome through community engagement. We also recognize that we need to fund and support research on NBS, especially as we enter a more pivotal point than ever before regarding water accessibility. Government and government-adjacent bodies could seek a path forward that helps build trust among themselves, other stakeholders, the community at large, and the scientific community by funding and encouraging education on these practices. As the push for a more

ecologically mindful world grows, education remains the most conducive platform for community change.

In our efforts to promote data-driven decision-making, we paired our case studies with locally acquired data. Our pilot application with Texas A&M University-San Antonio biology students provides a multifaceted proof of concept and a model for a way forward. While the results of the initial wetland monitoring are nuanced, they paint a picture of an effective wetland remediation model with the potential for greater impact through expansion to match the suggestion that increased retention time correlates with greater remediation. Long-term monitoring built into the local school curriculum poses a real opportunity to learn about how attitudes toward NBS can be changed.

The deployment of the case studies offers an even more nuanced glimpse into the mindsets of young people with the greatest potential for community change. While the observed group of respondents scored high in both attitudes and knowledge, both groups saw gains, even with high ceilings. While a small percentage were swayed away from the validity of NBS, a large portion of uninformed and undecided respondents moved toward greater understanding and, with that, increased support of NBS. This model of engagement has the potential to expand acceptance of NBS across multiple levels of the community, thereby increasing the availability and acceptance of recycled water applications.

In future semesters, we intend to refine the timing of the two case studies, expand our K–12 pilot with a fuller instrument, and pursue long-term monitoring of the wetland. We need to better understand the durability of NBS and to consider equity of access to NBS. We are also especially interested in engaging with rural Texas communities, who are too often left out of both data collection and the conversations about water reuse. It is in these rural communities that NBS methods, adopted evenly and equitably along with stakeholder buy-in, could have the greatest impact on water scarcity.

About the Authors



Alexis D. Denn is a graduate student in biology at Texas A&M University-San Antonio and a secondary school science schoolteacher. Her thesis research combines wetland water quality monitoring with the design of case studies and research-based curricula aimed at increasing public understanding of nature-based solutions.



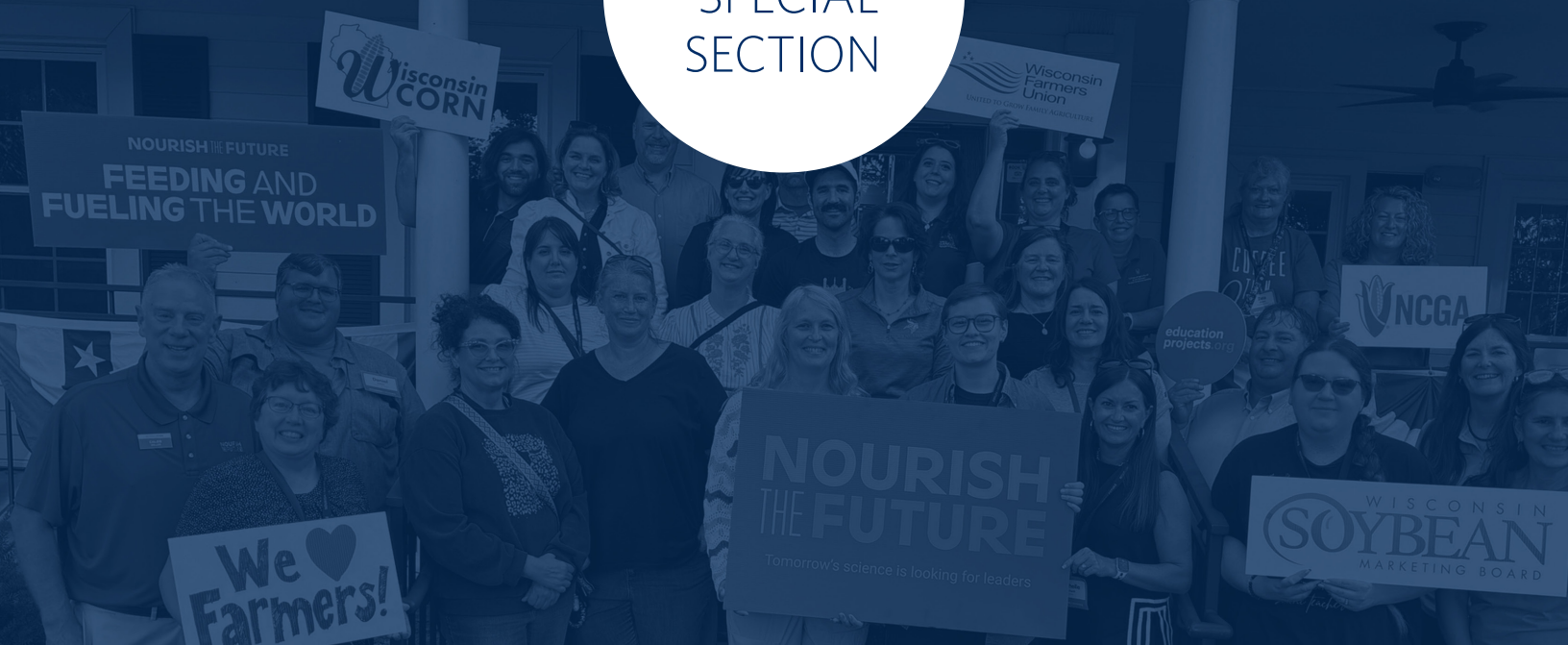
Davida S. Smyth, PhD, is Professor of Biology and Chairperson of Natural Sciences at Texas A&M University-San Antonio. Her research focuses on environmental and antibiotic-resistant microbes and on course-based undergraduate research experiences that connect students to issues relevant to their communities.

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TEACHING THROUGH WATER

Educating the Educator: Using Agriculture to Build Science Literacy

CHRISTINE GIRTAIN*Jersey Shore STEM Ecosystem***JANE HUNT***Ashland University*

Introduction

How do we prepare students to make informed decisions about food, water, energy, biotechnology, and environmental sustainability, when many of their science teachers have had little or no formal training in agriculture? Nourish the Future addresses this challenge by starting with the educator.

Nourish the Future, or NTF, is a free national education initiative developed by science teachers for science teachers. Its goal is to increase agricultural literacy by helping educators connect the science they already teach to modern agriculture, food production, environmental sustainability, biotechnology, and agricultural careers (Nourish the Future, 2026a). The program is supported by agricultural commodity organizations and

agribusinesses, including the national Soy Checkoff program, Bayer Crop Science, and state commodity groups.

This funding provides professional learning, curriculum, classroom materials, and supplies to participating teachers at no cost.

The strategy is simple but powerful. Agriculture provides an authentic context for required science content. NTF equips educators through industry experiences, teacher-tested curriculum, and practical classroom materials. Teachers bring those experiences to students and other educators, multiplying the impact throughout their careers.

Teachers Teaching Teachers

The foundation of NTF is that it is for teachers, by teachers. Teacher Leaders do not simply present curriculum. They engage educators as learners. Teachers collect data, manipulate materials, analyze evidence, make mistakes, ask questions, and discuss results. By experiencing the investigation first as learners, teachers encounter the same questions, procedural challenges, data interpretation problems, and opportunities for scientific reasoning that their students will encounter. A biology teacher who has never tested soil nutrients performs the test. An environmental science teacher investigates how agricultural practices affect a watershed. A chemistry teacher can explore biofuels through concepts already present in the curriculum.

Agriculture is the context for teaching science, not an additional subject competing for instructional time.

NTF uses two complementary professional learning models. The **National Teacher Leader Cohort** develops educators who deepen their understanding of modern agriculture, inquiry-based instruction, leadership, and agricultural careers. These teachers become part of a national network that shares curriculum and supports other educators.

The second model brings professional learning directly to states through two-day **Nourish the Future Feeding and Fueling the World** (NTF FFTW) workshops. During 2026, NTF FFTW workshops were held

in North Carolina, Alabama, North Dakota, Missouri, Indiana, Kentucky, Wisconsin, Nebraska, Michigan, and Minnesota.

Removing Barriers to Implementation

NTF FFTW workshops immerse middle and high school educators in phenomena-based investigations that are aligned with Next Generation Science Standards and connect biology, chemistry, environmental science, biotechnology, and other STEM disciplines to food and fuel production.

Each participating teacher receives equipment and classroom supplies valued at up to \$300. Materials can include water quality and watershed equipment and La-Motte soil testing kits. Teachers therefore leave the workshop not simply knowing about an activity but prepared to implement it.

The impact can also extend beyond individual classroom lessons. Some participants teach high school research courses yet before NTF training had never considered directing students toward agricultural research. Exposure to agricultural biotechnology, soil science, water quality, plant science, biofuels, and food systems gives teachers new areas for student research, and introduces students to agricultural STEM disciplines and career pathways they may not previously have encountered.

IMAGE 1. NTF FFTW WI 2026 Teachers and Industry Leaders Including Secretary of The Wisconsin Department of Agriculture, Trade and Consumer Protection, Randy Romanski



Water as an Entry Point to Civic Science

The NTF water quality curriculum demonstrates how this strategy connects science learning with civic engagement. Water connects communities, and decisions involving agriculture, development, stormwater, recreation, and ecosystem protection have consequences beyond property lines.

The NTF middle school water quality curriculum creates a particularly effective progression. Students move from watershed processes to human impacts to nutrients to abiotic testing to biological indicators and finally to evidence-based remediation (Nourish the Future, 2026b).

IMAGE 2. NTF FFTW KY teachers investigate water quality with the Understanding Watershed Activity

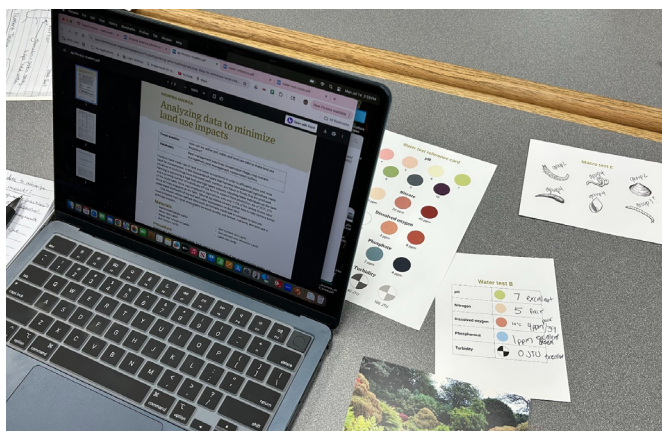


Students investigate watersheds, soil profiles, erosion, nutrient impacts, and relationships between land use and water quality. They can measure temperature, turbidity, pH, dissolved oxygen, nitrogen or nitrate, and phosphorus or phosphate. They investigate soil infiltration and erosion and examine macroinvertebrates as indicators of ecosystem health. Finally, students combine physical, chemical, and biological evidence to evaluate water health and develop remediation plans.

This final step is essential to civic engagement.

Students are not simply asked whether water is polluted. They must consider evidence, determine what may

IMAGE 3. Nourish the Future Resources for Students Investigating Land Use Impacts (including macroinvertebrates and water test cards)



be influencing the system, and propose actions that could improve it.

The progression mirrors the reasoning citizens need when confronting environmental issues in their communities. They observe a problem, gather evidence, evaluate explanations, understand human impacts, and consider solutions.

From Classroom Science to Community Science

Students can examine a local water system, identify surrounding land uses, and predict possible influences. Physical, chemical, and biological evidence can then be compared with maps, rainfall patterns, land use information, or publicly available environmental data.

The teacher's role changes from providing the correct explanation to helping students determine what claims the evidence supports.

This is where agricultural literacy and civic scientific literacy intersect. Agriculture should neither automatically be blamed for an environmental problem nor automatically be excluded as a possible contributor. Students should investigate evidence; they should examine agricultural practices intended to reduce nutrient and sediment loss, including vegetative buffers, nutrient management, reduced tillage, and practices that increase soil infiltration.

Students begin moving beyond statements such as "pollution associated with agriculture" or "farmers protect the environment" toward better questions. What does the evidence show? What practices are being used? What are the tradeoffs? What additional evidence is needed before making a recommendation?

That is science education serving civic engagement.

Extending Learning Through Research and Biotechnology

At the high school level, NTF water curriculum extends learning into biodiversity and biotechnology. Students can examine freshwater plankton biodiversity and use Simpson's Index of Diversity to investigate aquatic ecosystems. Water bioinformatics allows students to use

IMAGE 4. NTF FFTW NC 2026: Education And Outreach Coordinator, Sarah Dinger leads a tour of the NC State Vegetable Pathology Lab



DNA sequences and the National Center for Biotechnology Information database to identify organisms represented in water samples (Nourish the Future, 2026c). These experiences demonstrate that modern environmental monitoring combines field observations, chemistry, biology, mathematics, genetics, and computational tools.

NTF Teacher Leaders also include college educators. Dr. Brian Shmaefsky of Lone Star College, a former president of the Society for College Science Teachers, brings experience in environmental science, biology, faculty mentoring, and professional learning (Nourish the Future, n.d.). College faculty participation helps connect secondary science, undergraduate STEM learning, and agricultural career pathways. Agricultural science teachers provide specialized expertise and pathways, while general science teachers provide another avenue for expanding agricultural literacy through biology, chemistry, environmental science, earth science, and other STEM courses.

The Teacher Multiplier Effect

A student experiences a lesson once. An educator can teach that lesson repeatedly.

A science teacher reaching 130 students each year can reach 1,300 students over ten years. When that teacher shares an NTF investigation through district professional development, a state science teachers conference,

or a professional network, the original professional learning investment begins reaching students who were never taught by the original participant. This is especially important because most students will never enroll in an agriculture course. They do, however, take biology, environmental science, chemistry, earth science, and other science courses.

Educating the educator reaches not only today's students but future students throughout that educator's career.

Teacher leadership therefore scales agricultural and civic science literacy. Practicing educators understand classroom constraints and can tell colleagues, "I used this with my students, and this is how I made it work."

Preparing Students for Earth and Beyond

Agricultural literacy extends beyond traditional farming. Food, water, soil, energy, biotechnology, and sustainability are civic issues on Earth and will become survival issues as humans move beyond it. In future settlements on the Moon, Mars, or elsewhere, humans will again become pioneers, with everyone connected to food production and resource management. Students investigating these systems today are developing scientific knowledge needed to solve problems on Earth and eventually sustain communities beyond it.

Conclusion

The practical teaching strategy demonstrated by Nourish the Future is not simply providing teachers with more curriculum. It is building teacher capacity. Agriculture provides an authentic context for science, while NTF prepares teachers to use that context through firsthand investigations, classroom ready curriculum, equipment, and connections with scientists, agricultural professionals, college faculty, and other educators.

The National Teacher Leader Cohort and NTF FFTW workshops extend that impact as teachers reach new students each year and share their experiences with other educators. Water quality demonstrates the result. Students collect and interpret evidence, investigate

human interactions with natural systems, consider possible solutions, and use science to participate thoughtfully in civic decisions.

That is agricultural literacy. That is scientific literacy. And that is civic engagement.

About the Authors



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Jane Hunt serves as Education Director for EducationProjects.org. Jane taught middle school science, biology, and AP environmental science for 30 years in central Ohio. She is trained in problem-based learning, as a trainer of Next Generation Science Standards, and she is an adjunct professor at Ashland University. She designs workshops and oversees educational products including career videos, e-learning courses, and curriculum.

Resources

- ♦ **Nourish the Future:** <https://nourishthefuture.org/>
- ♦ **Nourish the Future Water Quality Curriculum:** <https://nourishthefuture.org/curriculum/water-quality>

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TEACHING THROUGH WATER

Dark Waters: A Case Study

JEENA JOSEPH*Palo Alto College*

Abstract

The NSF-funded Retention, Relevance, and Readiness Through Bridging Water Security Issues in San Antonio (WaTR3) project aimed to address two persisting challenges. The first being limited integration of limited integration of local water issues into existing courses in the Water Resources Science and Technology (WaTR) program and in STEM program courses. The second one is limited career pathways limited career pathways for students interested in water-related professions. This project developed water-focused curricular materials for an Organic Chemistry I course centered on a case study of per- and polyfluoroalkyl substances (PFAS) contamination. The case study was used by students to connect core chemistry concepts, including chemical persistence and toxicology, to real-world consequences, fulfilling the broader aim of teaching through the issues. Students also had the opportunity to participate in a two-week

Research Experiences for Undergraduates (REU) program held at Texas A&M University-San Antonio, and faculty presented their project at the SENCER Summer Institute as part of the project's professional development requirement.

Introduction

This project was a subaward to Palo Alto Community College from the Texas A&M University-San Antonio WaTR3 program funded by the National Science Foundation, which was established to emphasize the importance of integrating local water issues into the existing WaTR program and STEM program courses. For the chemistry program, this project was the first attempt to incorporate a localized community water issue into the curriculum.

In spring and summer of 2025, rigorous brainstorming sessions were conducted in learning communities to design curriculum models for different disciplines. A case study model based on a real-world water issue mediated by per- and polyfluoroalkyl substances (PFAS) contamination was selected for Organic Chemistry I during Fall 2025. PFAS are synthetic chemicals that do not break down easily because they contain strong carbon-fluorine bonds, which is why they are commonly called “forever chemicals” (Cordner et al., 2019; Evich et al., 2022). PFAS have become a national environmental health concern because of their contamination of drinking water, and they have been identified as a major threat to Texas water systems. In addition, the study of PFAS enables the incorporation of critical Organic Chemistry I concepts, including functional groups, polarity, and spectroscopic analysis. To link PFAS concepts to the levels of contamination reported across Texas (Dasu et al., 2022; Kurwadkar et al., 2022; Valdiviezo et al., 2022), students created a poster using instructor-provided guidelines and rubrics, and they completed a survey that gathered feedback on their experiences in the case study project.

The case study had two objectives: first to explore how the functional groups of organic molecules influence their solubility in water, and second to examine the chemical principles behind detecting major PFAS, using chromatography and spectroscopy, along with the importance of safe handling and disposal of environmental contaminants such as PFAS (Chow et al., 2021; Evich et al., 2022). These objectives were developed based upon the student learning outcomes identified for lecture and laboratory components of the Organic Chemistry I course syllabus.

The following student learning outcomes were met by the project. PFAS was used as an example while discussing each of these student learning outcomes.

1. Explain the chemical and physical behavior of organic compounds based on their functional groups, and predict this behavior for a compound whose functional group is known.
2. Determine the factors affecting the solubility of organic compounds in different polar and nonpolar solvents.

3. Apply chromatographic and spectroscopic techniques to elucidate the structure of organic molecules.
4. Utilize chemical knowledge to understand safe handling of chemicals and appreciate the role of chemistry in addressing societal challenges in areas such as energy, medicine, and health.
5. Apply chemical knowledge to ensure safe handling of chemicals and appreciate the role of chemistry in addressing societal challenges in multiple areas, especially energy, medicine, and health.

Case Study Assignment: Understanding PFAS through Dark Waters

Dupont, a pioneer in the development of Teflon-coating technology used PFOA (Perfluorooctanoic acid), a synthetic chemical, in their production plant. PFOA is a member of the PFAS group of chemicals, which build up in the human body because the body cannot break them down and remove them. Without proper disposal of this byproduct, DuPont company contaminated several water districts near its production unit, causing chronic illness among its employees and birth defects among children in the surrounding community. DuPont concealed these dangers for decades until an attorney began investigating the issue and brought the truth to light.

The film *Dark Waters* tells the true story of this investigation.

Interactive, Panopto videos of 20-minute modules were created from the *Dark Waters* film, with two interactive quizzes embedded in every module. It was a semester-long activity. The quizzes were graded for participation. Students were divided into groups on Canvas, the Learning Management System at Palo Alto College, to collaborate and discuss the questions which were tied to the learning objectives. The students used the discussion board to share insights and develop a comprehensive understanding of the topics. The discussion questions addressed PFAS utilization, solubility, analytical approaches, and structural elucidation. Students were encouraged to identify sources of PFAS exposure and suggest ways to

minimize it. Students also completed a survey on their experiences and understanding of the case study project.

The case study was presented in the SENCER (Science Education for New Civic Engagements and Responsibilities) Summer Institute, the goal of which is to connect basic science and civic engagement by teaching through issues.

Research Poster Presentation

To connect the case study to a local water issue, students were given the following prompt along with guidelines and a rubric to conduct research on the prompt and prepare a poster for presentation: "The EPA set its first-ever limits, in ppt (parts per trillion), for five types of PFAS chemicals in drinking water, and nearly 50 Texas public water systems have reported exceeding the new limits for at least one of them" (Martinez, 2024, 2025). Using this prompt, students conducted research on this topic and created a poster addressing the following major points.

- Major classes of PFAS
- Sources of PFAS in Texas (include 4-5 sources)
- Detection methods
- Health and environmental impact
- Limits and safety measures

The poster also served as a resource for the faculty during the project presentation at the SENCER Summer Institute.

