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Article

"Two Sides of the Same Coin": Benefits of Science–Art Collaboration and Field Immersion for Undergraduate Research Experiences

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Abstract: This study examined how incorporating art into an upper-level undergraduate field-based ecology research course influenced students' communication and collaboration skills, their career goals, and how they conceptualized the scientific method. Student pairs designed an independent research study that used artwork and a scientific research poster to disseminate their findings at an end-of-term exhibit. Students enrolled in either a local or a (subsidized) travel abroad section of the course. Students in both sections found new or deeper connections between art and science, developed a more sophisticated understanding of the science method, became more confident with their science skills, and reported an expanded perspective on their future careers (often including field work and a wider geographic job search). Science–art student teams indicated they wanted more opportunities for collaborative work in the future, and that their final products were more professional due to their collaborations, as compared to science–science teams. Additionally, the travel abroad students benefitted from experiencing new ecosystems and cultures, from working with science and art professionals from other countries, and from working in an isolated field station without distractions.

Keywords: STEAM; science–art; collaboration; course-based undergraduate research (CURE); undergraduate science; science inquiry; science method; field research; science confidence; STEM careers

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1. Introduction

This research project examined how student participation in a blended art–science course-based undergraduate research experience (CURE) with an immersive field component would influence students' conceptualization of the scientific method, their collaboration and communication skills, and their career goals.

1.1. Merging of Arts and Sciences in Undergraduate Education

The recent emergence of STEAM education is the re-acquaintance of two related fields of study—arts and science-related fields. Many early scientists/mathematicians/engineers, such as Leonardo da Vinci, embraced both art- and science-related fields in their work [1]. The fields diverged relatively recently, only during the 19th century, such that the word "scientist" was not invented until the 1800s [2,3]. Though modern thinking considers science and art as separate fields of study, the skills required for the two fields are similar, including those of observation, interpretation, and creativity. Furthermore, scientists who create works of visual art publish high-impact journal articles at higher rates, and Nobel laureate scientists have been found to be more likely than other scientists to engage in artistic pursuits [1]. Indeed, a study of personality traits of scientists versus non-scientists found that scientists demonstrate higher levels of openness (associated with investigation, experimentation and trying new experiences) and lower levels of conscientiousness (and therefore showing more non-conforming and creative behaviors) [4].

The inclusion of art into STEM undergraduate courses has the potential to benefit students and STEM fields in many ways. Students may benefit from learning diverse problem-solving strategies [5], participating in creative and innovative thinking [6], and practicing intersecting art–science skills and practices such as questioning, observing and drawing [7,8]. Additionally, STEM fields benefit from the inclusion of the arts by becoming more accessible to students who do not identify with STEM fields [8], and by providing innovative outlets for communicating science [9], such as through illustration and public art. Additionally, meaningful transdisciplinary collaborations between arts and STEM fields may provide pathways for historically excluded groups to engage with STEM fields through the elevation of indigenous knowledge and decolonization of STEM learning spaces [3,10].

The typical undergraduate science classroom composed of large groups of students listening to scripted lectures is unwelcoming and uninspiring to some students [11], especially those who are traditionally underrepresented in STEM fields [12,13]. Indeed, one study of undergraduate students found that most university curricula does not foster creative thinking [14]. Traditional STEM course environments may reinforce the stereotype of many people that scientists lack creativity [15]; however, creativity is a necessary scientific skill to develop novel hypotheses and methodologies [16] and innovative technology [17]. As such, when students do associate science with creativity, they are more likely to learn and demonstrate competence in science and develop an interest in pursuing a STEM career [18]. Classrooms that embrace interdisciplinary strategies, such as art–science courses, foster creativity and innovative thinking that are critical to advancing STEM research [6], and for recruiting a more diverse STEM workforce [8].

