



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.

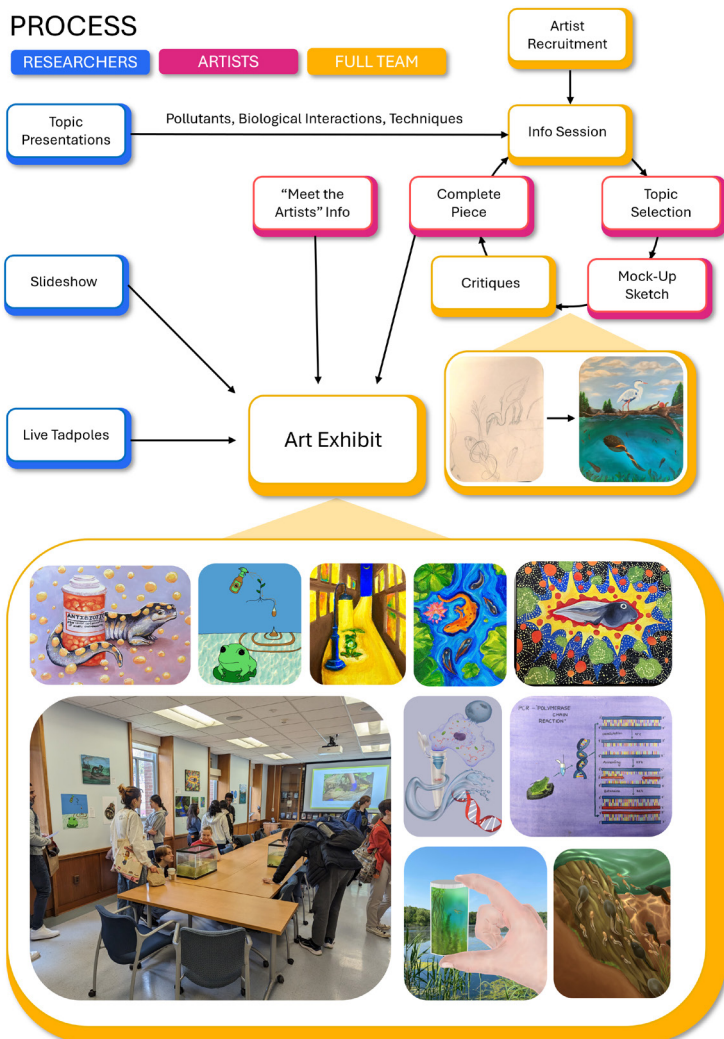
At the end of each meeting, artists selected a single topic to focus on within each theme (e.g., for Pollutants, one artist selected antibiotics while another selected pesticides). Artists then spent one week independently researching their topic and devising a mock-up sketch for an artistic piece to 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

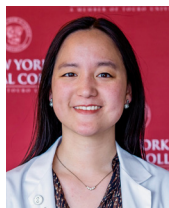
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About the Authors

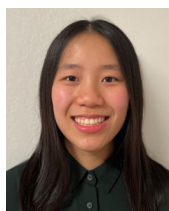


Kyra Ricci Shaw received her Ph.D. from the University of Wisconsin-Madison in the Department of Forest and Wildlife Ecology. She currently works as a participatory research scientist for the Wisconsin Department of Natural Resources.

Her research interests include community and citizen science, informal science education, science-art integration, and conservation ecology.



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Bryon F. Tuthill II earned his doctorate in biology from Binghamton University. His interests include gene expression studies, molecular basis for disease, and scientific outreach focused on incorporating veterans into citizen science initiatives.



Isabela Velasquez is a Ph.D. student in forest and wildlife ecology at the University of Wisconsin-Madison. Her research focuses on understanding how anthropogenic activities affect disease dynamics in amphibians. She is also passionate about promoting science education within the Spanish-speaking community.



Jessica Hua is an associate professor in the Department of Forest and Wildlife Ecology at the University of Wisconsin-Madison. Her expertise lies in conservation biology, disease ecology, and ecotoxicology. In the realm of science communication, she has worked on the following topics: teacher education, informal education, science communication, and community-engaged research.

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Appendix S1. Artist information.