The concern about limited career opportunities for students and water professionals was addressed by creating an undergraduate research program (REU), in which students participated in two weeks of paid research training in Texas A&M University-San Antonio laboratories to prepare them for the workforce.

Results and Conclusion

This project gave students insights into functional groups, chemical analysis, health effects (Fenton et al., 2021; Panieri et al., 2022), regulatory policies (O'Sullivan Bakshi et al., 2025), and environmental impacts of PFAS, as

reflected by their survey responses. Figure 1 compares the structure of acetic acid (vinegar) to PFAS, which have similar functional groups in them. As one student commented, this project helped them better understand how the structure of the PFAS molecules makes them water-repellent, heat-resistant, and non-destructible (Figure 1). The survey responses on interesting aspects of PFAS, detection methods of PFAS, and familiarity of students with PFAS were plotted as a percentage in Figure 2, reflects a good percentage of students have gained understanding about PFAS. The students were able to connect chemical persistence and toxicology to real world consequences (Dasu et al., 2022; Kurwadkar et al., 2022). The project increased the students' awareness of the proper handling and disposal of hazardous waste, and how to reduce damage to the environment and impacts on human life. New regulatory actions continue to be introduced nationwide to limit the exposure to PFAS, and research activities continue to help us better protect public health (Environmental Protection Agency, 2026). Students in this course became aware of hazardous chemical disposal, safety procedures, and regulatory measures (Figure 2) and had the opportunity for two weeks of paid research training. Faculty had the opportunity to present at the SENCER Summer Institute. This project established a foundation for educators in a variety of disciplines to incorporate contemporary real-world issues into their curriculum and instruction. It promoted students' critical thinking and inquiry and encouraged them to apply their academic knowledge to the issues in their local surroundings.

Acknowledgements

I would like to thank Prof. Davida S. Smyth, and Science Education for New Civic Engagements and Responsibilities (SENCER) for their valuable guidance and generous support for this project. This project was supported by funding from the National Science Foundation (NSF # 2247898). I am grateful for all the support from the Sciences and Kinesiology Department of Palo Alto College

FIGURE 1. Structure Comparison of Acetic Acid and PFAS

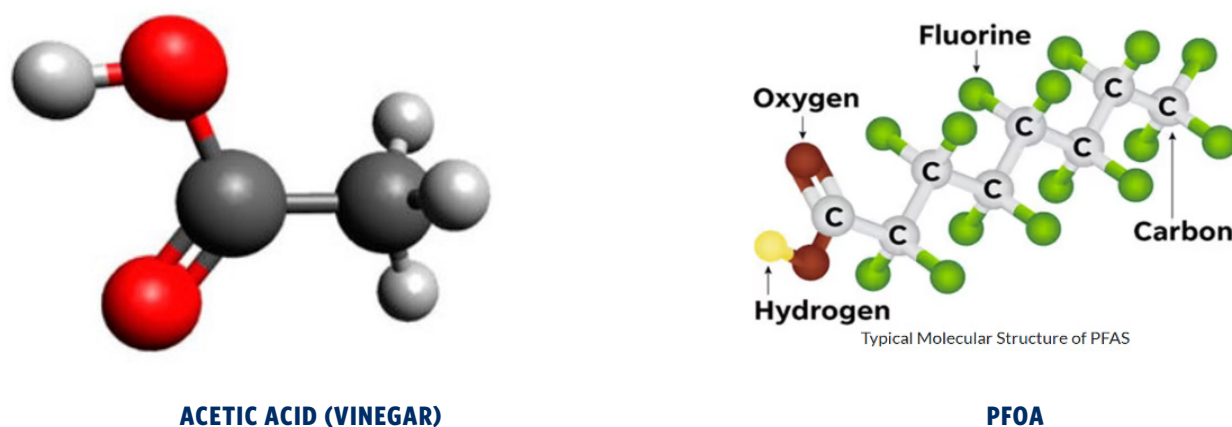
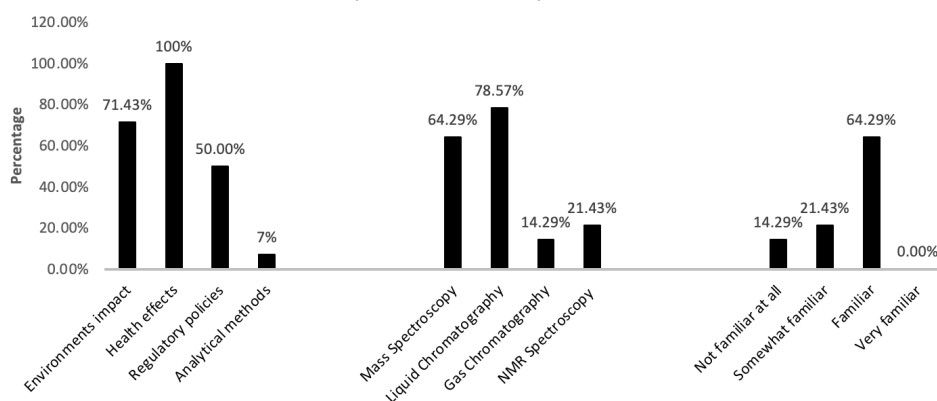


FIGURE 2. Results of Student Survey on PFAS Case Study



and from the Organic Chemistry I students at Palo Alto College.

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RESEARCH ARTICLE

Increasing Students' Scientific Self-Efficacy and Scientific Identity Through Community-Engaged Microbiology

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Abstract

Community-engaged (CE) microbiology courses allow students to apply microbiology concepts to real-world environmental challenges while contributing to community needs. Studies have demonstrated educational benefits of CE microbiology experiences, but less is known about their influence on psychosocial factors associated with STEM persistence. This study used the Tripartite Integration Model of Social Influence (TIMSI) to examine changes in students' scientific self-efficacy, scientific identity, and scientific value orientation in a CE undergraduate microbiology course at Bellarmine University. Students partnered with Kentucky Watershed Watch

(KyWW), a nonprofit organization focused on monitoring Kentucky waterways, to conduct water quality assessments and compare *E. coli* detection methods. Pre- and post-surveys revealed significant increases in students' scientific self-efficacy, scientific identity, and confidence in microbiology laboratory skills, while changes in scientific value orientation were not significant. These findings indicate that CE microbiology courses can not only support students' learning and integration into the scientific community but also contribute to community-based environmental efforts.

Introduction

Microbes play a critical role in many challenges that face modern society, including environmental health, infectious disease, and antimicrobial resistance. As a result, undergraduate microbiology courses increasingly prioritize helping students understand the connections between microbes and real-world issues. The American Society for Microbiology (ASM) Curriculum Guidelines encourage opportunities for students to develop conceptual understanding and scientific thinking, and for authentic application rather than the rote memorization of facts (Boury et al., 2024).

One approach to achieving these goals is community-engaged (CE) learning, a high-impact educational practice that combines students' learning with meaningful community partnerships, benefiting all parties. CE microbiology courses can provide students with opportunities to participate in real-world scientific practices that positively impact their communities. Research studies have demonstrated that CE or service-learning microbiology courses can deepen student understanding of microbiology concepts and enhance student civic responsibility and public health awareness (Webb, 2016; Webb, 2017). A CE course-based undergraduate research experience (CURE) in an undergraduate microbiology course increased students' scientific process skills, communication skills, and cultural competency (Malotky et al., 2020). A health professions microbiology course with student-driven service learning reported high student satisfaction and strong perceived relevance to population health (Lowrey, 2020).

Environmental microbiology is a subfield well suited to CE learning due to its connection to current environmental challenges and to the accessible nature of environmental samples. Students can often readily collect soil and water samples on or near their college campus, enabling the scientific investigation of microbial communities. Undergraduate students have contributed to environmental microbiology initiatives through CUREs and community partnerships focused on environmental monitoring (Adkins-Jablonsky et al., 2020; Fuhrmeister et al., 2021; Tawde & Williams, 2020).

We hypothesized that, in addition to increasing students' understanding of microbiology concepts, CE experiences may foster psychosocial factors associated with

student persistence and success in STEM disciplines. Scientific self-efficacy, defined as a person's confidence in their ability to perform scientific tasks and succeed in science, has been linked to academic achievement and satisfaction and is accomplished through participation in authentic scientific experiences (Syed et al., 2019; Nguyen et al., 2026). Scientific identity, the extent to which a person perceives themselves as a scientist and feels they belong in the scientific community, has been associated with higher persistence in STEM majors and careers, participation in undergraduate research experiences, and engagement in science despite academic challenges (Carlone & Johnson, 2007; Chemers et al., 2011; Hazari et al., 2010). Value orientation is the degree to which individuals believe science is useful, worthwhile, and important for their personal and professional lives, and research suggests it is a key motivational construct associated with persistence in STEM pathways (Guo et al., 2018; Perez et al., 2019). Together, scientific self-efficacy, scientific identity, and value orientation make up the core constructs of the Tripartite Integration Model of Social Influence (TIMSI), a framework used to explain students' integration into scientific communities and persistence in STEM pathways (Estrada et al., 2018).

While prior studies have investigated the educational benefits of CE microbiology experiences, relatively few have examined how these experiences influence students' scientific self-efficacy, scientific identity, and value orientation. To address this gap, we surveyed students before and after participation in a CE undergraduate microbiology course at Bellarmine University using the TIMSI. In the course, students partnered with the statewide nonprofit Kentucky Watershed Watch (KyWW) to conduct environmental microbiology studies focused on water quality monitoring. Students collected water quality data from two local creeks and conducted a comparative study testing two *E. coli* detection methods. Deliverables provided to KyWW included water quality assessment data and evidence supporting the comparability of the two detection methods, which informed KyWW's monitoring practices.

Through this work, the CE course provided students with an authentic opportunity to contribute to environmental stewardship efforts and apply microbiology

concepts in a real-world context. By examining the student outcomes of a CE microbiology course, this work contributes to the understanding of how CE learning supports student development and engagement in undergraduate STEM education.

Methods

Institutional Setting and Class Format

The institution is a liberal arts university located in the United States. It is a primarily undergraduate institution, with approximately 2,100 full-time undergraduate students and 570 full-time graduate students. Approximately 30% of students are from underrepresented racial or ethnic groups, 39% are first-generation college students, and 45% are Pell recipients. In 2025, the Carnegie Foundation and the American Council on Education designated Bellarmine as an Opportunity College and University.

To earn a Bachelor of Science in Biology, students are required to complete basic courses in biology and choose 12 credit hours from additional science courses, including microbiology. The four-credit-hour microbiology course is offered every fall semester and includes lecture and laboratory components. The course laboratory meets in person each week for three hours. Course learning objectives include an exploration of the functional, ecological, and evolutionary relationships among bacteria, fungi, viruses, and protozoa, focusing on microbial physiology, pathogenesis, and immunology.

Course Participants

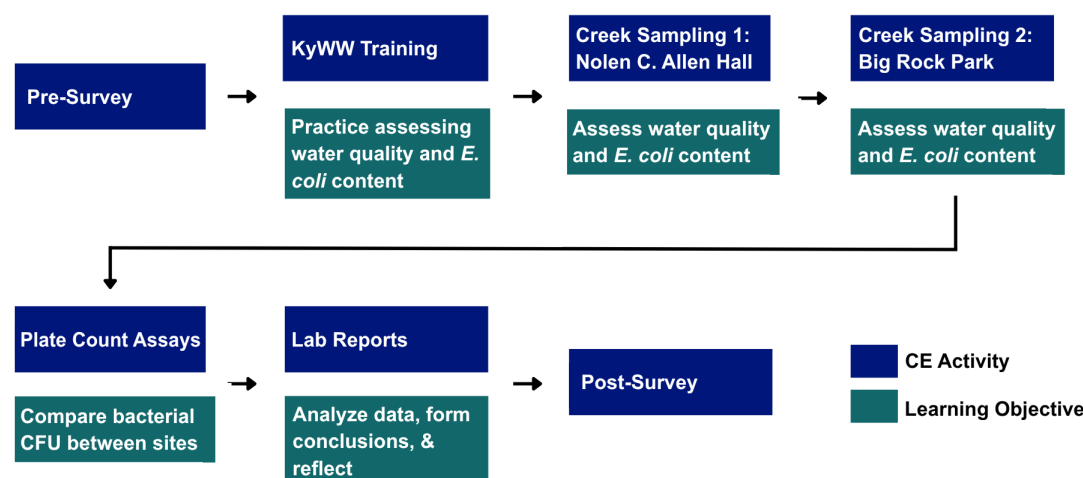
Twenty-one undergraduate students in the CE course completed both the pre- and post-surveys. Pre-surveys were administered during the course's first laboratory meeting, and post-surveys were administered during the course's last laboratory meeting, 12 weeks later. Approximately 86% of the students were white, and 71% were women. Students were either juniors (29%) or seniors (71%), and five students (24%) participated in faculty-mentored research outside of the CE course and during the same time period.

Community-Engaged Course Design

The instructor created a CE microbiology course through a partnership with KyWW, a statewide nonprofit organization formed to "support water quality monitoring that informs, connects, and empowers volunteers and their communities for the improvement and protection of Kentucky's water resources" (Kentucky Watershed Watch, n.d.). Course design reflected the goal to mutually benefit students and KyWW.

Most of the CE coursework occurred during course laboratory meetings, with some independent training, data analysis, and reflection outside of class time. Approximately 18 hours of laboratory course time over six three-hour laboratory meetings were dedicated to CE work. After taking pre-surveys, students ($N=21$) were trained in water quality sampling methods, including assessing water temperature, pH, conductivity, turbidity, stream flow, and bacterial contents (Figure 1). Following training,

FIGURE 1. Timeline of Course CE Activities. CE activities and learning objectives are shown in blue and green, respectively.



students completed two creek samplings of Beargrass Creek at sites near Bellarmine University's campus. Beargrass Creek is a watershed running through Louisville, Kentucky, covering about 60 square miles. Two Beargrass Creek sites were chosen, primarily for their proximity to campus. The first is part of the South Fork of Beargrass Creek and is on Bellarmine University's campus, running behind Nolen C. Allen Hall. The second creek sampling site is part of the Middle Fork of Beargrass Creek and is approximately two miles from the campus.

Students assessed water quality at both sites. They also measured creek water *E. coli* concentrations via two methods: R-cards and IDEXX Quanti-Tray tests. R-cards, produced by Roth Biosciences, are self-contained, rapid microbiological tests used to quantify *E. coli*. R-cards are cost effective, portable, and volunteer friendly, and KyWW uses them to monitor stream water quality. IDEXX Quanti-Trays are a U.S. Environmental Protection Agency-approved method that utilizes the most probable number (MPN) approach to determine the number of *E. coli* in a water sample. IDEXX Quanti-Trays are laboratory based and require more reagents, equipment, and skills than the R-card method. Students measured *E. coli* concentrations in the same creek water samples using both the R-card and IDEXX Quanti-Tray methods and completed subsequent analysis to compare the agreement between the two methodologies. KyWW representatives used this comparative study to inform their approach to monitoring water quality.

Students also completed plate count assays to assess and compare total bacterial colony-forming units (CFU) at the two creek sites. Upon completion of the laboratory experiments, students presented their work in a formal laboratory report, which was graded by the instructor. In the laboratory report, students also reflected on their experiences, including how they and the community partner benefited from the CE course, and whether they believed it was an effective way to learn environmental microbiology.

The course had three goals related to CE coursework: reflective learning, integrative learning, and collaborative action. These objectives were adapted by Bellarmine University's Center for Community Engagement from the Brown University Swearer Center for Public Service. Reflective learning involved the application of material learned through CE coursework to their lives and the

lives of those around them. Integrative learning involved students' connection of knowledge across fields of study and inquiry in relation to CE experiences. Collaborative action involved students' work with community partners to inform future actions and practices.

Community Partner Benefits

In a CE course, the community partner and students should benefit from the work. The laboratory component of the microbiology course was designed to ensure that student effort and work would produce meaningful information for KyWW. Student monitoring of water quality in Beargrass Creek contributed to the organization's mission to evaluate Kentucky waterways. Additionally, the comparison study of two methodologies for *E. coli* creek water concentrations provided valuable information regarding the validity of KyWW's current use of R-cards by citizen scientists across Kentucky. All data generated by students were shared promptly with KyWW.

Student Surveys

This research study was approved by Bellarmine University's Institutional Review Board. Surveys were administered on paper and matched using anonymous participant identifiers. Students were not required to participate, and results were not analyzed until after the course had closed.

Survey questions assessing students' perspectives on CE were adapted from the student survey (longer version) in *Assessing Service-Learning and Civic Engagement: Principles and Techniques* (Gelmon et al., 2018). The TIMSI model was used to assess students' scientific self-efficacy, scientific identity, and value orientation (Estrada et al., 2018). The researchers developed eight survey questions to assess students' confidence in performing microbiology laboratory tasks, including performing a four-quadrant streak plate to isolate bacterial colonies, using a compound microscope to observe bacteria, preparing and interpreting a Gram stain, measuring *E. coli* in environmental water samples, analyzing experimental data, designing a microbiology experiment, accurately interpreting laboratory observations and results, and following safety protocols. These items aligned with course learning objectives.

Likert response options for scientific self-efficacy and confidence performing microbiology laboratory tasks ranged from 1 (not at all confident) to 5 (absolutely confident). Response options for scientific identity and student perspectives on CE ranged from 1 (strongly disagree)

to 5 (strongly agree), whereas response options for value orientation ranged from 1 (not at all like me) to 5 (very much like me). Pre- and post-survey data were analyzed using IBM SPSS Statistics Version 29. Normality was assessed, and normally distributed variables were analyzed via paired samples t-tests. Non-normally distributed variables were evaluated using a Wilcoxon signed-rank test. Statistical significance was established at $p=0.05$. Internal consistency was assessed using Cronbach's α .

Student Assessments and Reflections

At the conclusion of the CE project, students presented their findings in formal laboratory reports. Laboratory reports included an abstract, introduction, materials and methods, results, and conclusion, and accounted for 5% of the final grade. Students also completed a 400-word written reflection. Reflections addressed three prompts: (1) How did you benefit from the work? (2) How did KyWW benefit from the work? and (3) Do you think this partnership is an effective way to learn environmental

microbiology? Reflection responses were analyzed using an inductive thematic approach. All reflections were reviewed multiple times to identify recurring ideas, which were grouped into themes. The frequency of each theme was then recorded to characterize common student experiences.

Results

Scientific Self-Efficacy, Scientific Identity, and Value Orientation

The TIMSI framework was used to measure the effects of the CE course on students' scientific self-efficacy, scientific identity, and value orientation. Internal consistency of the constructs was assessed using Cronbach's α (Table 1), which ranged from .74–.86, indicating acceptable to good reliability and supporting the use of averaged item responses to create composite scores.