Courses that merge art and science principles and practices are still not very common in traditional Western undergraduate curriculum; however, some examples may be found in literature. In one example, students from a biochemistry and an art studio class worked collaboratively to create a metal sculpture of a protein molecule for a campus art exhibit [7]. In another collaboration, students from a chemistry and an art history course studied existing works of art using chemical analyses and historical context data [19]. Students who participated in an artistic CURE in microbiology studied the aesthetic properties of bacterial colonies (color, shape, size) and then created works of art on agar plates that were streaked with bacterial colonies based on these aesthetic properties [20]. Students in the biochemistry–art courses were so excited about the project that they recruited students from outside both courses to work on the project [7]. Similarly, Adkins et al. [20] and Wells and Haaf [19] reported that students involved with their courses developed further questions that they wished to explore based on their preliminary work.

1.2. CUREs and Field Experiences

Students are generally interested in science, but often demonstrate less enthusiasm for traditional science education [16,21]. The inclusion of science inquiry in the classroom, across all grades and ages, has been demonstrated to increase student interest, motivation and attitudes about science [21,22]. Similarly, context-based science education is important for student engagement [21,23].

Traditional undergraduate STEM courses often do not allow students to develop authentic scientific questions and testable hypotheses [16,20,22,24–26]. Students learn valuable science inquiry skills through participation in CUREs, and other hands-on, personally relevant research projects. They learn how to form and test a hypothesis, and improve their confidence, conceptual understanding and interest in science [27–30]. Participation in a CURE early in a student's undergraduate career is a wonderful way to break down barriers and assist students who identify as female, first-generation, or part of a historically excluded group to participate in subsequent individualized research experiences [31]. These experiences often launch students into more long-term research experiences [32], and they generally lack social stigma associated with research programs that are labeled as minority-serving [33].

Early field experiences for non-majors and majors alike, even without an explicit research component, can still be very useful for recruiting new students into STEM or retaining existing students. Intensive field courses allow students to get to know science faculty members in a less formal outdoor setting, and provide students with memorable experiences that make them more likely to explore science-related career paths [34,35]. Wolfe and Martin [36] taught an interdisciplinary Earth and Life Science field course during which students were asked to respond to open-ended questions and to draw inferences about one site based on their observations at another. While this course was not a CURE, the open-ended nature of the questions and student reflections in course journals allowed for an immersive experience in which students refined their observation and science inquiry skills.

1.3. The Need for Art in Science Communication and Inquiry

Communication of scientific research through artistic works allows for outreach to new audiences. Further, students who engage in this work will broaden their ability to communicate science broadly, which is a valuable skill whether they become a career scientist, a science journalist, or an artist who is inspired by science topics. Scientists also benefit by finding new ways to communicate scientific results and conclusions to address potentially polarizing issues in science, such as climate change and vaccines. For example, one way to motivate people to address climate change through the reduction in greenhouse gas emissions is to appeal to their emotions rather than just provide them with evidence. The goal of the emotional response, however, is to motivate changes in behaviors rather than just scaring people or making them feel like a situation is hopeless [37], and by reaching people from a diversity of perspectives [38]. Art can evoke emotional responses from the public, by making the evidence visible and engaging. Furthermore, while interdisciplinary art–science endeavors may help to engage a wider audience for dissemination of scientific findings, they also help to expand upon who directs and conducts research and how it is carried out [39,40].

Science inquiry, in both professional contexts and educational environments, is an epistemic experience. Affect plays an important role in these experiences and provides students with an appreciation of scientific discovery. As stated by Jaber and Hammer [22],

> "*Asking questions is central to science and is largely motivated by confusion or surprise; argumentation and problem solving are the means to pursue questions and are often driven by frustration, confusion, or the anticipated joy of discovery.*"

Scientists [41] and mathematicians alike [42] are driven by feelings of restlessness or frustration about an unanswered question, and the feelings of excitement and satisfaction when they are able to answer a question. Similarly, when students participate meaningfully in science inquiry exercises, and come to know that not knowing is part of the process, they become more comfortable with uncertainty and even excited by feelings of discovery [43].

This project helped to train science students with a new avenue for dissemination of their results to a broad audience, laying the foundation for a future scientific career built on stronger communication skills. Simultaneously, art students became more sophisticated in their use and understanding of the scientific method and were exposed to the potential career path of using their artistic training for science communication.