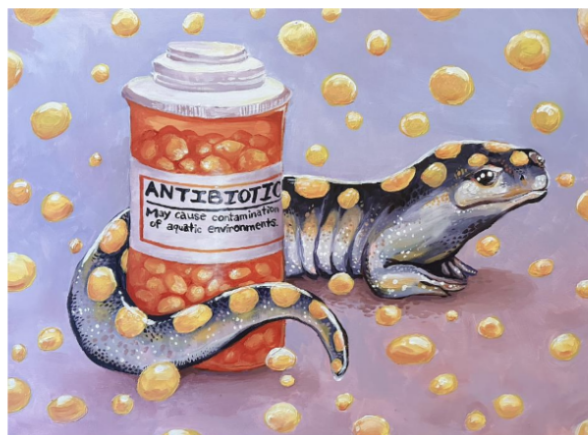
Artist	Description
A	Fourth year undergraduate biology major. Also a member of the research team. Collaborated with our lab group previously on science-art projects (graphic novel). Interested in pursuing medicine as a career.
B	Fourth year undergraduate with dual majors in biology and graphic design. 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.



Carabaryl Pollution

Ingrid Shen

Section I: Pollutants

Wood frog populations with more exposure to the pesticide Carabaryl 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?

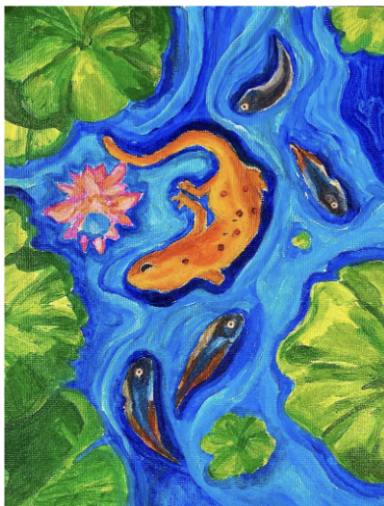


Tadpole Competition

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

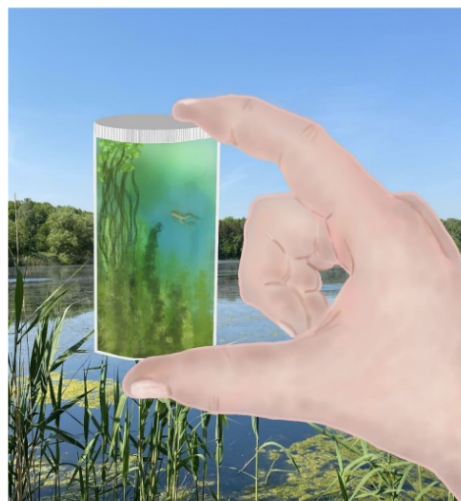
Kathleen Lu

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.

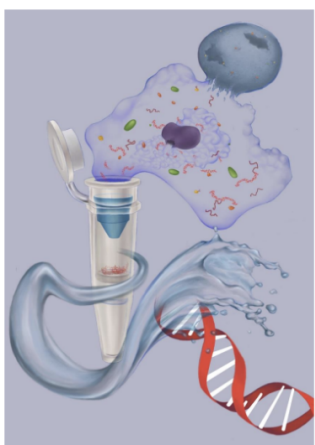


Student Begins PCR Process on Tadpole DNA

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.

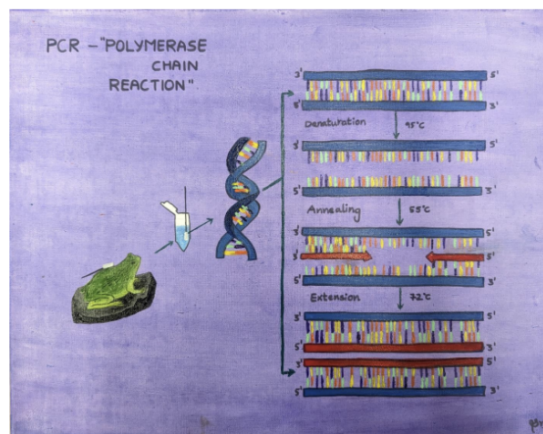


DNA Extraction

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)				