TABLE 1. Cronbach's Alpha for Pre- and Post-Assessments (N=21)

CONSTRUCT	ITEMS	PRE-SURVEY	POST-SURVEY
Scientific Self-Efficacy	6	0.75	0.86
Scientific Identity	5	0.77	0.80
Value Orientation	4	0.81	0.74

FIGURE 2. Composite pre- and post-assessment scores (N=21) for the TIMSI student survey measuring scientific self-efficacy (A), scientific identity (B), and value orientation (C)

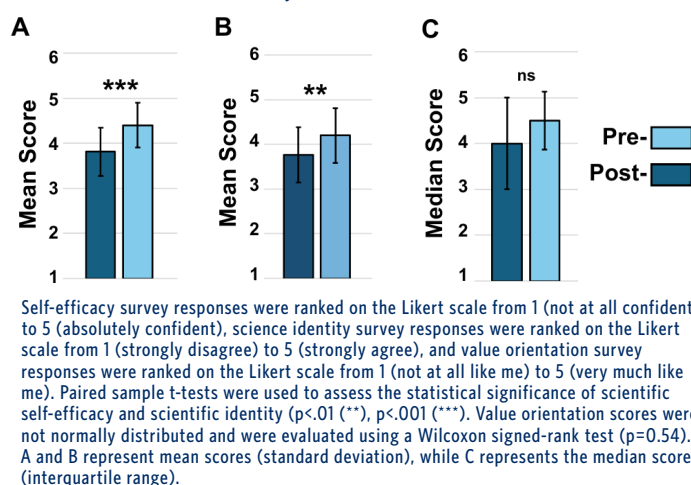


TABLE 2. Pre- and Post-Assessment Means for Scientific Self-Efficacy and Scientific Identity (N=21)

	PRE- MEAN (SD)	POST-MEAN (SD)	MEAN DIFFERENCE	t	p VALUE	COHEN'S d
Scientific Self-Efficacy	3.81 (0.53)	4.40 (0.50)	0.59	4.55	<.001	0.99
Scientific Identity	3.76 (0.62)	4.20 (0.61)	0.44	3.58	.002	0.78

TABLE 3. Pre- and Post-Assessment Medians for Value Orientation (N=21)

	PRE-MEDIAN (IQR)	POST-MEDIAN (IQR)	Z	p VALUE	COHEN'S d
Value Orientation	4.0 (1.0)	4.5 (0.63)	-1.93	.054	0.99

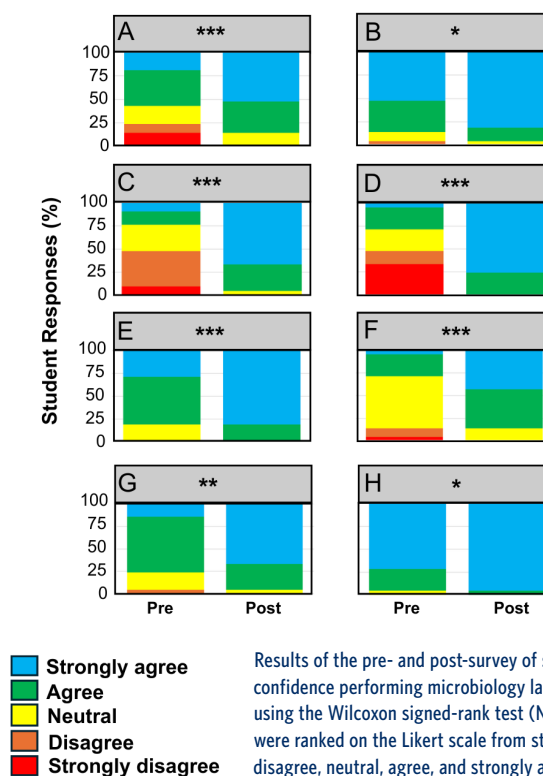
TABLE 4. Pre- and Post-Survey Assessment of Students' Confidence Performing Microbiology Laboratory Skills (N=21)

	Question	Z	P-value	Pre-Survey Median (IQR)	Post-Survey Median (IQR)	Effect size
A	Perform a four-quadrant streak plate to isolate bacterial colonies.	-3.08	0.002	4.0 (1.5)	5.0 (1.0)	0.67
B	Use a compound microscope to observe bacteria.	-2.309	0.021	5.0 (1.0)	5.0 (0.0)	0.50
C	Prepare and interpret a Gram stain of bacterial samples.	-3.764	<.001	3.0 (1.5)	5.0 (1.0)	0.82
D	Measure <i>E. coli</i> in environmental water samples using microbiological techniques.	-3.85	<.001	3.0 (3.0)	5.0 (0.5)	0.84
E	Analyze experimental data from lab experiments.	-3.419	<.001	4.0 (1.0)	5.0 (0.0)	0.75
F	Design an experiment to test a microbiology-related hypothesis.	-3.501	<.001	3.0 (1.0)	4.0 (1.0)	0.76
G	Accurately interpret lab observations and results.	-3.013	0.003	4.0 (0.5)	5.0 (1.0)	0.66
H	Follow safety protocols when working with bacterial cultures.	-2.121	0.034	5.0 (1.0)	5.0 (0.0)	0.46

Pre- and post-surveys measured scientific self-efficacy using six items designed to measure students' confidence in performing scientific activities. An example item is, "I can generate a research question to answer." Mean scientific self-efficacy scores significantly increased from 3.81 (SD=0.53) to 4.40 (SD=0.50), $t(20)=4.55$, $p<.001$, $d=0.99$ (Table 2; Figure 2A).

Scientific identity was measured using five items designed to evaluate the extent to which students identified as scientists. An example item is, "I feel like I belong in the field of science." Mean scientific identity scores increased from 3.76 (SD=0.62) to 4.20 (SD=0.61) (Table 2; Figure 2B). A paired-samples t -test indicated that this increase was statistically significant, $t(20)=3.58$, $p=.002$, with a large effect size ($d=0.78$).

The value orientation measure was evaluated using four items designed to assess how much students value scientific objectives, the specific, measurable goals that guide scientific research. An example item is "A person who feels discovering something new in the sciences is thrilling." Value orientation scores (Table 3, Figure 2C)

FIGURE 3. Microbiology Lab Skills

Results of the pre- and post-survey of students' confidence performing microbiology laboratory skills using the Wilcoxon signed-rank test (N=21). All questions were ranked on the Likert scale from strongly disagree, disagree, neutral, agree, and strongly agree from 1 to 5, respectively. Median and interquartile range values were rounded to the nearest tenth. $p<.05$ (*), $p<.01$ (**), and $p<.001$ (***).

TABLE 5. Likert-Scale Survey Items Used to Assess Students' Perspectives on Community-Based Learning Before and After the Course (N=21)

	Question	Z	P-value	Pre-Survey Median (IQR)	Post-Survey Median (IQR)	Effect Size
A	The community participation aspect of this course (will help/helped) me to see how microbiology can be used in everyday life and work.	-2.309	0.021	5.0 (1.0)	5.0 (0.0)	0.50
B	The community work I do through this course (will help/helped) me to better understand the lectures and readings in this course.	-2.814	0.005	4.0 (1.0)	5.0 (1.0)	0.61
C	The idea of combining work in the community with university coursework should be practiced in more classes at this university.	-2.443	0.015	4.0 (2.0)	5.0 (1.0)	0.53
D	I (am/was) responsible for the quantity and quality of the knowledge that I (obtain/obtained) from this course.	-1.613	0.107	4.0 (1.0)	5.0 (1.0)	0.35
E	The community work involved in this course (will help/helped) me to become more aware of the needs in my community.	0.0	1.0	4.0 (1.0)	4.0 (1.0)	0.00
F	I have a responsibility to serve my community.	-0.378	0.705	4.0 (1.0)	4.0 (1.0)	0.08
G	Most people can make a difference in their community.	0.0	1.0	5.0 (1.0)	5.0 (1.0)	0.00
H	The work I perform in the community (will enhance/enhanced) my ability to communicate my ideas in a real-world context.	-0.707	0.48	4.0 (1.0)	5.0 (1.0)	0.15

Note. Wording in pre- and post-surveys differed slightly, and both versions are presented in parentheses for each survey item, with pre-survey verbiage appearing before post-survey. Items A-H correspond to panels A-H in Figure 4.

were not normally distributed and were evaluated using a Wilcoxon signed-rank test. The median score increased from 4.0 (IQR=1.0) to 4.5 (IQR=0.63); this change was not statistically significant ($Z=-1.93$, $p=.054$), despite a moderate effect size ($d=.42$).

Confidence in Performing Microbiology Laboratory Skills

The course learning objectives included fundamental microbiology laboratory skills. Survey items asked students about their confidence performing a four-quadrant streak plate, using a microscope to observe bacteria, preparing and interpreting a Gram stain of bacteria, measuring *E. coli* in environmental samples, analyzing experimental

data, designing an experiment, interpreting observations and results, and following safety protocols while working with bacteria (Table 4). Pre- and post-surveys indicated significant increases in all eight measures of student confidence in the microbiology laboratory (Table 4; Figure 3).

Perspectives on Community-Engaged Work

Pre- and post-survey items assessed students' perspectives on this CE course, attitudes toward community involvement, and personal reflections (Table 5). Questions A, B, and C showed statistically significant increases. These items assessed students' views on the role of community participation in demonstrating the relevance of microbiology to everyday life and work, enhancing

TABLE 6. Selected Quotations from Student Reflections Upon Conclusion of the CE Project

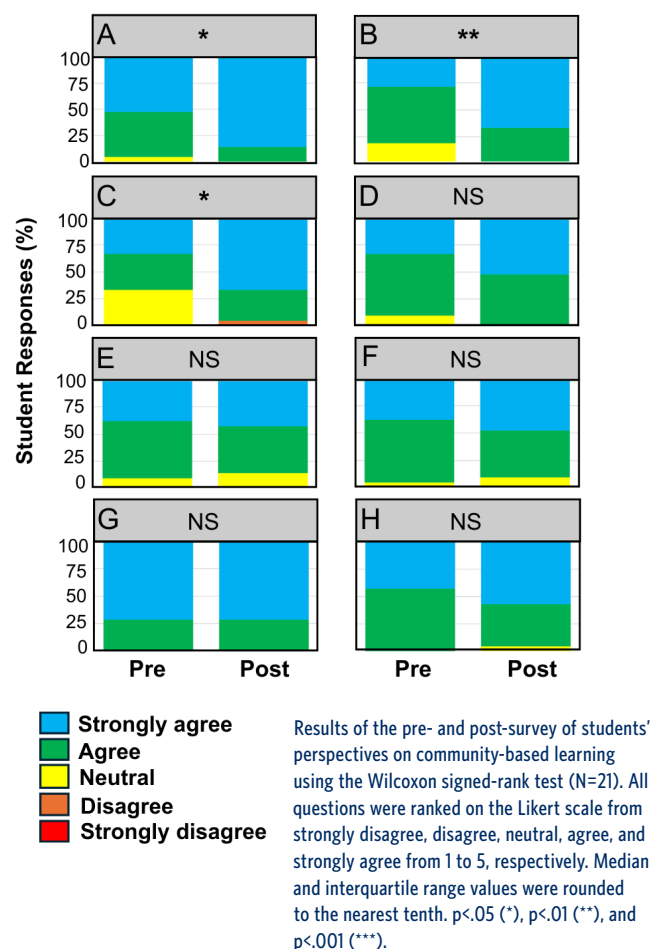
QUOTE
"I believe this partnership was an extremely effective way to learn environmental microbiology, proving that experiential learning strengthens understanding far more than classroom learning alone."
"Through this community engagement collaboration, we not only gained hands-on experience in a lab but also field experience that connected classroom learning to real-world application ... I also appreciated knowing that our testing served a larger purpose beyond the classroom."
"It's one thing to sit in class and learn about microbes and their effects, which is great, but getting to see it in action and actually being able to be part of something bigger than ourselves is such an eye-opening opportunity."
"The partnership with KyWW is a great way to learn, it changes things like serial dilution and <i>E. coli</i> calculations from abstract steps into tools for helping the community."
"While we have discussed <i>E. coli</i> in coursework, using the IDEXX protocol to quantify its actual presence in a campus creek made the public health implications feel immediate and eye-opening. It was exciting as a class to venture out of the lab setting and test waterways around campus and at nearby sites because it put a different meaning behind our time in the lab."

understanding of course lectures and readings, and combining university coursework with community-based experiences, respectively. No statistically significant changes were observed for the remaining items over the duration of the course.

Student Reflections

Following CE laboratory work, students were asked to present the collected data in a formal laboratory report and to write a 400-word reflection on their experience. Generally, students expressed enthusiasm for the CE project in their reflections. Three primary themes emerged from student reflections: reinforcement of course content (9/21), appreciation for authentic, real-world experience and skill development (12/21), and enthusiasm for laboratory work that served a meaningful purpose (15/21). Table 6 presents selected quotations from student reflections; each was written by a different student.

FIGURE 4. CE Perspectives



Discussion

In this study, students in a CE undergraduate microbiology course partnered with a nonprofit organization focused on water quality monitoring with the intention of mutually benefiting both parties. The course community partner, KyWW, benefited from gaining water quality data from 44 creek water samples to add to its database and data that informed its approach to measuring *E. coli* concentrations in water samples. Students generated comparable *E. coli* concentration data from the samples using R-cards and IDEXX Quanti-Trays, supporting KyWW's use of R-cards in their citizen scientist efforts across Kentucky. KyWW published a news article about the project on its website, highlighting its value to the organization. The article explained, "Kentucky Watershed Watch recently embraced the R-card method, which offers greater flexibility in sample logistics and helps cut costs. But how does it stack up against the tried-and-true lab techniques we've relied on for years? Enter Dr. Carroll and her dedicated team,

eager to put their skills to work in service of science and the local waterways" (Kentucky Watershed Watch, 2025).

Pre-/post-survey student assessments using the TIMSI framework showed significant increases in scientific self-efficacy and scientific identity following participation in the course, suggesting that a real-world, authentic environmental microbiology experience helped them feel more competent as scientists and see themselves as part of the scientific community. The CE coursework may have influenced scientific self-efficacy and scientific identity because students contributed real data, produced useful knowledge, and interacted with a community stakeholder. These findings align with previous reports that authentic research and CE experiences can strengthen students' scientific self-efficacy and scientific identity by allowing them to participate in meaningful scientific work (Borlee et al., 2024; Murphy & Kelp, 2023; Newell & Ulrich, 2022). Value orientation scores increased but did not reach significance. The one-semester course may not have been long enough to alter students' internalization of scientific values. Additionally, these 300-level students began the course with high scientific value orientation scores (pre-survey median=4.0), and that may have created a ceiling effect with minimal room for increases.

Because a significant portion of the microbiology laboratory class time was spent doing CE work, we felt it was important to assess students' confidence performing key microbiology laboratory tasks. Some items aligned closely with CE work (Table 4 D, E, G, and H), while others aligned with non-CE coursework. Students had laboratory class time dedicated to non-CE work, when they learned how to perform and interpret a Gram stain, run biochemical tests to identify an unknown bacterial sample, and perform enzyme-linked immunosorbent assays (ELISAs) to test for the presence of an antigen. Surveys indicated that students had increased confidence in their microbiology laboratory skills, including significant increases in students' confidence related to performing a four-quadrant streak plate, preparing and interpreting a Gram stain, and measuring *E. coli* in environmental water samples (Table 4 A, C, and D), skills that students likely hadn't acquired before taking this course, which may have contributed to the increases. Overall, students reported greater confidence performing a variety of microbiology laboratory tasks despite

spending a significant amount of course time on CE work. These findings suggest that incorporating CE activities into a microbiology laboratory curriculum does not need to come at the expense of skill development.

Assessments of students' perspectives on CE work showed significant increases in three items (Table 5 A-C), indicating that, after the CE course, students more strongly believed that the CE project helped them understand the traditional microbiology coursework and recognize the usefulness of microbiology in their lives and work. They also had higher levels of agreement with the idea that more university courses should have a CE component, indicating their support of community partnerships as a way to enhance learning more generally.

Student reflections were overall positive and enthusiastic about the project. It is possible that the reflections were somewhat performative, as students knew their instructor would read them. However, throughout the semester, students consistently showed positive attitudes and genuine effort when completing CE tasks. Student reflections frequently emphasized enthusiasm for laboratory work that served a meaningful purpose (15/21), suggesting that students viewed the work as meaningful beyond course completion requirements. Students also expressed appreciation for real-world experience (12/21), indicating that they valued opportunities to apply microbiology concepts outside of a traditional classroom context. Students' appreciation for purposeful, authentic scientific work may help explain the observed increases in scientific identity and self-efficacy. Participation in laboratory work that generated data for a community partner may have allowed students to view themselves as contributors to scientific and civic work with tangible impacts rather than solely as learners completing course requirements.

Because most students planned careers in health professions, it was uncertain whether they would perceive an environmental microbiology project as relevant and interesting. However, student reflections suggested strong engagement despite the indirect connection to the students' professional goals.

The study results have several limitations. The sample size is small ($N=21$), and there was no control group, as all students participated in the CE project. The one-semester time frame was also limited. The CE project will continue

in future semesters, and future iterations will strive to provide optimal outcomes for students and KyWW. Studies that replicate these findings across multiple semesters or compare the effects to traditional microbiology laboratory activities could build on the results. Additionally, analysis of the longitudinal effects on career development could paint a clearer picture of the project's long-term effects. Despite these limitations, the findings suggest that CE microbiology can simultaneously support student development and positive laboratory learning outcomes, while fostering meaningful community partnerships.

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PROJECT REPORT

The Regenerative Bioscience Open House: A Promising Community-Engaged Outreach Initiative

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Abstract

This article presents a case study of the Regenerative Bioscience (RBIO) Open House, a community-engaged science outreach initiative designed to reach secondary students and science teachers. The project emerged in response to community-identified needs for greater exposure to advanced science topics, career awareness, and personal interaction with scientists. The event offered high school students and teachers an immersive introduction to regenerative bioscience, a field with broad implications for biomedicine. Students engaged with researchers, exploring cutting-edge therapies and biotechnologies through interactive programming. Teachers gained content knowledge, pedagogical resources, and hands-on experience to integrate into their curricula. The event also

served the regenerative bioscience community by enabling scientist-teacher collaboration and by facilitating student recruitment. Survey data revealed strong alignment with project goals and highlighted the reciprocal benefits of meaningful outreach. As a model of community-engaged scholarship, the RBIO Open House represents a promising approach to science engagement, workforce development, and academic-community partnership.

Introduction and Literature Review

Secondary science education plays a foundational role in shaping how students understand the world and envision their role within it. However, even the most thoughtfully designed curricula often cannot capture the depth, complexity, or interdisciplinary nature of contemporary

scientific fields. As a result, secondary students often lack exposure to advanced STEM fields and do not have a clear sense of how science evolves through experimentation, innovation, and collaboration, which can impact their interest in and preparedness for further scientific study (National Research Council, 2012; Nagle, 2013). These limitations can create an artificial distance between students and science, particularly for those whose schools lack the resources to supplement classroom instruction with experiential or research-based learning.

Regenerative bioscience is a multidisciplinary field that investigates the cellular and molecular mechanisms underlying tissue growth, repair, and replacement. Drawing upon tools from developmental biology and bioengineering, it explores the regenerative capacity of living systems and the potential to harness these processes for therapeutic use. A subset of this field, regenerative medicine, is focused on the clinical translation of regenerative bioscience approaches to restore or replace damaged tissues and organs. The term broadly encompasses cell and gene therapies (CGT), as well as tissue engineering, nanotherapies, and biomaterials (Yamada et al., 2021).

The field of regenerative bioscience represents both the promise and the inaccessibility of modern science. While technologies are advancing rapidly and moving from laboratory discoveries to clinical applications within a matter of years, public understanding remains limited, especially among youth (National Academies of Sciences, Engineering, and Medicine, 2017). Introducing students to this field in ways that are interactive and inclusive can help foster awareness, as well as a sense of possibility and belonging in science (Chen et al., 2016). This is also vital to developing the regenerative medicine workforce: it is imperative to train and support the burgeoning scientists and healthcare practitioners who will go on to innovate and administer these therapies (Hopewell et al., 2024).

To address these challenges, universities must take a more active role in bridging the gap between advanced scientific research and the communities they serve (Rollwagen-Bollens et al., 2022). Community-engaged science programming offers one avenue for doing so; by partnering with local educators, scientists and institutions can co-create learning experiences that are both rigorous and accessible. In the sections that follow, we outline key frameworks that guided the development of one such

initiative, the Regenerative Bioscience (RBIO) Open House, and situate it within the broader literature on science identity, educator partnerships, public engagement, and workforce development.

Youth Engagement and Science Identity

National data show that while many 10- to 14-year-old students enjoy science and recognize its societal value, relatively few aspire to become scientists. This disconnect between science interest and aspiration may stem from gaps in identity formation, access to mentorship, and early exposure to career pathways (Woods-Townsend et al., 2016). Stereotypical perceptions of science and scientists can adversely impact students' motivation, self-efficacy, and ability to envision themselves in science-related roles (Barry et al., 2023; González-Espada, 2007; Woods-Townsend et al., 2016). Student-scientist interactions can play a powerful role in closing these gaps by guiding adolescents to consider themselves capable of succeeding in scientific careers. Scientific educational outreach increases understanding of the sciences while fostering positive relationships between young people and scientists.

The American Association for the Advancement of Science (AAAS) emphasizes that all students should have access to high-quality science education, and that barriers such as age, gender, or cultural or socioeconomic background must not impede this goal (American Association for the Advancement of Science, 1990). Despite rapid advancements in biomedical research and biotechnology, high school students, particularly in rural or under-resourced school districts, often lack meaningful opportunities to engage with emerging scientific fields (Goldman, 2019; Means, 2019). Many students encounter barriers to participation long before college, including limited course offerings, few extracurricular science experiences, and little contact with practicing scientists. These barriers can impact students' knowledge and influence their self-belief.

Regenerative bioscience is emblematic of this barrier to access: as a highly interdisciplinary and rapidly evolving area of research, it is rarely included in high school curricula and remains inaccessible to most secondary students. Without intervention, this gap not only limits public understanding of science, but also narrows the future workforce pipeline. Programs that provide direct engagement with scientists can enhance students' interest

in science, demystify the scientific process, and support the development of a science identity (Barry et al., 2023; Kompella et al., 2020; Salonen et al., 2017). Research on science identity suggests that early exposure to scientific ideas, tools, and mentors is essential for fostering a sense of belonging in science and supporting long-term persistence in STEM pathways (Penuel et al., 2024; Vossen et al., 2023).

Supporting Science Educators as Community Partners

Teachers play a dual role in science outreach: as learners gaining exposure to current research and as educators translating that knowledge into pedagogical models of scientific practice (Houseal et al., 2014; Shanahan, M.-C., & Bechtel, R., 2020). They also act as influential connectors, guiding students toward post-secondary opportunities in science and healthcare. Yet, a persistent gap exists between those who teach science and those who practice it (Abramowitz et al., 2024; González-Espada, 2007). Scientist-teacher partnerships are crucial in bridging this divide: they augment teachers' pedagogical content knowledge and confidence, while drawing on the complementary strengths of both groups (Abramowitz et al., 2021; Houseal et al., 2014). Scientists contribute content expertise, while teachers offer instructional skill and deeper relationships with students (González-Espada, 2007).