1.4. Current Study and Research Questions

This study examines how art and science undergraduate students' ideas about science and science identity evolved during participation in an interdisciplinary science–art research course. This course, BioArt, was developed from the concept of a CURE in which students design and conduct their own research project. The primary differences between this course and other CUREs is that (1) it was co-developed and taught by a science AND an art professor with a blended art–science curriculum, (2) students worked in pairs, when possible as a science student teamed with an art student, to investigate a question and communicate their findings through a piece of art for a truly interdisciplinary experience, (3) the students conducted research in two different biological regions (the local hot desert as well as the low Arctic, an ecosystem never before experienced by these students) by merging this CURE with a study abroad experience, and (4) scholarships were offered to enable students, regardless of income-level, to take the course. While there are CUREs that incorporate biology with other topics, such as mathematics and computing [44,45], art–science CUREs are much less common. Thus, we are examining the following guiding research questions:

- How does the inclusion of art–science collaborations in an interdisciplinary art–science CURE influence students' understanding of the scientific method and enhance their science communication skills?
- How does the addition of an immersive travel abroad field research experience impact student perspective and career goals (in art and science)?

2. Materials and Methods

2.1. Art–Sscience Course and Participating Students

The art–science CURE was offered four times; twice as a travel abroad course over two summer sessions, and twice during the spring semester as a local course. Students who traveled abroad completed their research during a 2-week immersive experience at a biological field station in Arctic Finland. The other group completed their research during a traditional 16-week semester in their home setting of the desert southwestern U.S. Both the traveling and local iterations of the course covered hot desert and Arctic ecology, though only the travel abroad group was able to experience the low Arctic first-hand and conduct field research in that setting. The course curriculum is available to view and use at the project website: https://sites.google.com/asu.edu/bioart/teaching-materials (accessed on 6 June 2024).

The travel abroad group was balanced approximately evenly between science and art students, but only science students enrolled in the local offering of the course. The institution offering this course is a Hispanic Serving Institution with a large community of first-generation and non-traditional students. Students (art and science) took surveys at the beginning and end of each course, and they were asked to participate in an interview to discuss their experiences (participation was voluntary). A total of 38 student surveys were submitted before the course, and 44 student surveys were submitted after the course. Student demographics are reported for students who took the post-course survey in Table 1. A total of 23 individual and group interviews were conducted, 14 of which were with students or student groups who traveled abroad, while the other 9 interviews were with local students. Students chose whether they wanted to participate in an interview individually or with their partner—most students participated as a group. Due to low overall numbers of students from some groups (such as Native American students) we did not analyze student results by race/ethnicity or gender.

Table 1. Student demographics reported by students who took the post-course survey. All age gender, racial and ethnic identities are self-reported. Some students reported more than one racial/ethnic identity, such that they may be counted more than once. Other students chose not to report.

Identity	Number of Students in Post-Survey
Female	25
Male	14
Gender non-binary/non-conforming	2
African American	2
Asian	4
Caucasian	20
Hispanic/Latino	15

Table 1. *Cont.*

Identity	Number of Students in Post-Survey
Hawaiian/Pacific Islander	1
Native Alaskan	1
Native American	1
Average Age [1]	24.1 years old

[1] Age is reported as an average of all students who reported their age. The range was from 19 to 48 years old.

This study was approved by the Arizona State University Institutional Review Board as project STUDY00006196.

2.2. Study Framework

This study employed a mixed method design. The qualitative portion provided themes that were further investigated through quantitative analysis of pre- and post-course Likert scale survey questions. A grounded theory approach, through the lens of a post-positivistic paradigm [46], was employed for the qualitative analysis that guided this study. Further, a thematic analysis [47], was used to examine students' experiences and learning outcomes from participation in the course. This qualitative aspect of the study provided themes that were further examined through a quantitative survey of students, using a simple ex post facto design [48]. Only aspects of the survey that aligned with identified themes were examined quantitatively to further examine students' reported ideas about their experiences in the course. This type of study was employed due to the small sample size of students, which allowed for in-depth interviews.