Although secondary educators play a critical role in shaping students' experiences with science, they often face their own set of barriers when it comes to integrating new content areas into their teaching. As a parallel discipline to regenerative bioscience, biotechnology also represents a high-demand but underrepresented field within high school curricula, and secondary school teachers often feel underprepared and overwhelmed by the prospect of biotechnology instruction (Borgerding et al., 2013). Consequently, professional development in this area will be essential for teachers to keep pace with evolving educational paradigms and emerging technologies (Bates et al., 2022; Mihir Kumar Jena, 2024). Engaged outreach initiatives can enable teachers' professional development and provide the support they need to effectively guide their students.

Mutual Learning and the Role of University Scientists

Community engagement literature emphasizes that outreach should not be a one-way transfer of knowledge, but rather a reciprocal exchange in which all parties gain value (Clark et al., 2016; Reyes-Arriagada et al., 2021). These reflections align with a growing body of research advocating for public engagement as a form of professional development and pedagogical training for early-career scientists. Participation in such collaborations enables scientists, especially trainees, to hone their skills in communication, mentoring, and teaching, while serving as accessible role models for students (Abramowitz et al., 2021; Kompella et al., 2020). Explaining complex research to non-specialist audiences has been shown to measurably improve scientists' communication abilities and can positively shift attitudes toward the importance of outreach and public engagement (Clark et al., 2016; Kompella et al., 2020). Additionally, science communication skills are highly transferable across a vast array of science careers; thus, participating in educational outreach can serve as a valuable career development opportunity for scientists (Ritchie & McCartney, 2019). Beyond professional skill development, the personal benefits of community-engaged outreach are equally significant. Scientists who participate in public-facing outreach often report increased self-efficacy, a deeper sense of connection to their communities, and enhanced personal fulfillment (Abramowitz et al., 2021).

The Public Engagement Imperative and Workforce Readiness

Public engagement is essential to cultivating a scientifically literate society capable of making educated decisions about health and medicine. As biomedical technologies grow more complex, science communication must evolve to empower public understanding and support informed decision-making (National Academies of Sciences, Engineering, and Medicine, 2017). Equipping the public with this understanding as early as possible is an educational priority and an ethical imperative. Effective engagement also fosters trust between scientists and communities, promotes transparency in scientific practices, and enables scientific citizenship, particularly

among individuals historically excluded from traditional academic and clinical spaces (Ballard et al., 2023; Rufo, 2017). As regenerative therapies advance toward clinical application, individuals and families will increasingly face choices about cell-based treatments, gene therapies, and novel diagnostics. Higher education institutions, particularly those conducting cutting-edge biomedical research, have a responsibility to make this knowledge accessible (Regenberg & Schall, 2015). By engaging youth in regenerative bioscience, universities can help to cultivate an informed public, including future patients, caregivers, voters, and decision-makers. Even students who do not pursue science careers benefit from understanding technologies that may one day shape their lives or the lives of those they love.

The need for public engagement with science extends beyond educational equity; it is also central to workforce development. As of 2025, Georgia is home to more than 330 life sciences operations, employing over 36,000 professionals, as well as 500,000 healthcare practitioners and support workers—representing a 40% increase since 2010 (Georgia Power/Economic Development, 2026). The state ranks 14th nationally in bio-related occupational employment, and life science jobs are projected to grow 12% in the next decade, with continued expansion across sectors such as pharmaceuticals, diagnostics, and medical device manufacturing (Georgia Power/Economic Development, 2026). As regenerative medicine becomes more central to the biomedical economy in Georgia and beyond, the demand for a highly qualified workforce will continue to grow.

Although still a nascent field, regenerative medicine is rapidly developing on a national scale. As of May 2025, the U.S. FDA Office of Therapeutic Products has licensed 45 cellular and gene therapy CGT products—more than 1.6 times the total approved just two years prior—signaling a dramatic rise in demand. Unlike traditional biologics, such as monoclonal antibodies or vaccines, these “living therapies” require highly specialized biomanufacturing processes, analytical validation, and robust quality control strategies to ensure safety and potency. This complexity has contributed to persistent and growing workforce gaps across CGT manufacturing, quality control, and regulatory compliance (Fekete et al., 2023). Without targeted investment in workforce development, these gaps risk

delaying product development and limiting patient access to life-saving therapies (Hopewell et al., 2024).

While significant attention has been devoted to addressing the physician training gap in regenerative medicine (Schulman et al., 2015; Wyles et al., 2019; Wyles et al., 2021; Yamada et al., 2021), fewer efforts have been undertaken to embed foundational regenerative bioscience in secondary and undergraduate science curricula (Bajek & Drewa, 2011; Sandoval et al., 2022). Consequently, the next generation of scientists and physicians is largely unaware of the potential career opportunities in this field and the training necessary for employment, including technical skills in bioprocessing, cell and molecular biology, biomedical engineering, and regulatory sciences. The Alliance for Regenerative Medicine has called for the inclusion of regenerative medicine, including CGT content, in education and outreach programs at all levels to prepare future scientists, clinicians, and technicians for careers in this emerging dynamic discipline (Fekete et al., 2023). As regenerative bioscience emerges as a transformative field across biotechnology and medicine, there is a growing need to train a workforce with core competencies in the cellular and molecular tools that underpin these innovations.

Supporting scientific citizenship and career exploration through educational outreach reinforces the critical role of universities in preparing communities for a rapidly evolving healthcare landscape. This article presents a case study of the Regenerative Bioscience (RBIO) Open House, a pilot outreach initiative rooted in scientist-teacher partnership and developed to address intersecting needs in science access, identity development, and workforce preparation. By centering community needs, promoting mutual learning, and leveraging university resources, the project offers a replicable model for community-engaged educational outreach.

Institutional Context and Community-Identified Needs

Within a land-grant institution with a public mission to promote statewide access to higher education, workforce development, and public engagement with scholarship, the research center spearheading this RBIO Open House is a multidisciplinary hub for research and innovation in

cellular therapies, tissue engineering, and translational medicine. The RBIO community spans multiple departments and colleges, leveraging the expertise of over 40 scientists with diverse research interests. Through its collaborative research and training mission, the research center advances fundamental science while preparing future leaders in regenerative medicine and allied health professions. However, awareness of regenerative bioscience and the educational programs in this discipline remain limited.

In the fall of 2024, scientists in the center initiated a partnership with a biotechnology instructor at a regional career academy who also serves as the state coordinator for the Biotechnology Aptitude and Competency Exam (BACE). From the outset, the planning process was intentionally community-responsive: the event's structure, messaging, and activities were shaped by conversations with our partner to assess gaps in science engagement and develop a reciprocal outreach initiative, thereby ensuring alignment with community needs. This emphasis on co-creation and reciprocity reflects best practices in community engagement, which center mutual benefit and shared authority in the design and implementation of outreach. Through this collaboration, we identified several consistent needs among secondary students and science teachers:

1. Foundational awareness of regenerative bioscience as an emerging field in healthcare and biotechnology
2. Exposure to career pathways in regenerative bioscience
3. Opportunities to interact directly with scientists through both mentorship and hands-on learning.

These needs echo broader state and national concerns about equity in STEM education and access to life science careers, as biotechnology remains a growing but underrepresented pathway in high school curricula, and many teachers report limited professional development opportunities in this area. Meanwhile, the state's bioscience industry continues to expand, requiring a pipeline of future workers with the necessary skills. Outreach initiatives that bridge university research with secondary education are increasingly essential to fill these gaps and make advanced science more inclusive.

Centers like ours are uniquely positioned to help address these disparities, due both to the number of research scientists capable of teaching and mentoring students and to their wide range of expertise, which can be leveraged in collaboration with community leaders. Additionally, community-engaged programs that bridge university research and secondary education serve to foster public trust and investment in science, which is of particular importance to advancing the adoption of regenerative therapies. The RBIO Open House was developed in direct response to these needs, offering students and teachers an opportunity to interact with our research in a way that was approachable, interactive, and responsive to local interests.

Project Description

The RBIO Open House was developed as a full-day educational outreach event designed to introduce secondary students and teachers to the interdisciplinary field of regenerative bioscience. The event was held on Saturday, December 7, 2024. Registration was promoted statewide through direct outreach to secondary science teachers and administrators, existing university and community partner networks, school and professional-organization newsletters, social media, and word of mouth. Secondary students and science teachers were the primary intended audience, and they were welcome to attend with accompanying family members, including their parents, siblings, and children. The event was structured to reflect three core aims: to increase foundational awareness of regenerative bioscience, to expose participants to diverse career paths in biotechnology and biomedical research, and to create opportunities for students and teachers to engage directly with scientists in a welcoming, hands-on environment.

The design of the event reflected principles of community engagement, including co-development with a community leader, responsiveness to stakeholder feedback, and an emphasis on mutual benefit. The format was intended to balance informative presentations with interactive learning experiences that would appeal to a diverse audience. In alignment with the university's mission of public service and outreach, the RBIO Open House was framed as a pilot model for science engagement that

could be scaled or adapted by other departments and institutions.

The day was divided into two portions: a structured morning session focused on foundational learning and a more exploratory afternoon session featuring hands-on demonstrations. All attendees participated together in the morning program in a large lecture hall; the session began with an interactive game of Regenerative Bioscience Bingo, developed as a warm-up activity to introduce key concepts and terminology in a fun, accessible way. This activity was intended to scaffold understanding for the presentations that followed, including a brief program overview by the RBIO undergraduate coordinator and short introductions from faculty instructors. Near-peer mentors, current undergraduate students in the regenerative bioscience major, led a student Q&A session to share their own journeys and answer questions about college and the RBIO program.

Following a catered lunch, the afternoon featured an Exhibitor Fair hosted by 22 graduate students from 11 RBIO research laboratories, staggered along the teaching wing of the facility. Each exhibitor table was designed to provide hands-on or visual demonstrations related to ongoing research projects in regenerative bioscience, including cell culture, tissue engineering, and molecular diagnostics (Photoset 1). Guests moved through these stations at their own pace and could ask questions, explore lab materials, and learn more about the scientific process by connecting directly with the graduate student exhibitors. Concurrently, RBIO faculty and graduate students hosted a stem cell culture demonstration and guided activity in the facility's teaching laboratory, also located within the teaching wing, where guests learned about the principles of stem cell biology and basic cell handling practices. Guests who wished to participate signed up for one of two afternoon time slots for the laboratory activity. The goal of this portion of the event was to demystify laboratory research and promote a more inclusive vision of who can become a scientist.

Exhibitor Fair Tables Representing RBIO Laboratories

PHOTOSET 1.



The lab activities and demonstrations included: (A) regeneration of small worms called planaria, pictured in labeled dishes; (B) stem cells in embryos, using chicken eggs as a model; (C) brain cells and how they signal in both healthy and degenerative disease states; and (D) brain regeneration in cancer and acute injury using rodent brains.

The day concluded with the distribution of goodie bags containing gifts and educational materials for both students and teachers. Throughout the event, the RBIO Open House employed a variety of evidence-based teaching strategies, including game-based learning, near-peer mentoring, and experiential science engagement. Overall, the event was structured to promote reciprocal engagement between the university and local schools. Rather than delivering content in a traditional lecture format, the design emphasized active learning and open dialogue. While long-term outcomes have yet to be studied, the Open House was intended as an opportunity to build trust, spark curiosity, and lay the groundwork for future collaboration between the RBIO research community and Georgia educators.

Early Indications of Impact

To evaluate the Open House's efficacy in meeting its community-identified goals, we invited student and teacher attendees to complete a voluntary feedback survey. The

University of Georgia Human Research Protection Program (HRPP) Office reviewed the manuscript and the activities described herein and issued a Not Human Research Determination, declaring that the project did not constitute research involving human subjects as defined by DHHS and FDA regulations and that the activity fell within a regulatory exception for scholarly activities. Therefore, IRB review and approval were not required. Responses helped us to understand how participants engaged with the program and what areas might be improved in future iterations. Findings are organized below by stakeholder group, reflecting the event's multifaceted design and its alignment with the literature on science identity, workforce development, and engaged scholarship.

Student Engagement and Science Identity Development

The RBIO Open House was intentionally designed to reach students across the state of Georgia, ultimately drawing registrants from sixteen counties (Table 1). The geographic distribution of registrants and attendees reflects both the strength of our marketing efforts and areas for future growth. Urban and suburban counties were well represented; specifically, our outreach to nearby counties was effective, likely due to local advertising and the influence of our community partner. In contrast, participation from rural counties remained low despite registrations. Ultimately, only three rural guests attended the event (Table 1). This disparity underscores the broader challenges in connecting rural communities to higher education outreach and emerging STEM fields (Goldman, 2019; Means, 2019).

TABLE 1. Registrant and Attendee Distribution by County Type

COUNTY TYPE ¹	REGISTRANTS	ATTENDEES
Rural	8	3
Urban/Suburban	31	23
Total	39	26

¹ County designations are based on data provided by the State Office of Rural Health, within the Georgia Department of Community Health.

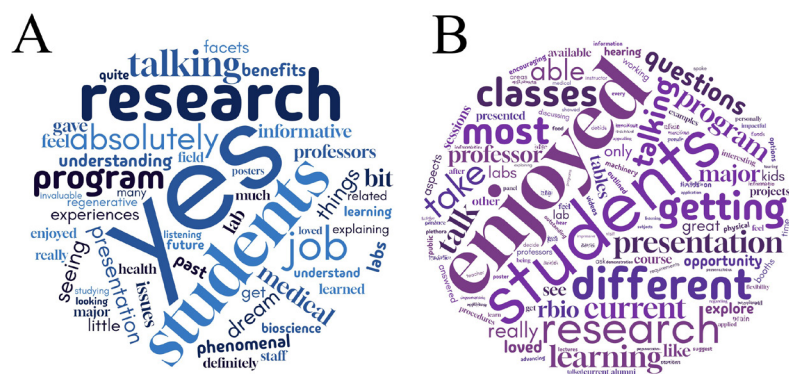
This table summarizes the geographic representation of the RBIO Open House, categorized by county type. Counties were classified as "rural" or "urban/suburban" based on the 2021 designations from the State Office of Rural Health and provided by the Georgia Department of Community Health. Although registration was open statewide, participation was highest among schools from urban and suburban counties, suggesting the need for targeted outreach and logistical support to improve access for rural regions.

Many student responses emphasized the value of interacting directly with scientists in an approachable and hands-on setting. The combination of guided activities, visual demonstrations, and casual Q&A with RBIO students and faculty contributed to an environment that encouraged curiosity and helped students feel more connected to their future in the field. One student attendee commented:

"I loved when the professors took the stage to talk about the subjects they teach, and also when we were able to visit different tables to take a closer look at research examples. The two parts were most memorable for me as it answered a lot of questions I had about the program, and allowed me to explore what I wanted to learn about."

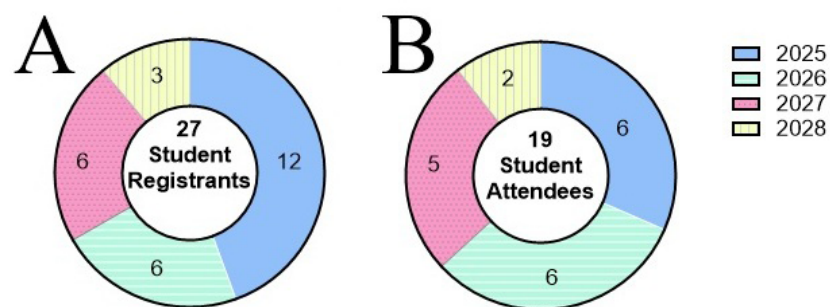
The event's impact was further reflected in qualitative responses to the feedback survey, completed voluntarily by 18 attendees. When asked whether the event supported their understanding of regenerative bioscience and the RBIO program, participants frequently used words related to learning, such as *studying*, *listening*, *understanding*, and *informative*, as well as aspirational terms like *dream*, *future*, and *job*. When describing what they found most enjoyable or impactful, attendees captured the essence of our student-centered approach, with *students* being the most frequent word to appear in their responses, followed by *research* and *classes* (Figure 1). Many remarked on the value of interacting with current RBIO students and faculty, and praised the hands-on, research-rich activities. These responses affirm the event's success in making regenerative bioscience and the broader work of the research center accessible, engaging, and relevant for our guests.

FIGURE 1. Word Clouds of the Long-Answer Responses Provided by Attendees



Eighteen answers were submitted in response to the questions (A) "Did our program support your understanding of and answer your questions about the field of regenerative bioscience and the RBIO program?" and (B) "What part(s) of our program for the day did you enjoy or find most impactful?", with larger font sizes in the word clouds indicating greater frequency in responses.

FIGURE 2. Graduation Year Distribution of Secondary Students



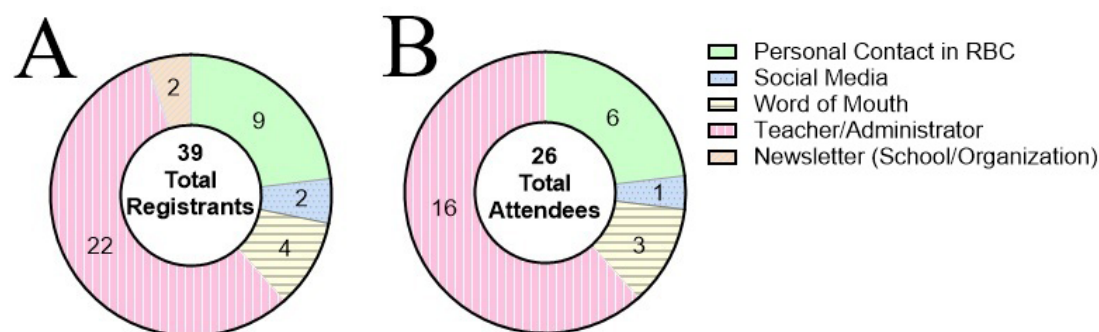
The distribution of (A) student *registrants* by graduation year, indicating a strong interest from upperclassmen, and (B) student *attendees*, showing the proportions of those who participated in the event

Eighteen answers were submitted in response to the questions (A) "Did our program support your understanding of and answer your questions about the field of regenerative bioscience and the RBIO program?" and (B) "What part(s) of our program for the day did you enjoy or find most impactful?", with larger font sizes in the word clouds indicating greater frequency in responses.

Upperclassmen (classes of 2025 and 2026) constituted the majority of student attendees, likely reflecting their proximity to college decision-making. However, half of

registered seniors did not attend, suggesting that they may have already finalized their post-secondary plans and were less motivated to explore a new major (Figure 2). Engagement from younger students (classes of 2027 and 2028) signals a growing curiosity about regenerative bioscience and an opportunity to build early connections with future applicants. Although promotional materials, including flyers and social media posts, targeted high school juniors and seniors, participation across grade levels highlights the broad appeal of the Open House and its potential to reach both immediate and long-term audiences. These findings affirm the value

FIGURE 3. RBIO Open House Recruitment by Advertisement Approach



Avenues through which (A) registrants and (B) attendees learned of the event, highlighting the significant role of educators and direct connections in spreading awareness about the event

of hands-on, interactive outreach in shaping science interest and identity (Kompella et al., 2020).

Teacher Integration and Classroom Integration

Recognizing that science teachers often serve as key advisors to students exploring future careers, we were interested in understanding their role in distributing information about the event. Registrants and attendees indicated the avenues through which they learned about the RBIO Open House; educators and personal contacts emerged as the most influential sources, especially teachers, administrators, and direct outreach within the RBIO community network. While some individuals registered via more impersonal channels, including school and organizational newsletters, there were ultimately no attendees from these groups (Figure 3). It is likely that many students were encouraged or accompanied by their science teachers, which may have increased their comfort in what might otherwise have been an intimidating setting. These patterns underscore the value of cultivating scientist-teacher partnerships to expand awareness and participation in outreach efforts.

The scientist-teacher partnership between the research center and our community collaborator, a secondary education and workforce development specialist, exemplifies the power of co-creation in academic-community engagement. This relationship informed both the content and format of the Open House and supported an alignment with real classroom needs. Based on his

guidance, we determined that a central goal of the event would be to equip educators with tools and resources to integrate regenerative bioscience content into their curricula. This included specialized goodie bags containing additional materials, resources, and contact information, which were identified as high-priority by our community partner. Teachers expressed appreciation for the opportunity to connect with university researchers and explore new content areas for their classrooms. Several reported that the event helped them better understand regenerative bioscience and how to communicate its relevance to students. Feedback from teachers also highlighted areas for future collaboration and sustained scientist-teacher partnerships. Many requested follow-up opportunities such as field trips, virtual guest lectures, or virtual curriculum modules. One secondary educator wrote:

"If it is possible, I would like to have a speaker come and talk about your program, but also your research topics. I teach AP Environmental Science and Honors Biology at [redacted] High School and would love to have the opportunity for our students to see what research is possible and what they could major in. With the discussion about genetic research and cell therapies, this is right in line with our biology classes and will be the perfect presentation. I honestly would love for all biology classes to have the option to have you come and speak to them."

Scientist Participation and Mutual Benefit

Research has shown that programs grounded in scientist-teacher partnerships generate positive outcomes for all participants and address a well-documented need for greater public engagement with science (Abramowitz et al., 2021; Clark et al., 2016). At the RBIO Open House, 22 graduate students and 10 faculty members participated in the Exhibitor Fair and hands-on activities; while not formally requested or recorded, their unsolicited perceptions of the event were overwhelmingly positive, aligning with existing research on the benefits of scientist engagement in community-centered programming. Many noted that this was a worthwhile experience which helped them articulate their research more clearly and build confidence in engaging with non-specialist audiences. One exhibitor shared that it was their first time explaining their work to families and that the challenge of doing so was both energizing and rewarding. This mutual benefit of providing professional development for university scientists while supporting public engagement is a key principle of community-engaged scholarship. While not formally assessed in this pilot event, the enthusiasm and reflections shared by presenters suggest that future iterations of the RBIO Open House could incorporate more intentional evaluation of student-scientist outcomes.

Lessons Learned and Feedback to Action

The RBIO Open House was designed to inspire the next generation of scientists and healthcare professionals while raising awareness about the transformative potential of regenerative bioscience. By engaging both students and educators, the event sought to demystify advanced scientific concepts, introduce career pathways, and support workforce development in this emerging field. Our analysis of event data and participant feedback surfaced several key lessons, which will guide the construction of future events and may be valuable to other institutions seeking to replicate this work.

Lessons Learned

1. Strong community partnerships drive success.

Collaborating with a workforce development specialist in secondary education ensured that the event addressed

authentic community-identified needs and that our event format and content were relevant and accessible. This partnership informed the structure of the day, helped to craft teacher-specific materials, and extended our outreach through established educator networks. However, we also recognize that the community-identified needs we set out to meet were broadly articulated; the needs of pre-college students and science teachers in Georgia are diverse and may evolve or expand just as our scientist-teacher partnerships do.

2. Reaching rural communities requires deeper investment.

While the event reached registrants from 16 counties, it drew attendees from only 11 counties, and rural communities were underrepresented (Table 1). Most attendees came from counties with direct ties to our community partner, illustrating the importance of relationship-driven outreach. To address this, we plan to pursue earlier and deeper engagement with educators, administrators, and community-based organizations in rural school systems. Additional options to improve access, including transportation assistance and developing a parallel virtual experience, will also be explored.

3. Personal connections outperform mass marketing, but recruitment efforts must minimize gatekeeping.

Our analysis showed that most attendees learned about the event through teachers or personal recommendations. By contrast, promotion through newsletters and social media yielded little measurable engagement (Figure 3). This pattern reveals an important limitation. Because the event was advertised primarily to students interested in science or health, and since participation was voluntary, attendees likely represented a self-selected group with at least some pre-existing interest in STEM. Reliance on teacher-mediated outreach may also unintentionally narrow access if opportunities primarily reach students who are already recognized as "science students." Informal STEM scholarship cautions that educator practices can shape who gains access to and feels welcome in enrichment spaces, and established biomedical outreach programs have addressed this concern by recruiting students based on who may benefit from exposure rather than on prior achievement or an established commitment to science (Greenberg et al., 2025; Witzel et al., 2020). Future recruitment will

therefore preserve strong educator partnerships while broadening outreach through school counselors, public libraries, youth organizations, rural community partners, and messaging that explicitly welcomes students who are curious about science but do not yet strongly identify with it.

4. Future assessment should include scientist outcomes.

For graduate student exhibitors and undergraduate near-peer mentors, the event served as an opportunity to build science communication and mentoring skills in a real-world setting. Intentionally designing space for mutual learning, and providing more preparatory training in future iterations, can increase the professional development value for university participants. While the evaluation of the first RBIO Open House focused on participant feedback and demographics, future assessment efforts will also include surveying graduate and undergraduate student volunteers and faculty about their experience of the event. Given the documented benefits of community-engaged scholarship for scientists, we would like to better understand how the Open House influenced trainees via validated evaluation strategies.

Feedback to Action

Survey responses from attendees emphasized the value of personal interactions with scientists and hands-on experiences with regenerative bioscience tools and topics (Figure 1). Our guests expressed a desire for more opportunities to engage deeply with the center's research and training mission. Future iterations of the RBIO Open House will incorporate community feedback aimed at enhancing this impact.

1. Breakout sessions

Our community partner remarked that secondary science teachers would benefit from more guidance and support in incorporating RBIO content in their own classrooms. While this first iteration of the Open House may have provided inspiration, our future events will include more deliberate coaching, which will enable these science teachers to better teach RBIO concepts. Similarly, feedback from secondary student attendees reflected an appreciation for interactions with current university students,

with several participants indicating that speaking with RBIO undergraduates was the most impactful part of the day, and that they would have liked to hear more student stories. Smaller, dedicated breakout sessions will allow for more tailored engagement; while secondary science teachers co-develop lesson plans with RBIO instructors, high school students will benefit from additional near-peer mentoring by current RBIO undergraduates, and more focused time to ask questions about college, research, and the student experience.

2. Guided laboratory tours

Interactive activities like Regenerative Bioscience Bingo and lab demonstrations were consistently cited as highlights, as these hands-on elements not only supported knowledge retention but also fostered excitement and confidence among students. Many participants asked about touring the center's facilities, and while we were not able to invite visitors into the laboratories during our first RBIO Open House due to scheduled building maintenance, we intend to do so in the future to further encourage these feelings of enthusiasm. Graduate students will lead staggered small group tours of select laboratories, offering guests a closer look at the scientific environment and active research underway. We will station current undergraduate research assistants in each of the labs to greet guests, answer questions about their experiences conducting research, and demonstrate some of their ongoing work.

3. Expanded research displays

One feedback survey response specifically commented on the benefits of seeing what a poster presentation should look like. Although only a few of the tables featured a poster in their displays, the event space could be made more functional by taking advantage of unused wall space to support learning. For future Open House events, graduate students from each lab will bring their own research posters to line the hallways. This would pair well with the guided lab tours, as the posters would serve as a precursor to the research overviews.

Conclusion

The RBIO Open House was developed in response to community-identified needs and grounded in principles of community-engaged outreach. The event set out to make advanced science accessible, to support local educators, and to inspire students from all backgrounds to see themselves in scientific roles. While the program was modest in scope, it serves as a meaningful example of how university-led outreach can be designed not only to inform, but also to deeply engage future scientists in active learning processes. The RBIO Open House will continue to evolve based on our target community needs, and future iterations will incorporate structured evaluation tools in order for all stakeholder groups to better assess the reciprocal impacts of participation. This project contributes to ongoing conversations about the role of higher education in preparing a scientifically literate, workforce-ready public. As institutions seek to expand their community engagement efforts, especially in the sciences, it is critical to adopt approaches that are responsive and relationship-driven. The essence of co-creation and mutual benefit that guided the planning of the RBIO Open House offers a replicable foundation for such work. The combination of these elements will prepare students, support educators, and strengthen the regenerative bioscience workforce pipeline in Georgia and beyond.

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RESEARCH ARTICLE

Evaluating an Integrated Independent Study Model for Science-Art Collaborations

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Abstract

Science-art collaborations allow practitioners to exercise interdisciplinary skills and build relationship networks, while simultaneously presenting opportunities to teach about science through art. Yet collaborations between scientists and artists are limited by challenges such as identifying collaborators, accessing resources, and working across disciplines. To address these challenges, we integrated student artists into an ecology research lab, using a modified version of the independent study model, where researchers worked with six student artists to

create visual artworks about wetland ecology. These student works were exhibited at a campus art show intended to informally educate about wetland wildlife research. Interviews with student artists showed that the collaboration offered them opportunities to grow career-relevant, interdisciplinary skills. Furthermore, visitor evaluations showed that attending the exhibit facilitated learning about wetland wildlife and ecological research. We provide reflections on and recommendations for building on this model, as one opportunity to reduce existing barriers to science-art collaborations in higher education settings.

Introduction

Visual art as a strategy for teaching about scientific topics has gained increased attention in recent years because of its ability to effectively facilitate knowledge acquisition, emotional engagement, and behavioral changes among diverse audiences (Adkins et al., 2018; Bättig-Frey et al., 2018; Bentz & O'Brien, 2019; Brock et al., 2022; Jacobson et al., 2007; Lesen et al., 2016; Ricci & Li, 2024; Sommer et al., 2019). Particularly in contrast to other modes of teaching, visual arts have been praised for their ability to evoke emotional and personal reflections on science-related issues (Li et al., 2023; Ricci et al., 2023, 2024; Silvia, 2005). Beyond the benefit to learners, the creation of artistic teaching tools also offers an opportunity for practitioners to engage in cross-disciplinary collaboration, as creating science-art often necessitates partnership between scientists and artists. Scientist-artist collaborations offer many benefits to practitioners, such as heightening cross-disciplinary understanding, deepening connections with science and nature, and facilitating new relationship networks (Colavito et al., 2020; Heras et al., 2021). Consequently, both the practice of creating science-art tools, as well as the use of those tools to teach about science, are areas of increasing interest to scientists, artists, and educators alike.

Despite the growing attention to science-art, practical barriers to interdisciplinary initiatives can limit the opportunities for interested parties to create these projects (Black et al., 2023). It is not easy to acquire the necessary time, funding, and personnel required to make science-art collaborations possible, and both scientists (Black et al., 2023) and artists (Gewin, 2021) report difficulty in identifying and contacting potential collaborators. Furthermore, scientists and artists are often challenged by the differing practices and norms of the other discipline; while scientists prioritize structure and rapid timelines, artists typically require more flexibility and opportunities for iteration (Black et al., 2023; Heras et al., 2021).

In this piece, we propose a practice to overcome some of these barriers: integrating student artists into science research labs, using the independent study model. Efforts to integrate the arts and sciences within formal coursework settings have found success in engaging students across science, technology, and humanities disciplines (Adkins et al., 2018; Bentz, 2020; Needle et al., 2007), yet

independent study as a mode of facilitating collaboration between scientists and artists remains largely unexplored. Many scientists who are affiliated with colleges and universities already engage in independent study or apprenticeship models to train science students by providing professional support, mentorship, academic course credit, and material resources (Ahmad & Al-Thani, 2022; Sadler et al., 2010). Independent study allows space for both structure and creativity, as projects are mentored by a senior researcher while students contribute their own creative directions (Council on Undergraduate Research, 2021). By creating a similar space for art students within a science lab, we reason that everyone stands to benefit: scientists can connect with interested artists and reduce barriers associated with science-art projects (e.g., time, personnel), student artists can benefit from opportunities available through independent study (e.g., mentorship, course credit), and all can grow through the practice of interdisciplinary collaboration (e.g., broadening understanding, building relationships).

From a student development perspective, interdisciplinary competencies like reflexivity, perspective-seeking, and integrative thinking are increasingly desired skills (Imbruce et al., 2024; Kjellberg et al., 2018; Repko & Szostak, 2020). A growing body of evidence demonstrates that integrating the arts with science is associated with positive development of these competencies for students across disciplines (Bourdeau, 2021; Imbruce et al., 2024; National Academies of Sciences, Engineering, and Medicine, 2018). Involving student artists in collaborative science-art projects has the potential to provide them with opportunities to exercise and deepen these interdisciplinary skills.

To address barriers to science-art collaborations while providing student development opportunities, we present an interdisciplinary practice that uses an independent study approach to integrate artists into scientific labs. Specifically, we describe a process in which our ecology research group collaborated with student artists to create a science-art exhibit that was subsequently exhibited to informally teach our campus community about ecology research. We evaluate our practice by asking the following questions:

1. Does integrating student artists into a science research lab using the independent study model facilitate positive experiences and opportunities to grow interdisciplinary skills for artists?
2. Does the resulting science-art exhibit promote learning and enjoyment for exhibit visitors?

Methods

Science Subject: Wetland Ecology

For the science topic of the project, we chose wetland ecology with a focus on amphibians. Wetlands are critical ecosystems that are increasingly threatened by anthropogenic change (LePage, 2011). Wetlands provide important ecosystem services, including carbon sequestration, water filtration, and protection from flooding (Mitsch et al., 2015), while also providing habitat for a rich diversity of species (Gibbs, 2000). Yet wetlands are disappearing at alarming rates, with an estimated 21% of wetlands lost globally over the past 300 years, primarily due to conversion to agricultural lands (Fluet-Chouinard et al., 2023).

Amphibians play a critical role in wetland ecosystems and are highly sensitive organisms that act as indicators of overall wetland health (Luedtke et al., 2023). Furthermore, due in part to their extreme sensitivity and vulnerability to environmental change, amphibians have been identified as the most threatened vertebrate group on Earth (Luedtke et al., 2023). The plight of amphibians represents the growing challenges associated with wetland ecosystem degradation, including pollution, habitat loss, climate change, and emerging infectious diseases (IUCN, 2024). Our research lab (hereafter, research team) is comprised of a faculty member, postdoctoral scholars, graduate students, and undergraduate students focused on researching multiple dimensions of wetland and amphibian ecology, providing the necessary topical expertise to oversee the independent study.

To guide both the independent study curriculum and the content in the final art exhibit, the research team selected three themes related to environmental challenges that wetlands face and the ways that scientists are studying them. These themes included (a) Pollutants, referring to significant wetland pollutants (e.g., antibiotics, pesticides, artificial light at night) and their effects on wetland

organisms; (b) Biological Interactions, referring to interactions between organisms in the wetlands (e.g., competition, predation, disease transmission, microbial symbiosis) and the ways that those interactions can be affected by humans; and (c) Techniques, referring to tools researchers employ to study wetland ecology (e.g., monitoring wildlife in the field, eDNA, DNA extraction, PCR, and qPCR). By selecting these specific yet broad themes, we aimed to provide structure for the artists while also allowing ample opportunities for creative directions.

Artist Recruitment

To find student artists to participate in the independent study, we used two methods. First, we leveraged an existing relationship with an undergraduate student who was currently conducting research with our research team through a traditional ecology independent study. We knew from previous work with this student that she was also an artist who had expressed interest in using her artistic skills to teach about science. This student agreed to shift her independent study to focus on creating the art exhibit and joined as our first student artist.

Second, we reached out to the university's student-run art club. Like student clubs in many higher education settings, this club is comprised of students from any discipline who are looking for community and for opportunities to make art, thus representing an ideal point of contact with interested artists. We contacted the president of the club and arranged to have a call for applications sent to all club members via email. We received seven applications from the art club, and five of those applicants agreed to attend an initial interest meeting. All who attended the interest meeting agreed to join the project.

This group of six (one student from an existing relationship and five students from the art club) ultimately comprised our group of student artists. Included among the artists were undergraduate and graduate students from various academic disciplines (e.g., pharmacy, economics, graphic design, biology), artistic backgrounds (e.g., art as a hobby, art as a potential career path), and experience communicating science through art (e.g., previous experience and no previous experience; for additional artist information, see Appendix S1). Aligning with the model we use to train our traditional ecology students, artists earned

independent study course credit for their research efforts and artistic outputs. Additionally, all costs associated with this work (i.e., art supplies, exhibit expenses) were covered by our research group via mechanisms similar to those we use to support our students engaged in science research (i.e., society and federal grants; see Acknowledgements).

Independent Study and Artwork Development

The exhibit was collaboratively developed by the research team and student artists through an iterative process throughout the independent study (Figure 1). Students were instructed to create one artistic piece for each of the wetland ecology themes to be covered in the exhibit (Pollutants, Biological Interactions, and Techniques) over the course of the independent study, with the exhibit as their final project. To accomplish this, a graduate mentor from the research team (lead author of this article, supervised

by a faculty mentor who is also one of the authors of this article) first held group meetings with the student artists to introduce a theme. For example, at our first meeting, the graduate mentor covered the Pollutants theme by describing which significant pollutants are contaminating wetland ecosystems, how they enter the wetlands, and how they affect wetland organisms. The graduate mentor reviewed current research within the theme and provided resources for further reading.

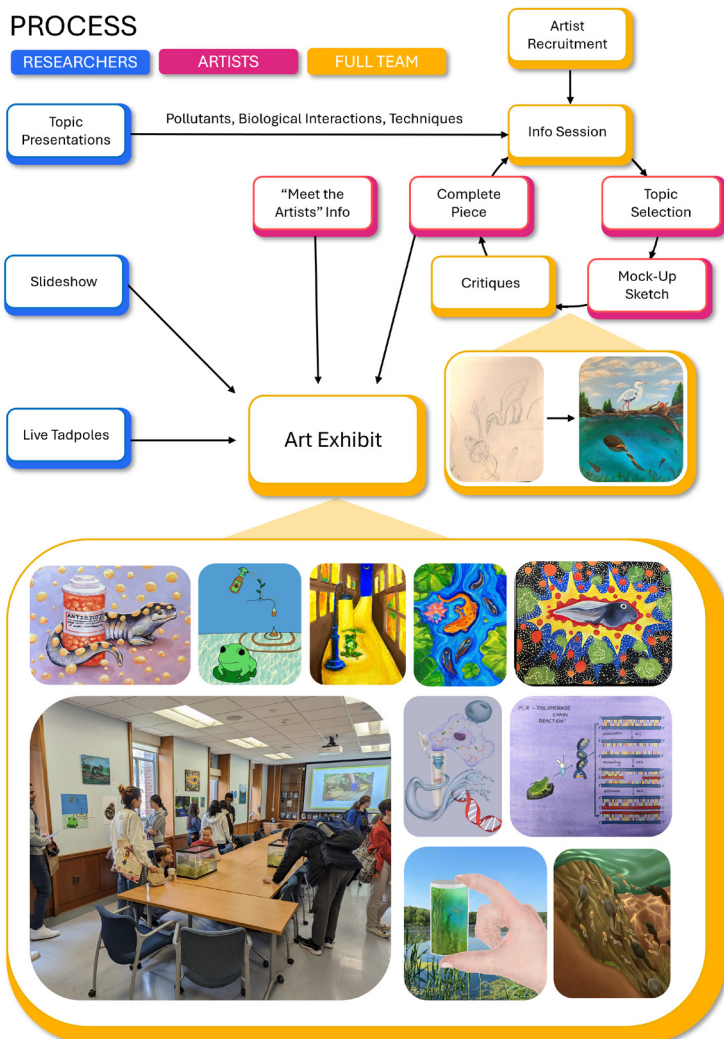
At the end of each meeting, artists selected a single topic to focus on within each theme (e.g., for Pollutants, one artist selected antibiotics while another selected pesticides). Artists then spent one week independently researching their topic and devising a mock-up sketch for an artistic piece to represent it, touching base with the graduate mentor as needed with any questions or clarifications about scientific content or overall direction.

Mock-ups were submitted for review by the full research team for scientific accuracy and by peer student artists for aesthetic critique. All research team members and student artists reviewed each mock-up before attending a meeting to provide feedback for each sketch. Artists took turns introducing and explaining their mock-up, followed by unstructured feedback from the group. For example, one mock-up for the theme Biological Interactions depicted the multi-host life cycle of a trematode parasite, which infects tadpoles. Feedback from the research team revealed that one of the trematode hosts (freshwater snails) was missing from the sketch and should be added to the final piece, while peer artists suggested alterations to the size of different elements (e.g., making the heron smaller and moving it from foreground to background) to help with visual clarity (Figure 1).

Artists were given approximately one month to integrate this feedback and complete their final piece before moving on to the next theme. This process was repeated once for each theme, with each artist ultimately creating three pieces between December 2022 and April 2023 (except one student who was not available to work on the first theme and created only two pieces), roughly aligning with a one-semester independent study course.

FIGURE 1. Modified Independent Study Process.

Researchers and student artists worked together in an iterative process modeled on independent study to create the exhibit.



Art Exhibit

At the end of the semester, student artwork was exhibited for the campus community. The art exhibit (*The Wetlands and You: A Science-Art Exhibition*) took place on Friday, 28 April 2023, from 2–5 p.m. at Binghamton University's Bartle Library (Figure 1; for full artwork and captions, see Appendix S2). We chose this high-traffic location and time to attract members of the public and campus community who were entering and exiting the library. The exhibit was advertised by the research team and student artists through several department and student club email listservs and university-wide communications regarding campus events (emails, flyers, website).