2.3. Qualitative Analysis: Themes

During post-course interviews, all students (art and science) were asked about how they conceptualize the scientific method, similarities and connections between the science method and the process of creating art, their identity as a scientist (or artist), the process of creating a science poster and a work of art, and what they learned from the experience of collaborating. Furthermore, the students who traveled abroad were asked how their travel experience influenced their educational and research experiences. The themes arising from these interviews are shown in Figure 1, and the guiding questions used in the interview are in Appendix A. Students who traveled abroad were asked about their experience at the end of each interview, but not all students traveled abroad so this theme is not shown in Figure 1.

Students were interviewed at the end of each course, in-person or via Zoom. The students who traveled abroad were required to participate in the interview as part of their travel scholarship, while the other students were encouraged to participate by offering them a $25 gift card of their choosing. Most student interviews were audio recorded on a phone recorder or via Zoom. Only interviews that had successful audio recordings were transcribed and used for thematic analysis.

The thematic analysis was conducted using the basic steps outlined by Braun and Clarke [47]. The first author read through all of the transcripts and developed a list of codes or categories. Then, the third author on the paper read through the transcripts once to look for examples of existing codes, and to add any further codes. The two authors conferred to discuss and finalize the codes, and to discuss examples of each code (quotes) from the transcripts. Then the third author went through the transcripts one more time to tally codes and identify further quotes in the transcripts. The two authors then conferred again to consolidate codes under unifying themes. Each theme is related to one of the interview questions.

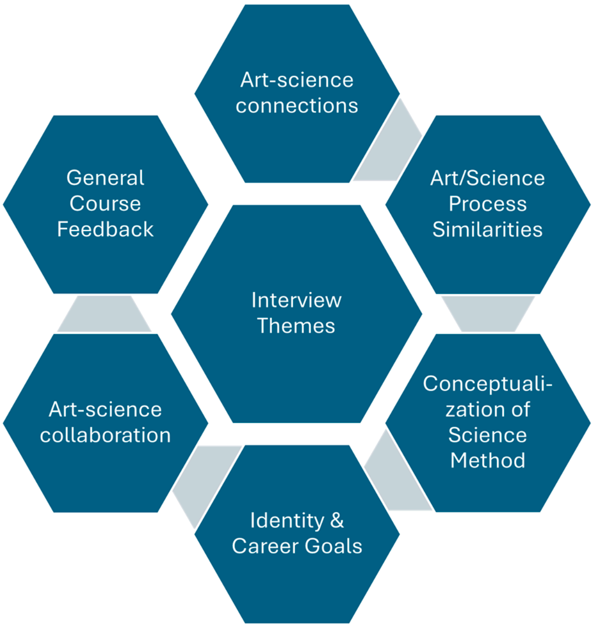

Figure 1. Interview Themes.

2.4. Survey Data Collection and Analysis

In addition to collecting interview data from students in the course, students also completed detailed pre- and post-course surveys asking them how much they agreed with a list of statements on a Likert scale. The general topics included environmental stewardship, sources of environmental influences, understanding of environmental issues, content questions (related to course content), environmental stewardship actions, post-course statements about skills students gained, student self-efficacy and preconceptions about ability in science and art, mindset (in arts and sciences), sense of belonging in science and art, science and art stereotypes, attitudes and interests and demographic information.

The detailed survey contained questions from a number of published and validated science and environmental education sources [49–55]. Several content items relevant to course objectives were also added by the authors of this paper.

For this study, we allowed the interview themes to guide the analysis of the survey data. With such an extensive survey, false positives would be more likely when comparing pre- and post-course data, or when comparing the travel abroad and local student responses, if every statement and question was analyzed. Following thematic analysis of the interview data, we examined survey questions that related to the common themes that emerged, to determine if there was any difference between groups. An independent samples *t*-test with Levene's test (for unequal variances) was used to compare the responses from the travel abroad students and the local students. A two-sided, matched-pairs *t*-test with Levene's test for unequal variances was used to compare the responses of students before and after the course.