The artwork was organized to sequentially lead visitors through the exhibit one theme at a time, with the final stop being a "Meet the Artists" section including photos and bios of each of the artists. In addition to the artwork, the research team prepared a slideshow showcasing photos and audio of seven amphibian species found in the local wetlands, which was played on a continuous loop at a location that could be viewed and heard from the entire room (Figure 1). On the morning of the exhibit, the research team also collected live green frog (*Rana clamitans*) and American bullfrog (*Rana catesbeianus*) tadpoles to be displayed in two aquaria for visitor viewing (IACUC Protocol No. A006634, Approved 7 Nov 2022). The exhibit represented the student artists' final project and concluded the semester's independent study.

Evaluations

To evaluate our first question (Does integrating student artists into a science research lab using the independent study model facilitate positive experiences and opportunities to grow interdisciplinary skills for artists?), the graduate mentor conducted one-on-one semi-structured interviews with each artist after the conclusion of the exhibit. Interview questions were adapted from Fleerackers et al. (2022) and were structured to understand artists' experiences related to creating environmental art through this collaboration (Appendix S3). All six artists participated in interviews, and audio recordings were transcribed to text for evaluation.

To evaluate our second question (Does the resulting science-art exhibit promote learning and enjoyment for exhibit visitors?), each visitor was approached by a member of the research team before leaving the exhibit and

asked to fill out a short survey providing demographic information (Appendix S4) and responses to two open-ended questions ("Describe something you learned," and "Describe what you most enjoyed"). In total, 117 visitors completed surveys. While we were unable to assess the total number of exhibit attendees to calculate a response rate, we note that there appeared to be very few visitors (<10) who declined to complete the survey. All study design and data collection instruments were reviewed and determined to be exempt by the UW-Madison IRB (Protocol No. 2022-1494, Approved 17 Nov 2022).

To evaluate both artist interviews and visitor open-ended responses, we utilized a combination of inductive and deductive thematic analysis (Saldana, 2021). For each dataset, all responses were read and reread by at least two coders, who independently grouped the data according to salient similarities and differences. In an iterative process, coders then came together to discuss, revise, discard, and refine possible themes until consensus was reached. Results and discussion are presented below for each research aim individually, followed by an overall discussion of practice contributions and recommendations for future work.

Results and Discussion

Evaluating Student Artists' Experiences and Skills Development

Artist Results

The first theme from artist interviews (Figure 2) was related to Learning and Teaching about wetland and amphibian ecology. In their role as learners, artists recounted acquiring new knowledge through the group information sessions and during their independent research. They described gaining both a general understanding of this research area and having to dig deep into a specific topic to find inspiration for their paintings. The process of learning new content for this project was reportedly highly enjoyable for the artists.

"I definitely learned a lot about amphibians and frogs in the environment."

"It was nice, learning about different biological concepts. I didn't really know anything about swabbing and pollution, and it was fun to convey that message through art."

"It was a very different experience for me because I started to read articles on how to conserve nature, how to preserve nature and everything. And also, the frog research is really interesting. When I started reading the papers, there's a lot to know about it, actually. I really liked it. I had a lot of fun. [...] I think I'm gonna read more articles on that."

In their role as communicators and educators, artists described their perspective on finding creative ways to effectively convey this new information to an audience. They talked about being conscious of trying to balance accuracy with artistry in order to convey the best viewer experience.

"I just wanted to create something that people visually like to look at and thought was interesting and helps convey an idea that you guys were trying to teach the general public about. I feel like the pieces I did were pretty good at conveying that."

"I wanted to balance the art aspect of the drawing and also making sure that it is accurate."

A second theme related to the artists' experiences was a sense of Enjoyment and Fun. They were surprised and excited by the success of the exhibit, describing that they were very pleased with the turnout and that visitors were highly engaged. For several artists, this was their first experience of having their art displayed at a public venue, which made them especially excited to see such high levels of visitor interest.

"People were really interested in learning more about the topics. They were actually staring at the paintings for a long time and reading the captions."

"It's my first time seeing my drawings being exhibited like that, that was pretty cool. Also, I also liked the tadpoles in the exhibit."

"I think we exceeded expectations. A lot of people seem to really be impressed with what we put out."

A recurring sentiment was that having an opportunity to make art was simply fun. Artists enjoyed the process of creating their pieces, and they were further excited to have an opportunity to make art for a purpose. Especially as university students with many other competing demands, they appreciated the opportunity to make art (a fun and stress-relieving activity) as a means of accomplishing the

FIGURE 2. Artist Interview Themes.

In post-exhibit interviews, artists revealed three key themes of their experiences: Enjoyment and Fun, Process and Preparation, and Learning and Teaching.

Enjoyment & Fun	Process & Preparation	Learning & Teaching
Art is fun <i>"It was really great just to have a reason to make art in general."</i>	Pride in process <i>"I had to go through papers [...] and then actually find my own unique way to translate that into art."</i>	Learning new content <i>"When I started reading the papers, there's a lot to know about it."</i>
Great exhibit <i>"They [visitors] were actually staring at the paintings for a long time and reading the captions."</i>	Experimenting <i>"I think that my art style developed better. [...] It was fun experimenting."</i>	Art of teaching <i>"I wanted to balance the art aspect [...] and also making sure that it is accurate."</i>
	Career options <i>"I found out about scientific illustration."</i>	

necessary (and sometimes stressful) goal of working towards completing their degrees (i.e., by receiving course credit).

"I should really thank you, because I didn't even expect that I'll get into this. I thought it was a volunteering thing, but also you gave me credit.... So thank you so much."

"I use art as a stress buster, so exposing myself to a lot of colors made me really happy.... My whole semester was a lot of stress."

"It was really great just to have a reason to make art in general."

The final theme from artists' experiences was related to their Process and Preparation. When asked which piece they were most proud of and why, their answers were primarily related to being proud of the thoughtfulness, research, and iteration that they undertook to create their favorite piece. They were proud of their process in learning more about the topics, trying new styles, and ultimately creating a piece that they felt represented what they wanted to convey.

"The [Biological Interactions] piece. It actually started out being my least favorite, but I think after I added some details, I actually liked how it looked and thought it was more eye-catching than the other two."

"I would say the [Biological Interactions] one. Just because that one, I learned the most from."

"I really enjoyed the one with [Biological Interactions] because I had to go through papers, find the information, and then actually find my own unique way to translate that into art."

Artists were given the freedom to determine their media, and they used this as an opportunity to expand their horizons and experiment with different techniques. In two notable examples, one artist used a digital platform for the first time, while another tried painting with color instead of her usual black-and-white ink style. After being inspired by seeing different styles and techniques used by other artists in the project, some also expressed an intention to experiment more in the future.

"I had always wanted to try digital illustration. This is actually the first time I really tried it."

"I never used colors for painting. This is the first time that I've tried painting because I want to try something new, which is not my thing. So I tried painting and I think the artwork came out well.... People who digitized the art came out very well. So I think I'm going to try that."

"I think that my art style developed better. I had a better sense of what kind of art style I have, and it was fun experimenting with different materials."

Three artists reported that this project gave them new awareness or deepening interest in careers that integrate art and science. This experience helped them to gain new perspectives on related careers like scientific illustration, and they indicated that they would seek more information about related careers in the future.

"I wouldn't say specifically from this experience. But also, around the same time, I found out about scientific illustration, medical illustration. I thought that was kind of similar to our topic. That might be something I'm interested in in the future."

"This past semester, along with doing this, I've also been taking a science communication class, and between the two of them, I really wanted to start looking in that direction as possibly a career move. Because I've always felt like there's something lacking in science communication, and art seems to be a really good way to

bridge the two. It's definitely opened my eyes to what is possible."

Artist Discussion

Interviews revealed that student artists exercised interdisciplinary competencies (reflexivity, perspective-seeking, integrative thinking) that are increasingly desired for college graduates (Imbruce et al., 2024; Kjellberg et al., 2018). These skills were demonstrated as students conducted research on scientific topics and integrated these ideas into an artistic vision, experimenting with different ideas and considering different ways to effectively convey information to their audience. Furthermore, artists took it upon themselves to shape opportunities for personal and professional development by exploring new techniques and engaging in reflexivity as they gave and received feedback from multidisciplinary peers and mentors during critique sessions. These practices are in alignment with those of professional visual artists (Kolyvas & Kostagiolas, 2023).

Engaging in the creative process also allowed some students to develop a new understanding of the synergistic roles of art and science in society (Guyotte et al., 2014) and the ways that they could contribute through their interdisciplinary practice (e.g., "I've always felt like there's something lacking in science communication, and art seems to be a really good way to bridge the two. It's definitely opened my eyes to what is possible."). Particularly as the world faces increasing "wicked problems" (Lönngren & van Poeck, 2021; Rittel & Webber, 1973), it is critical for future generations to develop these interdisciplinary competencies. Our findings agree with previous work (Bourdeau, 2021; National Academies of Sciences, Engineering, and Medicine, 2018) by demonstrating that cross-disciplinary science-art collaboration can facilitate opportunities to exercise these skills.

Evaluating Exhibit Visitor Learning and Enjoyment

Visitor Results

When asked to describe something they learned from the exhibit, the majority (79 responses) relayed a specific fact (Figure 3). Facts from all three themed sections (Pollutants, Biological Interactions, and Techniques) were represented in visitor responses. In reading through the responses, the

research team noted that conveyed facts were largely accurate based on the information presented, suggesting that visitors engaged with all parts of the exhibit and were able to understand the content presented.

Some visitors (23 responses) went beyond a specific fact to describe what we deemed a “broader takeaway.” These responses indicated a new awareness of bigger-picture conservation concepts such as the threatened status of amphibians, the variety of research being conducted in this discipline, and how humans are influencing the environment in unexpected ways. A small number (three responses) connected these issues to personal introspection or responsibility (“I need to learn about my environment more”). Others (4 responses) commented that they learned something about art or the integration of art and science.

When asked to describe what they most enjoyed about the exhibit, the majority (54 responses) reported most enjoying the artwork (Figure 4). These responses described the artwork generally or named their favorite pieces or artists. Some visitors went on to tell why they enjoyed the artwork, highlighting aspects like their beauty, creativity, and variety.

Tadpoles were the second most popular aspect of the exhibit (38 responses). While most respondents in this category simply wrote “tadpoles,” a few added adjectives such as “cute,” “live,” “real,” and “large,” providing insight into why they enjoyed them. Other aspects of the exhibit were also mentioned (9 responses), such as the “Meet the Artists” section, the slideshow, or simply “all” or “everything.”

Some visitors (19 responses) commented that what they most enjoyed was the integration of art and science as a means of sharing information. These comments revealed that visitors saw particular value in the combined power of art and science. For some, this value came from seeing familiar information in a new light (“the art illustrating familiar concepts in new ways”), while others commented that art made new information easier to understand (“illustrating scientific concepts with art! Easier + more engaging to understand”). Others enjoyed the combination of art and science for its own sake (“I love seeing a blend of science and arts. Both are so important and more powerful together”).

Visitor Discussion

Visitors relayed key information related to wetland pollutants, threats of wildlife diseases, and the influence of

FIGURE 3. What Visitors Learned.

In response to the open-ended question, “Describe something you learned,” visitors relayed specific facts learned from the exhibit, broader takeaways about the environment and research, and comments about art or the integration of art and science. The size of each slice represents the frequency of the response type.



FIGURE 4. What Visitors Most Enjoyed.

In response to the open-ended question, “Describe what you most enjoyed,” visitors reported enjoying the artwork, the tadpoles, the combination of art and science, and other exhibit elements. The size of each slice represents the frequency of each response type.



humans on the environment. Alongside the acquisition of new knowledge, visitors connected emotionally with the material through appreciation of the beautiful artworks and the integration of art and science. The ability of visual art to evoke emotional connections is particularly important, because it allows for information to be processed using both cognitions and emotions (Flemming et al., 2018), making learning through art more enjoyable and accessible (Azagra-Caro & Pavone, 2024). Indeed, this view was expressed by multiple visitors (e.g., “Illustrating scientific concepts with art! Easier + more engaging to understand”). Emotional connection can be helpful in spurring individuals to take actions like seeking more information, discussing science topics with others, and making more sustainable choices (Bendor et al., 2017; Brock et al., 2022; Dennison, 2024). Overall, our findings agree with previous work showing the powerful properties of visual art exhibits to promote learning and enjoyment of science (Arce-Nazario, 2016; Colavito et al., 2020; Ricci et al., 2023) and demonstrate that our process of collaborating with student artists can result in an exhibit that meets these public engagement goals.

Overall Discussion

Our results demonstrate that we were successful in our two main goals: facilitating positive experiences and opportunities to grow interdisciplinary skills for student artists, and promoting visitor learning about and enjoyment of science via an art exhibit. Our practice allowed us to overcome existing barriers to science-art collaborations in three meaningful ways:

1. Access to potential collaborators. Scientists and artists often find it difficult to identify and connect with one another (Black et al., 2023; Gewin, 2021), yet university systems offer a unique environment where developing professionals from multiple fields can interact. By leveraging existing student relationships and collaborating with student groups on campus, our science research group was able to effectively identify and connect with artists. In this case, the project was scientist-initiated, but the idea can go both ways: artists interested in initiating projects could connect with campus research labs or student science groups to find collaborators. It could also be interesting to leverage the university environment to create a

cross-disciplinary mentorship team, including both science and art faculty or graduate students working together as mentors.

2. Balance of structure and creativity. One challenge to science-art collaborations is the differing norms and practices among the two disciplines (Black et al., 2023; Heras et al., 2021). Using the independent study model, we were able to overcome some of these challenges by providing a structure that was amenable to the research team (e.g., overall content themes, timing aligned with the semester) while also leaving many opportunities for creativity and flexibility for the artists (e.g., specific artistic subjects, creative directions). Additionally, multiple artists and researchers working together allowed for effort (e.g., creating each piece, curating and planning the exhibit) to be spread among multiple people to complete the entire project relatively quickly (five months from artist recruitment to final exhibition) without undue time pressure on each individual, which is often cited as a frustration for artists (Black et al., 2023; Heras et al., 2021). The structured, iterative process for creating each piece also allowed for continuous quality control, creative feedback, and points of contact between team members.

3. Resources. Resources can be a significant barrier to science-art collaborations (Black et al., 2023). While it would be ideal to pay competitive commission and consulting fees to artists and scientists involved in these projects, this is not always feasible. The independent study model presents an opportunity to ensure that artists are compensated for their work through existing mechanisms, by providing students with course credit and mentorship. We were also able to pay for the materials used to create the artwork (e.g., canvas, paint) by leveraging our existing funding for research and outreach. However, we acknowledge that this may not be feasible for all research or student groups. It may be interesting to explore lower-cost options such as creating an all-digital exhibit to further reduce material resource barriers, especially considering that the artists in this study enjoyed creating artwork digitally. Additionally, deeper cross-disciplinary collaborations, such as those suggested above, could reveal new opportunities for cost sharing between the students’ or faculty mentors’ departments (e.g., from art and/or science departments). As the

primary expense for this project was art materials, it could be valuable to connect with art departments to seek donations of materials for the students to use.

Recommendations and Conclusions

When asked what could be improved in the future, artists suggested integrating more opportunities for teamwork and critique, such as dedicated sessions to work on pieces collaboratively or more opportunities to receive feedback on iterative drafts. One suggested that future iterations could include more hands-on opportunities for the artists to take part in research activities alongside the research team (e.g., going into the lab or the field). Similarly, research team members would likely benefit from sessions to learn from the artists about their artistic process and perspectives on communication. Overall, incorporating even more teamwork and integrated activities could improve this work. We also suggest that in the future, formal interviews of the research team would be valuable for a better understanding of the impacts that this cross-disciplinary collaboration had on scientists' personal and professional development alongside those of the student artists.

Similarly, future efforts to improve the exhibition itself could incorporate additional hands-on opportunities for visitors, for example by bringing research props or experiments (as suggested by one visitor) or providing opportunities for visitors to create artwork themselves (e.g., Renowden et al., 2022). Notably, interacting with tadpoles proved to be a large contributor to visitor enjoyment of the exhibit. Future efforts related to animal science should consider incorporating live animals alongside art exhibitions (where possible and ethical), particularly as charismatic animals can be a powerful way to promote the importance of wildlife conservation (Colléony et al., 2017; Marris, 2013).

Our exhibit was also held on a university campus; for that reason, while the exhibit was open to the public, we had an audience of primarily university students and staff. To reach wider audiences, future exhibitions could be advertised in public community spaces and be held in more accessible locations such as community centers or public libraries.

Finally, reflecting on our process of guiding the independent study, we note that we were consistently impressed by each individual student's initiative, talent, and attention

to both scientific and artistic detail. That additional feedback and guidance beyond what is reported here was not needed is likely a testament to the students themselves rather than to the process alone. Others seeking to implement a similar process should consider points where more structure can be added for students who require additional guidance, such as a grading rubric, more structured lessons, or more structured feedback opportunities. It may also be valuable to narrow the scope of the topic (e.g., focusing the entire semester Biological Interactions), so that students (particularly those who are not trained in the sciences) are able to take more time to explore the content before creating the pieces.

Overall, the practice of integrating student artists into a science research lab can reduce known barriers to science-art collaborations, provide positive experiences for art viewers, and facilitate valued skills development for art creators. By providing insight into our practice, we aim to increase the accessibility of science-art collaborations and facilitate more opportunities for practitioners to teach about science topics using visual art.

Acknowledgements

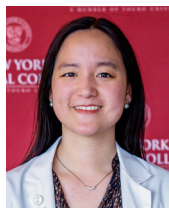
We thank the artists Olivia Cashimere, Kathleen Lu, Angela Luo, Lila Pomerantz, Ingrid Shen, and Nagasri Thota; Paris Thompson, and Lindsey Keller for their help in preparing artist educational materials; the Binghamton Art Club for connecting our lab with the artists; and the reviewers for their helpful comments and suggestions to strengthen this manuscript. We thank the National Science Foundation (NSF Graduate Research Fellowship No. 2137424, NSF award No. 2314625) and the Society for the Study of Amphibians and Reptiles (SSAR) Roger Conant Grants in Herpetology for funding support.

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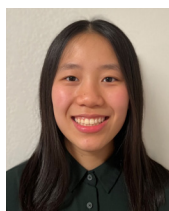


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Appendix S1. Artist information.

Artist	Description
A	Fourth year undergraduate biology major. Also a member of the research team. Collaborated with our lab group previously on science-art projects (graphic novel). Interested in pursuing medicine as a career.
B	Fourth year undergraduate with dual majors in biology and graphic design. Vice president of Binghamton University's student-run Art Club. Joined the collaboration for experience to explore medical illustration as a potential career.
C	First year undergraduate economics major. Joined the collaboration to combine interests in art, sustainability, and curiosity to learn alongside a science team.
D	Master's student in Earth Science with a BS in geology and a minor in art studio. Joined the collaboration for an outlet to combine interests in science and art.
E	First year undergraduate undeclared major. Joined the collaboration as an opportunity to get involved in making art while accommodating a busy schedule.
F	Master's student in pharmaceutical sciences. Previously created artworks to raise mental health awareness. Joined the collaboration to bring awareness to issues of environmental health.

APPENDIX

Appendix S2. Virtual exhibit tour.

Section I: Pollutants

What pollutants are found in the wetlands? How do they affect organisms in our local environment, specifically amphibians and aquatic organisms?



Amphibiotics

Kathleen Lu

Section I: Pollutants

Amphibians tend to have sensitive skin, so when discarded antibiotics find their way into aquatic environments, they can be absorbed into amphibian skin and affect their fitness and relationships with other creatures. This painting features a spotted salamander, which is commonly found around vernal pools and forests.

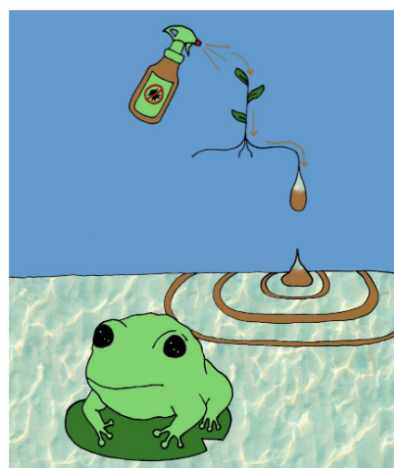


Light Pollution

Angela Luo

Section I: Pollutants

Artificial light can have devastating effects on amphibians such as frogs as it disrupts their natural 24h rhythms and negatively affects their behavior and development. Through this piece, I hope to display the excessive illuminations of light from indoor lighting and outdoor lighting. Some simple ways we can reduce light pollution are by turning off lights when they are not in use and keeping blinds and drapes closed at night.



Pesticides

Lila Pomerantz

Section I: Pollutants

Pesticides seep through the soil and enter the runoff, which carries their toxic chemicals to streams and other aquatic ecosystems where they are absorbed by delicate amphibian skin. To portray this process, I created a design on photoshop, with a focus on the use of color to portray a message. I chose to color the runoff as an orange-brown tone, and a bright blue pattern for the water. I wanted there to be a strong contrast between these two colors to drive in the unnatural properties of pesticides.



Carbaryl Pollution

Ingrid Shen

Section I: Pollutants

Wood frog populations with more exposure to the pesticide Carbaryl are modestly more susceptible to trematode (a parasite) infections. Trematode cysts cause massive disruption and abnormal cellular growth involving the limb buds of infected individuals, causing deformities in the frogs' limbs.



Pollution is Threatening the Survival of Frogs and Their Habitats

Nagasri Thota

Section I: Pollutants

As pollution continues to wreak havoc on our planet, the survival of frogs and their habitats are at risk. Let's take action to reduce pollution and protect these important species before it's too late.

Section II: Biological Interactions

How do organisms interact with one another in the environment? What benefits and stressors do these interactions create for the organism and the ecosystem? How do pollutants and other stressors influence these interactions?

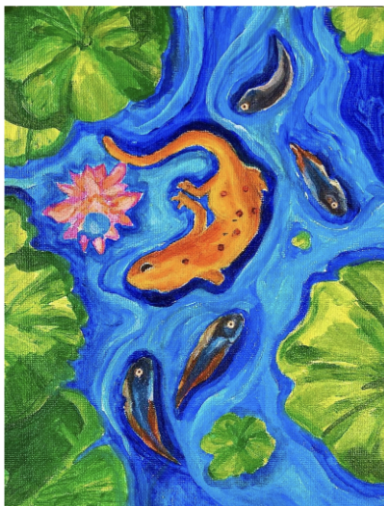


Tadpole Competition

Ingrid Shen

Section II: Biological Interactions

Competition is an interaction between organisms or species in which both require a resource that is in limited supply. Competition in tadpoles can cause them to become shorter and lighter or to experience faster metamorphosis, allowing them to move onto land for other resources. Some tadpoles may also induce cannivory in the presence of competition.



Fight or Flight

Angela Luo

Section II: Biological Interactions

Caption: This piece shows the predator-prey interactions between the predatory eastern newt and gray treefrog tadpoles. When people are exposed to threatening situations, stress hormones are produced to get our bodies ready to either defend themselves or escape. Like humans, when these tadpoles sense the predatory eastern newt, they produce stress hormones that actually allow them to grow larger bright red color tails as a fight or flight response to have a greater chance of surviving a predatory attack.



The Life Cycle of a Trematode Parasite

Olivia Cashimere

Section II: Biological Interactions

Trematode parasites start their life cycle by infecting aquatic snails. Snails then shed the parasite into the water where tadpoles live. In this painting, the tadpole within the water is thrashing around as it gets attacked by the trematode parasite. In the background a Great Blue Heron is feasting on tadpoles from the pond. Eventually the Great Blue Heron feeds upon a tadpole infected with the parasite. The parasite then infects its desired host, the Great Blue Heron.



Host-Microbiota Interactions

Lila Pomerantz

Section II: Biological Interactions

The microbiota living on the skin of amphibians, specifically different frog species, differs in regard to a variety of factors. These include life stages, environment, climate, and sex of the frog. This design portrays the differences in life stages; a tadpole, a froglet, and an adult frog. Done in a program called Krita, differing microbiota is drawn directly onto the skin of the frogs in each life stage with its own set of colors.



Attack on Fungus

Kathleen Lu

Section II: Biological Interactions

Tadpoles actually produce a biofilm of bacteria on their skin that release antifungal compounds. In this painting, the antifungals are fighting off the invading fungal disease Bd. (Red=bacteria, Yellow=antifungal secretions, Green=Bd).



Disease Transmission in Tadpoles: How Healthy Individuals Can be Affected by Infected Peers

Nagasri Thota

Section II: Biological Interactions

Disease transmission can occur even in the earliest stages of life, as healthy tadpoles can contact infected peers and become sick. Understanding how diseases are transmitted among tadpoles can help us better protect amphibian populations from devastating outbreaks.



Dipnetting is Like a Box of Chocolates

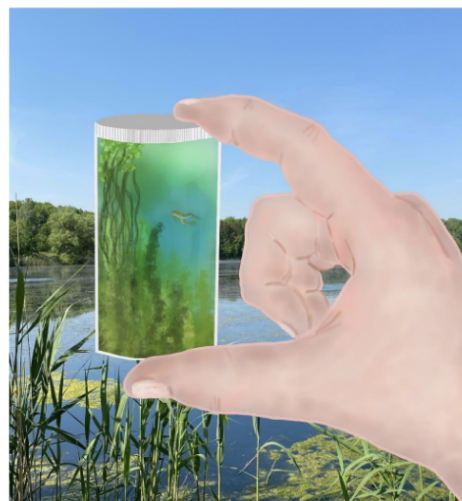
Kathleen Lu

Section III: Techniques

You never know what you're gonna get! This is how researchers catch tadpoles, newts, etc. Just go into a muddy, marshy area and "dip" the net a few times. It's pretty fun!

Section III: Techniques

How do researchers study these pollutants and biological interactions in the field and in the lab?



eDNA

Lila Pomerantz

Section III: Techniques

eDNA stands for "environmental DNA", and it involves using genetic material obtained from environmental samples which can be used to quantify the amount of different pathogens and organisms present in an area. This information led me to the idea of someone holding a sample, with a pond habitat inside the container, to show where the different pathogens may be found in the environment. This design was also drawn in Krita, with the background image taken by a friend visiting a park on Long Island.



Swabbing

Angela Luo

Section III: Techniques

There is a hand holding the frog with another using a q tip to swab. The magnifying glass shows chytrid fungi to show how the frog has been tested with *Chytridiomycosis* as an infectious disease. This disease is a significant problem causing the decline in the frog population that can be tested through the swabbing technique.

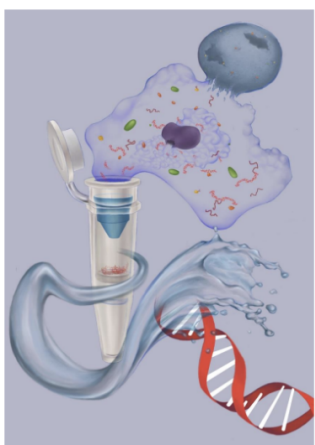


Student Begins PCR Process on Tadpole DNA

Olivia Cashimere

Section III: Techniques

A student is undergoing the process of extracting some tadpole DNA to place it within the PCR machine for DNA analysis. These tests are helpful for studies on infection, disease transmission, species identification, and many other helpful studies.

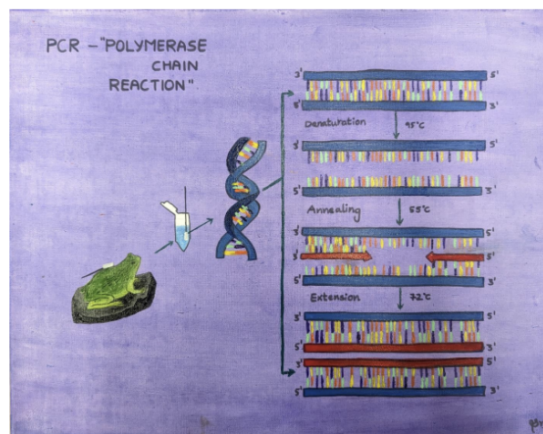


DNA Extraction

Ingrid Shen

Section III: Techniques

To analyze DNA, it must first be extracted from a sample. The first step of DNA extraction is "lysis": using a soap and an enzyme to break up cell walls and membranes and make it so everything (DNA, protein, lipid) is floating together in the solution. In this drawing, the DNA is separated using a small filter to separate it from everything else (like proteins) in the sample. Once the DNA is separated, it is washed and "eluted" into its own, pure aqueous (in water) sample. Now, it's ready for analysis (like PCR)!



PCR-Based Detection of Disease in Frogs and Tadpoles: An Essential Tool for Conservation and Management

Nagasri Thota

Section III: Techniques

PCR technology has revolutionized disease detection in frogs and tadpoles, helping to protect vulnerable species from outbreaks and decline.

APPENDIX

Appendix S3. Artist interview questions.

1. How did you find this experience developing art for the purpose of communicating a specific message? If you have done something similar before, how does it compare to your previous experience?
2. What materials did you use to create your artwork?
3. Did you find it worthwhile to participate in this project? Why or why not?
4. Do you feel that you achieved any of the personal goals you set out to achieve by participating in this project?
5. Did you learn anything from participating in this project?
6. From your perception, what do you think the science team learned?
7. Do you think visitors had the experience you expected when engaging with the exhibit?
8. Was there anything throughout this program that inspired you personally, artistically, or scientifically?
9. Was there anything about this experience that surprised you?
10. Which piece are you most proud of from this project and why?
11. Do you have any suggestions for things we could improve for the future?
12. Is there anything else you want to tell us?

Appendix S4. Visitor demographic information.

Race/Ethnicity		Gender		Highest Level of Education	
White	42.74% (50)	Woman	41.88% (49)	Some College	47.86% (56)
Asian	25.64% (30)	Man	30.77% (36)	Associate's degree	2.56% (3)
Hispanic or Latino/a	6.84% (8)	Nonbinary	7.69% (9)	Bachelor's degree	16.24% (19)
Black or African American	3.42% (4)			Graduate or Terminal degree	24.79 (29)
Multiple or Mixed	7.69% (9)				



RESEARCH ARTICLE

Cultivating Changemakers: Global Health Education for Global Citizenship

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Abstract

Students in higher education are at a critical time of their lives when they are learning the importance of civic engagement and community. Presenting students with the principles of global health, ethics, health disparities, key content issues of communicable disease, gender, and women's rights, are essential pieces of knowledge for developing the whole person and global citizen. At a mid-sized university in the Midwest, a global health course is an option for students to complete as a general education credit. After institutional review board approval was obtained in Summer 2024, a pre/post cross-sectional survey methodology was used to measure student ($n = 179$) attitudes ($n = 10$, $\alpha = 0.878$) and behaviors ($n = 6$, $\alpha = 0.845$) and engagement ($n = 17$, $\alpha = 0.953$) based on

their learning in a global health general education course across four semesters. Results indicate a statistically significant increase in civic attitudes, behaviors, and engagement, with students having a strong sense of empathy and moral cosmopolitan views.

Introduction

Global health is a course that is often only available to students who have a health or biology major focus and may not be available to students outside of those disciplines. Learning about how diseases transcend boundaries, the historical role of disease transmission, and as Dr. Paul Farmer and the organization Partners in Health (2026) have stated, the incredible inequalities that have placed the "staff, stuff, space, systems, and social support"

in disproportionate and inequitable locations around the world, should be available content for all students to explore. College students are at an important time in their lives where they are beginning to understand their place in the world, who they are, and who they want to become. They are becoming more involved with their local communities and are engaging in service learning and civic engagement. Often, students may not even know where to begin to become involved and may be completely unaware of global health challenges and successes. What better way to learn more about the world—and how students can be part of the action—than transcending your local and state knowledge with an adventure into global health?

Civic engagement is an essential component of active community participation, both locally and globally. Civic engagement is an example of high impact practices (HIPs); service learning, global learning, and community-based practices associate positively with student learning gains (Chittum et al., 2022). Personal and social responsibility are also outcomes associated with HIPs, particularly with local and global knowledge and engagement, intercultural competence, ethical and moral reasoning, taking action, and creating foundations for lifelong learning (American Association of Colleges and Universities, 2021). An important component of civic engagement is the role of the global citizen. This person engages positively with other identities and cultures while being aware of and trying to understand the wider world around them, and thus chooses to take an active role in their community (Oxfam Great Britain, n.d.). Inspiring student empathy toward the global community is key. The role of global health in education positively impacts undergraduate students, promotes civic engagement, and further develops a sense of communal empathy. The origin of student involvement may also prove to be relevant, whether it begins at home or through local efforts.

According to the United Nations, global citizenship is an umbrella term that targets social, political, environmental, and economic actions of individuals and communities. The term acknowledges the belief that individuals worldwide are components of "multiple, diverse, local, and non-local networks rather than single actors affecting isolated societies," and addresses the need for the

acceptance and enhancement of individual social responsibility that can result in global benefits (United Nations, n.d.). While the motivation of a global citizen can be contested, global citizenship is essential for the development of a sense of humanity and moral responsibility and interdependence (Nussbaum, 2002), as well as collaboration, and creative decision making for global diplomacy (Haigh & Clifford, 2011; Clifford & Montgomery, 2017). The lack of interest amongst individuals to advocate and engage with current global issues has surged, not just as a public health issue, but also as a global health challenge. A peer-reviewed study found that "efforts to address social and global problems such as poverty, mass hunger, and mass-atrocity crimes are hindered significantly by apathy and low levels of active civil and political engagement amongst populations in developed countries" (Wilson, 2010). Students have concerns, empathy, and interest in various health and worldly issues. However, there is often a sense of apathy when it comes to addressing those issues. Studies have identified recent generations as being more narcissistic as well (Twenge, 2006; Mallan, 2009), stating that young adults as a cohort are more individualistic versus collectivist (Konrath et al., 2011). Apathy towards global citizenship and global health issues impacts a range of individuals, groups, and potential generations. The disconnect presents a challenge for public health: how can empathy can be transformed into action?

The purpose of this study was to examine how the knowledge gained in an undergraduate-level global health course impacts students' attitudes and behaviors towards civic engagement on an individual and collective level. College students in all disciplines can benefit from learning about how to be a global citizen and an active participant in communities both locally and globally. Stoner et al. (2014) maintain that by teaching global health under the umbrella of global citizenship, higher education institutions can play a significant role in cultivating civically engaged students who have the tools to produce meaningful change in society.

Student Apathy

Mousavi and Milasi (2022) discovered that college students exhibited above average levels of social apathy in real-world and virtual environments. Social apathy has two dimensions, civic and altruistic apathy. Civic apathy

is disengagement from public and civic formations, and altruistic apathy involves reduced empathy and concern for others. Social apathy was characterized by disinterest in sociopolitical issues, distrust of participation, and feelings of inefficacy. Universities need to encourage civic engagement among students to strengthen social cohesion and democratic participation.

Between 1979 and 2009 empathy significantly declined among over 13,000 college students, and the sharpest decline was in empathic concern: feelings of compassion, sympathy, and concern for others. Students may feel less connected to social problems or experiences of others, which can contribute to civic disengagement and apathy. Perspective-taking also declined, and students showed a reduced ability and willingness to understand situations from another person's point of view. The largest downshift was after the 2000s, which could be due to increased technology use, reality television, violence, etc. (Konrath, 2011.) Studies from 2016–2018 have also indicated that students will alter their in-person behavior for fear of being ridiculed or mocked (as seen in online platforms) and thus are more likely to shield themselves in person, thereby appearing to be apathetic, uninterested, or unwilling (Marder et al., 2016; Opp, 2018; Kitts & Quintane, 2020; Hoffman et al., 2026). Whether these recoiling behaviors equate to disengagement remains uncertain.

Civic Engagement

Civic engagement is a powerful force that strengthens communities and improves public health. It serves as an important indicator for community health and public health measures. Alberti et al. (2022) discuss how communities that are civically engaged have more social connectedness, trust, and better resource networks. Civic engagement rates are higher in more affluent individuals as well as those with higher education experience. Individuals are most likely to vote as a form of civic engagement, and universities were viewed as the second most appropriate location to vote after libraries, supporting the idea that universities are truly a hub for resource sharing and civic engagement (Alberti et al., 2022).

Barnhardt et al. (2015) discovered that college students who perceive their university as a proponent of

civic engagement and collective responsibility are more likely to participate and implement civic values. Campus culture and messages from faculty and peers alongside campus public advocacy events encourage students to be involved and engage in civic development. Interviews with students revealed that those who recognized civic expectations were more likely to adopt those beliefs as part of their identity. It is apparent that universities have a central role in developing students into the whole person and global citizen.

Global Citizenship

Global citizenship is social, environmental, and economic and involves understanding how actions and decisions in one area of the world can impact people elsewhere. It also involves a willingness to interact positively with different identities and cultures and to actively contribute to making the world more peaceful and just. Global citizenship is fostered by global awareness, social responsibility, and civic engagement (Stoner et al., 2019). Examples of global citizenship include understanding connections between local communities and the wider world, learning about local and global social justice issues, exploring global challenges from different viewpoints, and encouraging people's voices to be heard (Oxfam Great Britain, n.d.). The research study we present here contributes to the knowledge of how civic engagement and global citizenship intertwine and how best to strengthen this among students. We address the gaps in current knowledge regarding the most effective strategies for increasing civic engagement among students and the skills students perceive as a necessary for global citizenship.

Key Research Questions

1. How does knowledge gained by students in a global health course impact attitudes and behaviors toward civic engagement?
2. How do students in the global health course define a "global citizen?"
3. What skills do students feel are necessary for working with local and global communities?
4. How do students feel about the responsibility to address global health issues?

Methods

Study Sample

At a medium-sized university ($n = \sim 21,000$) in the Midwest, all full-time students who were enrolled in the Global Health general education course were invited to participate in the study. Approximately 179 students completed the pre/post surveys, with females being more likely to answer both a pre- and post-survey (73.2%). About 53% of students were Caucasian, 25% identified as African American or Black, and about 6% each identified as Hispanic, Latin(o/a) or Latinx or Asian or Asian American, respectively. At the University, about 60% of students identify as white or Caucasian, with the remaining number encompassing students from underrepresented groups. About 56% of students were involved in a registered student organization (RSO) and live on campus (53.1%).

Project Design

The global health course was developed around a theme of the United Nations Sustainable Development Goals (SDGs) with weekly "adventure" modules that are completed for all courses (in person or online). The topics in the modules are scaffolded starting with principles of global health, health equity and social determinants, culture and health, and health systems as the four primary elements. The remaining modules centered on topics related to specific areas, including child and maternal health. In the online courses, adventure modules included readings, videos, and an activity to engage with the weekly content. All students read Tracy Kidder's book *Mountains Beyond Mountains: The Quest of Dr. Paul Farmer, the Man Who Would Cure the World* and reflected on the experiences of Dr. Paul Farmer and his colleagues in the development of the global non-profit, Partners in Health. Students in the in-person global health class were engaged in several opportunities for civic engagement, including working with a local elementary school to create a Social Development Goals (SDG) quilt (SDG 4, 17), trick-or-treating for UNICEF (SDG 1, 3, 17), school grounds and park cleanup (SDG 15, 17), creation of pollution awareness posters displayed at a local children's museum (SDG 14, 15, 17), establishment of a greenhouse (SDG 13, 14, 15,

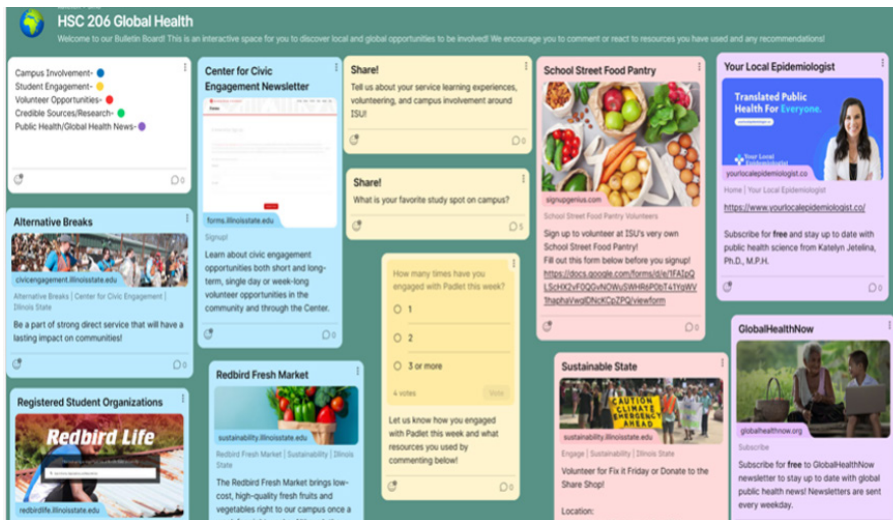
17), and partnership with local libraries to celebrate the International Day of Peace (SDG 16, 17). Since students in the online global health courses were unable to engage in some of the more hands-on aspects of the course offered to the in-person classes, the online platform, *Padlet*, was used as a staging for civic engagement opportunities for students in the global health course (Figure 1). The project design involved a pre/post cross-sectional survey design to collect data at two points during the semester. Four semesters of data collection occurred from Spring 2025 until Spring 2026. Project approval was received by the Institutional Review Board in Summer 2024.

Primary Data Collection

A survey was created using Qualtrics and contained a total of 29 questions, including eight demographic questions, ten civic attitudes, six civic engagement behaviors, and five open-ended questions focused on the students' views of global civic engagement and activism. Civic attitudes were defined as personal beliefs and feelings that students have about their own involvement in their community and their perceived ability to make a difference (Doolittle & Faul, 2013). Civic engagement behaviors were defined as actions that a student can take to engage in and make a difference in their community (Doolittle & Faul 2013). The attitude and behavior scales were based on the survey by Doolittle and Faul (2013) and included a ranking seven-point scale for each. The attitude scale ranged from seven to one, with seven expressing strong agreement and one expressing strong disagreement. The options for responding to behavior questions focused on participation, from always (7) to never (1). Open-ended questions were developed to provide insight into students' personal experiences and interpretations of global citizenship and service responsibilities.