3. Results

Common codes were identified from student interview responses, and these were consolidated under broader themes and then used to guide the quantitative analysis of the survey questions. The student posters and works of art were presented annually (as a combination of that year's traveling and local groups and therefore scientist–artist and scientist–scientist pairs) at an exhibition at a library and nature center. They also may be viewed at a virtual gallery at this website: https://sites.google.com/asu.edu/bioart/virtual-exhibit (accessed on 6 June 2024). These took many forms. One work of art was a sculpture with images of soil microarthropods engraved in clay tiles representing the soils in which they live. It used colors from the flag of the Sami people who were indigenous to the region from which the soil samples were collected. Another work of art, related to a study of increasing soil moisture due to climate change, was a sonic and visual representation of melting Arctic ice. In one of the desert studies about the role of desert animals in propagating cacti, an interactive cactus sculpture and soundscape were created. While the Arctic-themed artwork led by artists from artist-scientist teams were completed with often greater practiced skill, the Sonoran-Desert-themed artwork created by science-only teams was equally inspired and creative.

3.1. Interview Themes and Responses

Student codes were categorized based on the questions that students responded to during the interviews. The travel abroad students were more talkative because they discussed their travel experiences in addition to their experiences completing the project in the course. The number of student responses that corresponded to the most common codes are listed in Table 2.

Table 2. Course experience codes from student interviews. Only codes with at least 5 total student responses, or 4 from one group of students, are included.

Question	Response Codes	Number of Responses: Local	Number of Responses: Travel Abroad
1. Connections between science and art	• Always saw a connection between science and art.	1	4
	• After course, saw a new connection or deeper connection.	5	7
	• Specific connections were noted. "Both require..." See below.	1–2	1–3
2. Conceptualization of scientific method	• It provides a necessary framework, structure, boundary, or pathway to obtain consistent results.	2	7
	• Good guideline, but process must be flexible to allow for backtracking to redesign hypothesis or experimental design if found to be flawed.	3	9
3. Process similarities—science and art	• Starts with brainstorming and inspiration.	3	4
	• Trial and error involved in process.	1	4
	• Product is novel or original.	-	5
4. Change in science (or art) identity?	• More confident about identity, skills and career goals.	3	6
	• Developed skills that integrate art and science	2	6
	• Expanded perspective on career fields and how art and science careers intersect.	1	4
	• Confidence/interest in field work.	2	3
	• Ability to work independently on a "real world" project.	2	3
5. Science poster and artwork collaboration	• Took more time than students predicted.	2	3
	• Wanted more collaboration between art and science students.	-	4
	• Students found collaboration between art and science students to be enjoyable and product was more professional. *	-	5
6. Course feedback	• More art time and supplies.	-	4
	• Encourage more collaboration between art and science students.	-	5
	• A more extended course schedule, not such a concentrated time frame. *	-	4
7. Travel abroad experience important? *	• Enabled students to compare ecosystems in a pristine ecosystem.	-	6
	• Experienced new cultures and perspectives, different ways of thinking.	-	7
	• Learned about research from students, scientists and artists from other countries. Encouraged them to pursue research.	-	7
	• Isolation and time away from distractions emphasized work and bonding as a group.	-	5

* This question was only asked of the travel abroad students OR this response only applies to students in the travel abroad course sections that included art students.

3.1.1. Connections between Science and Art

When describing connections between science and art, many students noted that both disciplines include some of the same components. For example, some students noted that both require a trial-and-error process, use visual components (such as maps) and/or materials, or incorporate colors, textures, patterns and/or structures. Additionally, some noted that they both start with observations, and/or require a creative spark. As one student mentioned,

> *"Well, before I always thought that art and science were two sides of the same coin... they both use a similar process of coming up with an idea, then going through experiments with trial and error."*

Finally, a few students noted in response to this question that, while not a connection per se, scientists need art to communicate science. As one student said, "Nobody wants to sit there and read a lab report".

3.1.2. Conceptualization of the Scientific Method

Regarding how students conceptualize the scientific method, students fell into two camps. The traditionalists argued that the science method is necessary to provide a framework so that science researchers obtain consistent, repeatable results. One student stated it this way,

> *"Science has bounds. And if you can't work within that frame, the science would not have the validity."*

Other students argued that the framework of the scientific method is helpful, but that their work on the research project in the course taught them that the process is not linear. They argued that sometimes they would get into their study and learn that their hypothesis or experimental design needed to be refined, and so they would have to backtrack and make changes before proceeding with their project. As one student put it, they instead, "Use it as a guide and fall in where it fits.". Finally, the inquiry focus of the course helped students to develop a new appreciation for using the scientific method as a vehicle for discovery.

> *"The difference is that there's no creativity. When you're in ... a gen chem lab ... you can't come up with a new idea and then be like, oh, I want to try this out. You have to stick to this protocol. When I say I want to do more research, I think I'm referring to ... extracurricular stuff because in the chem labs and stuff like that, I don't think I would ever feel like that discovery ... a rush, I guess."*

3.1.3. Process Similarities between Science and Art

Students discussed a number of parallels between the process of doing science and creating art. The idea of brainstorming was a popular response. As one group who worked together stated it,

> *"You have a general idea of what you want to do. So, for me and xxx we just wanted to use some trail cams. And then you narrow it down into more of a concrete idea, and what you want to show, what you want to prove."*

Similarly to how they conceptualized the need to adapt the scientific method, students felt like both art and science included a lot of trial and error, as their original ideas often needed to adapt due to time and supply constraints. As one art student described it,

> *"If you are attempting a new method of process and it doesn't work, then, you make note of that. You go back and you try something new. That would probably be the closest thing to scientific method."*

Finally, students discussed how both fields required novel ideas. In science, the question must be novel and with art, the product and process needed a novel component.

3.1.4. Art/Science Identity and Career Goals

Most students did not drastically change their career goals after participating in this course; however, many reported that they felt more confident with science skills and about achieving their goals. Many students also reported that the experience expanded their horizons such that they became more interested in exploring graduate schools or science jobs outside of their local region. As one student said,

> "*[The University] gives you a fair amount of hands-on experience, through different laboratories, but it's nice to go through the entire process of designing an experiment, and carrying it out, and figuring out what materials you need and everything. So I definitely feel more confident graduating after taking this class.*"

Others gained a new appreciation for integrating art and science in their future careers. For example, one art student said,

> "*(The program) ended up changing my focus . . . Instead of just focusing on performance art, I'm also now focusing on critical theory because I think that it was really beneficial to my growth both personally, and as an artist to be pushed to do more of that research.*"

Similarly, a science student said,

> "*So I've always wanted to either do field work or lab work when I start a career. But just last night when we were working on the art project, [project partner] brought up the scientific artist job, and now [professor] talked about it earlier and that seemed interesting as well to me, because I do like drawing and it'd be like a good way to incorporate my hobby.*"

3.1.5. Science Poster and Artwork Collaboration

Student research teams were tasked with creating a work of art and a science research poster. Students worked on the artwork along with the research project such that it was evolving alongside the research project. Students worked on the research poster after the experiment was complete and all data was collected and analyzed. Students had a dichotomy of responses to the question related to this experience of creating a research poster to complement their work of art for dissemination. Numerous students remarked that they found the collaboration between a science and art student to be very beneficial. One art student commented that they learned a lot from the process of working with a scientist on the project and poster,

> "*I'll say that actually did learn quite a bit from [science partner], I never actually done a real scientific experiment and she actually taught me how to do it in a professional manner.*"

A similar number of students, either additionally or alternatively, remarked that they wanted more collaboration. Often, in the art–science student teams, the art students completed much of the work on the art project while the science students performed more of the work on the science poster. For example, this art student commented that their group (which consisted of three students) had input and involvement in the artwork she was developing, but also indicated that it was something that she was creating.

> "*I've made sure that my group has had a say in what I'm making from the very beginning, I don't want it to be [name's] piece. I let them know what I'm doing. I involve them in what I'm doing.*"

Similarly, a science student discussed differences in the way the art and science students were focusing on the project from a science versus art lens, which lead them to divide tasks because each was an expert in their field and process.