Social cognitive theory (SCT) describes behavior as a dynamic and continuous interaction between personal factors, environmental influences, and individual actions. Developed by Bandura in 1977 (Bandura, 1977; McAlister et al., 2008), SCT suggests that individuals who have strong personal agency or self-efficacy are more likely to respond well to behavior change (U.S. Department of Health and Human Services, 2005). Social cognitive constructs related to knowledge, civic appreciation,

FIGURE 1. Padlet for the Global Health Course During Fall 2025 and Spring 2026



and skill sets are important for exploring the links with enhanced civic engagement (Owusu-Agyeman & Fourie-Malherbe, 2021; Metzger et al., 2018; Wray-Lake et al., 2017). After three semesters of data collection, constructs from social cognitive theory (reciprocal determinism, behavioral capability, expectations, self-efficacy, observational learning, and reinforcements) were incorporated to become variables ($n = 17$) in a survey scale. The study examined aspects of behavioral capability through students' existing knowledge and the skills they perceived as necessary for global citizenship (Table 1).

Open-ended questions provided more comprehensive insight into students' personal experiences and interpretations of global citizenship. Questions included, "Do people have a responsibility to address global issues?" "How would you describe a 'global citizen'?" "What skills do you think young adults need to feel empowered to address local and global issues?" (two separate questions), and "How do local efforts impact global successes?" Before the survey was administered during the fourth semester, in Spring 2026, the survey was updated to have one open-ended question, "What is your responsibility to address global health issues?" to try and reduce some of the redundancies in the questions.

The survey was administered to students enrolled in all global health courses during Week 1 and Week 15 of the semester. Completion of the survey was listed as an

assignment in the syllabus and required for all students in the course; however, only students who consented to the study were included for analysis. A Cronbach alpha test was conducted to verify the reliability of all scales, with the survey having high reliability for each scale (civic attitudes $\alpha = 0.878$, civic behaviors $\alpha = 0.845$, social cognitive $\alpha = 0.953$).

Data Analysis

Data was cleaned in Microsoft Excel by removing responses with missing data in addition to duplicate survey submissions. Pre- and post-surveys were also matched based on an identifier known to the participant, then removed from the aggregate dataset. After cleaning the data, a total of 179 participants' matching pre/post surveys were included in final analyses. Data was coded by using the pre-assigned seven (strongly agree and always) to one (strongly disagree and never). Pre- and post-scores were created for all three scales, with higher scores equating to the most positive attitudes and behaviors. The highest and lowest scores obtainable for participants were 70/10 for attitudes, 42/6 for behaviors, and 119/17 for social cognitive constructs, respectively. Closed questions were analyzed using IBM SPSS Statistics software with descriptive statistics for frequencies, percentages, and mean scores for survey scales. Inferential statistics were conducted exploring of correlation with pre-/post-attitudes and

TABLE 1. Social Cognitive Theory Scale, Constructions, and Average Question Scores

Survey Question	Social Cognitive Theory Construct	Pre-Score	Post-Score
The more I am involved, the more I notice positive changes in my community.^a	Reciprocal Determinism	5.20	5.81
My experiences in civic engagement have changed the way I view social or political issues.^b	Reciprocal Determinism	5.24	5.98
I can identify the steps I can take to become involved in my community.^b	Behavioral Capability	5.48	6.03
I know where to find volunteer or service opportunities in my community.^a	Behavioral Capability	5.75	6.18
Participating in local activities will help me develop my leadership skills.^a	Expectations	6.00	6.31
Participating in global activities will help me develop my leadership skills.	Expectations	6.01	6.29
My participation in civic engagement makes an impact on a global level.^a	Expectations	5.05	5.75
Participating in civic engagement helps reduce my feelings of helplessness about world issues.^a	Expectations	5.33	5.92
I feel confident that I can make a positive difference in my community.^a	Self-Efficacy	5.29	6.07
I know how to get involved locally.^a	Behavioral Capability	5.68	6.02
I know how to get involved globally.^b	Behavioral Capability	3.98	5.20
The action or community involvement of my peers impacts my inspiration to be involved.	Observational Learning	5.46	6.03
The action or community involvement of my professors impacts my inspiration to be involved.^b	Observational Learning	5.14	5.87
I receive positive feedback from my peers or instructors when I participate in civic engagement.^b	Reinforcements	5.48	6.01
I feel appreciated and acknowledged when I participate in civic engagement.^a	Reinforcements	5.62	5.98
My school recognizes students who contribute to local causes.^a	Reinforcements	5.09	5.59
My school recognizes students who contribute to global causes.	Reinforcements	5.22	5.55
My school recognizes students who contribute to global causes.	Reinforcements	5.22	5.55

^a Indicates a statistical significance, $p < 0.05$ ^b Indicates a statistical significance, $p < 0.001$

behaviors with paired and independent t-tests with independent variables of gender, year in school, race/ethnicity, and Registered Student Organizations (RSO) involvement. Non-parametric tests with Kruskal-Wallis and Mann Whitney U tests were conducted with race/ethnicity and gender variables due to their sample size variances.

Qualitative analysis of responses was conducted using a content analysis to create categories and overall themes (Merriam, 2009). For the question focused on personal responsibility, the article by Stapleton et al. (2014) was used as a guide to identify the participant's response to the global health ethical principles (egalitarian, utilitarian, cosmopolitan-moral, and political, anti-cosmopolitan-realist and pluralist). The alignment for the responses and principles was validated with researchers each matching the response to the principle and comparing responses with an 85% matching rate among researchers.

Results

In the four semesters, 900 students completed the surveys, however, only 179 completed both the pre- and post-test and consented to participate. The first research question explored the knowledge gained from the global health course and the impacts on students' attitudes and behaviors regarding civic engagement. Civic attitudes ($t(178) = -6.537, p = <0.001$) and civic engagement behaviors ($t(178) = -6.843, p = <0.001$) increased in all semesters, with the largest increases for behaviors (29.7 to 32.7) and attitudes (56.9 to 61.5) during Fall 2025. A repeated measures ANOVA indicated no significant differences in pre/post civic attitudes and behaviors by semester. Generally, as civic attitudes tend to increase, civic behaviors also increase over time ($r = 0.692, p = <0.001$). There were no significant differences in pre/post scale scores with respect to year in school, race/ethnicity, and whether students lived on or off campus.

For the social cognitive scale ($n = 54$), questions focused on civic engagement, with local to global actions. The average for each question in the scale increased; however, one question in particular, "I know how to get involved globally," had the largest gain from 3.98 to 5.20 (out of 7) (Table 1). The total score for pre- (91.38) to post-survey (100.83) was statistically significant ($t(53) =$

$-4.798, p = 0.001$). Seniors had the lowest pre/post SCT scale scores (81.72 to 95.09), whereas first-year students had the highest scores (98.5 to 105.18). Students who were involved in a registered student organization were more likely to have higher SCT scores (92.29 to 101.85 vs. 90.48 to 99.81), although this was not statistically significant. There were also no significant differences between whether a student lives on campus and their level of civic engagement or between gender and level of engagement. Qualitative questions explored student perceptions regarding the skills necessary for working with local and global communities and responsibilities to address global health issues.

Skill Sets Needed for Local and Global Action

On the pre-survey, social skills, confidence, and awareness were the skills reported as most important for addressing local issues. Social skills, confidence, and critical thinking and problem solving were the most highly rated skills reported on the post-survey. The number of students who reported support and encouragement, knowledge, platform and voice, and critical thinking and problem solving increased from pre- to post-survey (Figure 2). Regarding skills needed to address global issues, confidence, knowledge, and social skills were the skills rated most important on the pre-survey, whereas critical thinking and problem solving, awareness, cultural competence, and determination and willpower increased from pre- to post-survey (Figure 3). A shift in identifying the importance of skill sets for active participation and critical thinking occurred by the end of the course, with a collective change towards identifying how small successes lead to big impact, celebrating positive changes, taking local action, and collective responsibility.

Global Responsibilities

Approximately 70 responses from two semesters (Summer 2025 and Fall 2025) were used for qualitative analyses. On the pre-survey, most students already displayed moral-cosmopolitan ($n = 47$) ethical views, representing a collective responsibility to act and help others. On the post-survey, this trend stayed firm with most students ($n = 57$) continuing to display a moral-cosmopolitan view. On the post-survey, fewer students identified as

FIGURE 2. Bar Chart of the Skills Necessary for Addressing Local Issues

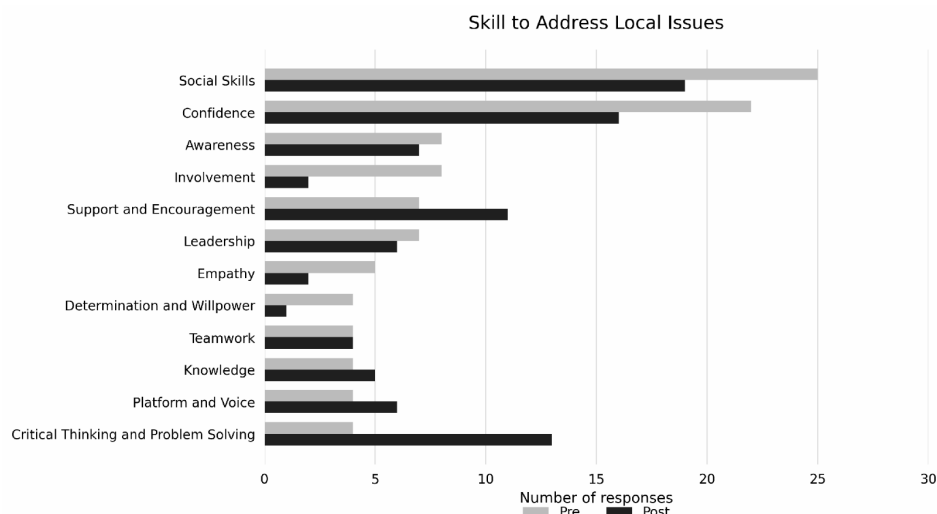
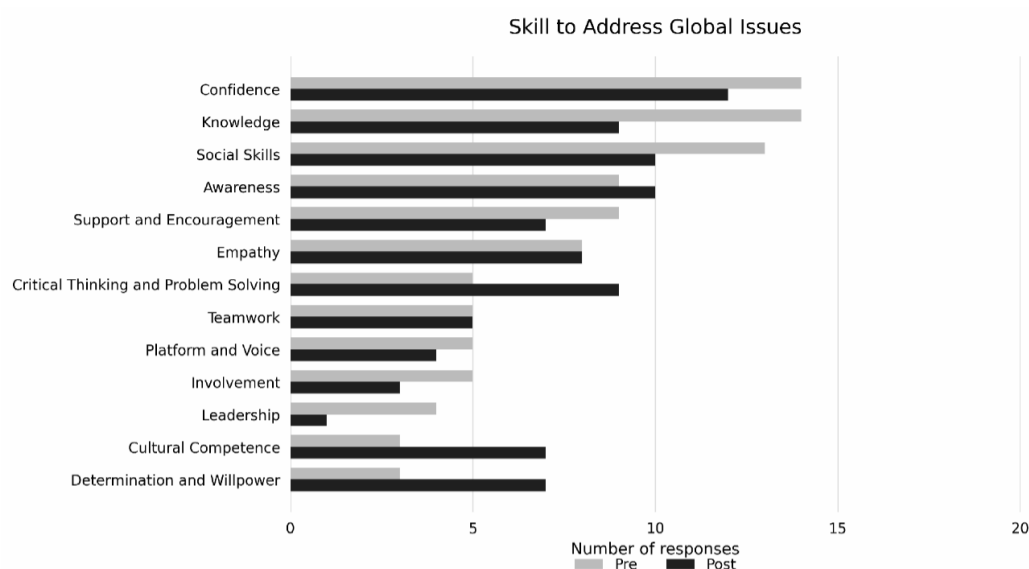


FIGURE 3. Bar Chart of the Student-Identified Skills Necessary for Addressing Global Issues



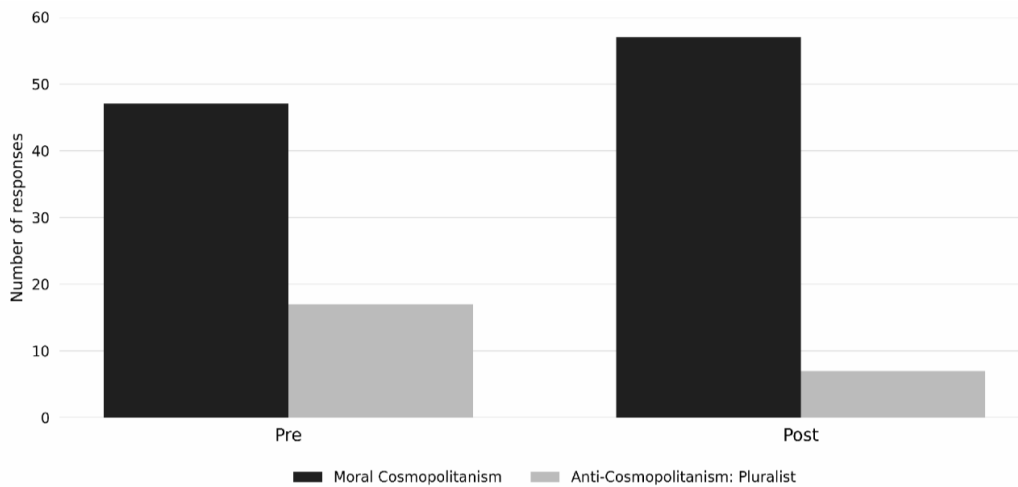
anti-cosmopolitan-pluralist, or as having more national and local interests ($n = 17$, pre; $n = 7$, post) (Figure 4). An example of a moral-cosmopolitan response was, "I think individuals do have a responsibility to address global issues because we should do our best to protect our planet and all of its residents." A student who gave a more anti-cosmopolitan response wrote, "I feel we don't have a responsibility but it's beneficial for all of us to be aware of what is going on." Local actions that lead to global successes was a final theme of the course, encouraging students not only to recognize the challenges in global health, but also to identify how problems are addressed. Students reflected on this experience, and three

themes—"small successes, large impacts," "collective responsibility," and "collective action"—were developed to unpack student responses (Table 2).

Discussion

One of the most important themes of the global health course focuses on learning not just about poverty, but about the causes of poverty around the world. Why are some countries flourishing and others taking multiple steps back from progress? In terms of student attitudes, their growth in recognizing the importance of addressing inequities and poverty had the highest increase (4.99 to 5.7 pre- to post-survey), which is not surprising given the

FIGURE 4. Pre- and Post-Survey Outcomes for Matching the Ethical Paradigm to the Open-Ended Question, "Do people have a responsibility to address global health issues?"



course content. Students also are more likely to start the course having favorable views on global health with the majority following a moral-cosmopolitan view. An important goal of the course, however, is to identify historical global inequities and to demonstrate how ethical principles can guide actions, rather than to identify whose viewpoint is "wrong" or "right." Students often comment on their lack of "power" to be able to make lasting change.

According to one student, "I believe that as a student my responsibility [is] to bring more awareness to these global health issues; since I am a student without any real power all I can do is bring awareness to the issues so people with power can bring a change" [Spring 2026]. Similar to the work of Wilson (2010), students in this study held high levels of concern for moral global health issues. Students in the current study also had high levels of empathy and engagement, which was different from the work of Wilson (2010) and Mousavi & Milasi (2022).

Perhaps student apathy research should be more focused on empowerment; it's not that they are apathetic, it's that they are not part of the change. We should think of addressing apathy as a collective social issue (Mousavi & Milasi, 2022); it occurs when students are not included in elections, witness a lack of compassion from individuals who have power, face reduced access to scholarships and higher education, and encounter discrimination and injustice in higher education (Mousavi & Milasi 2022).

Just as local efforts impact global successes, addressing student empowerment close to home at the college and university level is critically important for inspiring a sense of global empathy and citizenry.

While students made significant gains in their pre/post scores, more work can be done to help students find global health resources that create awareness not only on general topics, but also on when and how to be involved. Results indicated that participants need more support for identifying credible sources in global health, including NGOs, as well as government integrity and support. Emphasizing how and where students can locate these sources will be crucial in future studies. Just as the course focused on global successes, championing the work of students, staff, and faculty as well as community partners is essential to cultivate empowerment and resist burn-out. Linking back to social cognitive theory and, specifically, self-efficacy, participants stated they needed to feel confident, be heard, and have access to platforms where they can address local and global issues. Results suggests that students' ability to act as informed global citizens is closely tied to their perceived capability and the resources available to them. It will be important for future studies to focus on exploring how those specific needs can be addressed and met. Potential considerations could include integrating credible source identification and training and

TABLE 2. Themed Responses to the Question, "How do local actions impact global successes?"

Category Description	Definition of the Category	Pre-Survey Participant Example	Post-Survey Participant Example
Small successes, large impacts	Building Momentum	"Small successes lead to bigger successes, as the smaller ones will encourage other local programs to do the same, and from there it will be a domino effect." "As local problems are solved, it encourages more problems to be solved inspiring change on global efforts." "Everything starts somewhere, meaning that small differences can cannonball into a bigger difference when we all band together." "If you enforce the same efforts locally, and expand that, it will become a common idea."	"Local efforts cause a chain reaction that leads to global success." "As local efforts inspire change, more people become aware of issues and events and create a chain of events that inspires more change." "Local efforts lead to global success which means that small changes add up; when communities solve issues they may have, it inspires others and help them achieve worldwide goals like fighting poverty or climate change." "Local efforts impact global successes because everything starts small. When a community is able to help itself and the area around it, it creates stamina, popularity, and effectiveness of global efforts."
Collective	Reach	"Local efforts build off each other, far and wide. Addressing one local issue in a community, one place at a time, can build global success."	"Local efforts provide a framework solving specific issues. The successful frameworks from local efforts spread to other communities and eventually across the globe."
	Obligation	"I think that if someone is willing to dedicate their time to help out other local citizens they might put in more effort in helping out globally. So it is important that there are large numbers of people wanting to make changes within their local communities."	"They impact global successes because everybody starts locally and branches off. You need to gain experience and do what you think is right to help things going on globally even if its a small change in your community it can influence others."
Collective Action	Local practice	"Local efforts affect national efforts which then cause global successes due to the amount of people voicing what they believe in."	"By making local efforts, it makes it a lot easier to address issues on a global level. By practicing addressing issues in your local area, it makes it a lot easier to speak your opinions about global impacts."

facilitating direct engagement with community leaders and/or policymakers.

With regard to observational learning within social cognitive theory, an important consideration could be exploring more platforms, like Padlet where students can feel inspired to be a global citizen based on the experiences of others. Observing peers' service activities, volunteer reflections, and resource sharing can increase students' awareness of opportunities and enhance their belief that they, too, can contribute meaningfully. For

observational learning to translate into action, these platforms should not only showcase examples but also provide clear, accessible pathways for participation. Future investigations could examine how intentional design of these online spaces might further strengthen students' motivation, self-efficacy, and long-term engagement in both local and global initiatives. One way to explore student motivation would be to encourage online influencers to help to channel messages designed for youth civic engagement by talking about their own experiences,

showing how they engaged, and the outcomes (positive and negative). Finally, an evaluation of course impacts is important for determining whether, post-course, students' behaviors stayed the same or whether their level of civic engagement increased. This methodological goal might be achieved by encouraging the use of cohort strategies and incentives as well as retrospective analyses engaging the students who have previously taken the course.

Limitations

This study was an ongoing effort to document the impacts that taking a global health course can have on civic engagement. There are several limitations to the study, including the ongoing survey development and refinement; there were several semesters with different versions of the survey. There were also two modalities for the course (in-person and online), and while the content was similar, the experiences in learning the material were vastly different—particularly with regard to the students' ability to apply the course principles to service learning. In this small sample, there was no significant difference between the two modalities, which signals that any gains were from the course content.

Conclusion

Across all semesters, students benefit from having spaces where they can observe, learn, and be inspired by the work of global health advocates as they accomplished small tasks that led to large changes. Guided by social cognitive theory, this study shows that fostering confidence, providing credible resources, and creating supportive platforms are essential in preparing students to address local and global issues. Platforms like Padlet demonstrate the potential to bridge from inspiration to action by highlighting real examples of civic engagement and offering direct avenues for participation. Continued exploration of such tools, combined with intentional integration into course design, can help cultivate informed and empowered global citizens.

About the Authors

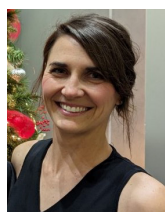


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