> "*I didn't realize that we weren't on the same page. So it was like they [art student] had all these great ideas, yes, and I would tell them that they were great ideas, but I'm like, no, we can't do that. That's not in the scope of our project. We can't be looking at reindeer when we're doing birds. We can't be looking at people and culture when we're doing*

birds. So mine was very like, this is your path, do not step a foot off the path. Whereas with the art, like I was trying to, and I realized this there too, I was trying to make that same box around their art too. And then it was a teachable moment that they had to teach me like, look like art's not like that. Yes, I'm not going to involve reindeer, but I'm going to involve a little bit of culture when I'm dealing with the man part of does man have an impact on birds."

When the teams consisted of science students only, the science students were forced outside of their comfort zone, and they tended to work collaboratively on both tasks.

3.1.6. Course Feedback

The course was well received by virtually all the students interviewed for this study (art and science students alike); however, the students did have suggestions for improving their experiences in the course. Potentially surprisingly, both science and art students verbalized their desire for access to more art supplies, and for more time to learn different artistic skills. They also mentioned a desire for more collaboration between art and science students, as discussed earlier. For the art–science teams, they asked for the course and assignments to be structured to require more collaboration so that they would not be as tempted to divide up their labor into science tasks and art tasks. The science-only student group mentioned that they would appreciate working with an art student to learn new art techniques and processes. As one science student in the local group indicated,

"*I thought we were going to be paired with an actual artist major. So that's the main reason I thought it'd be a good collaboration.*"

Finally, the travel abroad group also wanted the research phase of the course to be longer in duration. Due to financial constraints, they only had two weeks at the Arctic field station to conduct their research project (after 2 weeks of intensive pre-trip coursework and planning at their home institution), while the local group had 1–2 months after they developed their research plan.

3.1.7. Travel Abroad Experience

The travel abroad group was also asked about how the travel abroad aspect of the course influenced them. Many of these students had never left the region where they grew up, and so they found this aspect of the course to be extremely impactful. Traveling to a new country and observing a different culture and an entirely novel ecosystem encouraged them to think differently about their world. As one student described this impact,

"*Experiencing new cultures and people because that kind of diversity that we are experiencing helped us think in different ways that we might not have before.*"

Similarly, these students were fairly isolated at an international remote research station with professional scientists and students from many different countries. This helped them to learn about various types of research projects, and to closely interact with career scientists and graduate students—an experience that led a few science students to pursue further research opportunities at far-away places in subsequent summers and years. A student described this impact by saying,

"*I haven't been around so much research and so many people deeply involved in science.*"

Students also remarked that the isolation of the research station, and the fact that it was in a time zone much different from their own, helped them to focus and bond with their classmates. According to one student,

"*Being at the research station, you feel the need to be a little more social because you're away from home. What do you do? Sit in your room. That wasn't for me. So I wanted to go talk to the people, get to know them.*"

3.2. Quantitative Survey Findings

In this mixed-methods study, the qualitative thematic analysis was used to guide the quantitative analysis of survey responses. Students were asked to take a detailed survey to determine their agreement with statements about their self-efficacy in science and art, sense of belonging in each field, feelings about environmental stewardship, understanding of science concepts related to the course, mindset and common stereotypes about scientists and artists. This survey data was analyzed only for survey statements that related to the identified themes, quantitatively to determine if there were any significant differences between groups. Not all survey categories were analyzed for this study, including environmental stewardship, because these topics were not discussed in the interviews or identified as themes. Pre- and post-course student responses were compared to note changes in student attitudes about the identified themes over the time that they were in the course. Additionally, post-course responses from the travel abroad group were compared to those of the local group to determine differential effects of the travel abroad and art–science collaboration on student responses. A few notable differences were found (Table 3).

Table 3. Survey statements with significantly different group responses. Statements and numbers in bold had significant differences between groups.

Theme	Survey Statements	Compare Travel vs. Local			Compare Pre- vs. Post-Course		
		Local Mean	Travel Mean	*p*-Value	Pre-Mean	Post-Mean	*p*-Value
Connection between science and art	**I have seen art that depicts environmental issues.**	5.8	6.3	0.19	5.1	6.1	0.001
	I feel that art is an appropriate medium for influencing the public's ideas about environmental issues.	6.3	6.4	0.80	6.2	6.3	0.63
Science, art and science process self-efficacy	I am able to earn a good grade in my science classes.	6.3	6.3	0.93	6.2	6.3	0.68
	I am able to earn a good grade in my arts classes.	5.8	6.2	0.39	5.9	5.9	0.92
	I will be able to complete the requirements for the degree I am seeking.	6.6	6.9	0.15	6.8	6.8	0.82
	I am confident that I can use technical lab science skills (such as use lab tools, instruments and techniques).	6.2	5.7	0.10	5.8	6.2	0.20
	I am confident that I can generate a research question to answer.	6.5	6.5	0.91	**6.0**	**6.5**	**0.04**
	I am confident that I can figure out what data/observations to collect and how to collect them.	6.5	6.2	0.36	**5.9**	**6.4**	**0.05**
	I am confident that I can create explanations for the results of the study.	6.5	6.6	0.75	6.3	6.5	0.38
	I am confident in my ability to think and work creatively.	5.7	6.2	0.26	5.6	5.8	0.65
(Pre) Conceptions About Science and Art Ability	I am nervous about taking an art class because I feel that I am just not "artsy" enough.	2.5	1.9	0.15	2.2	2.4	0.57
	I am nervous about taking a science class because I feel that I am just not good at science.	1.7	1.4	0.41	1.6	1.5	0.91
Mindset (and Goals)	Learning (and doing) science requires a special talent.	2.0	1.9	0.85	2.2	2.0	0.46
	Learning (and doing) art requires a special talent.	2.6	2.3	0.39	2.7	2.5	0.42
Sense of Belonging	**I enjoy learning about science.**	4.8	4.8	0.99	4.8	4.9	0.79
	I enjoy learning about art.	4.2	4.5	0.37	4.4	4.3	0.76

Table 3. *Cont.*

Theme	Survey Statements	Compare Travel vs. Local			Compare Pre- vs. Post-Course		
		Local Mean	Travel Mean	p-Value	Pre-Mean	Post-Mean	p-Value
Science and Art Collaboration	**Scientists should work collaboratively—it is important to the scientific process to share ideas and findings.**	**4.2**	**4.8**	**0.01**	4.5	4.4	0.78
	Artists should work collaboratively—it is important to the artistic process to share their ideas and creations.	**3.6**	**4.4**	**0.04**	4.2	3.9	0.38
	Collaborations between scientist and artists can lead to innovation and a new way of thinking about and addressing societal issues.	4.6	4.8	0.24	4.7	4.7	0.59
	Collaborations between scientists and artists can lead to more creative ways to share information about societal issues with the public.	4.6	4.9	0.16	4.8	4.8	0.84

3.2.1. Pre- vs. Post-Course Differences

Students became more confident with science inquiry skills and gained an appreciation for using art to communicate about environmental issues as a result of taking the course. After taking the course, students in both groups agreed more positively with the statement that they had seen art that depicted environmental issues, as compared to student responses pre-course. These responses were scored on a 7-point Likert scale that ranged from "do not agree at all" (1) to "very much agree" (7). On the same scale, the students post-course also agreed with statements related to their self-efficacy with science processes for posing a scientific question and data collection strategies more positively than the same students pre-course. These survey results support the qualitative findings that students became more aware of how art–science partnerships may be employed to explore environmental issues and to depict scientific results related to environmental data. Additionally, these findings help to confirm that students learned important skills about the scientific process and gained hands-on experience with carrying out a scientific research project.

3.2.2. Local vs. Travel Groups

When student survey responses were analyzed to determine differences between responses for the local vs. travel groups, the only differences between groups related to student ideas about collaboration. Students were asked to rate the value of collaboration on a 5-point Likert scale from do not agree at all (1), to very much agree (5), for four different statements (listed in Table 2). The travel abroad students agreed more strongly with statements about the value of science collaborations, art collaborations, and the value of collaborations between science and art in addressing societal issues and sharing ideas, as compared to the local students who did not have art student collaborators. The travel abroad group also voiced the importance of collaboration and their desire for more art–science collaboration during their interviews. As discussed earlier, they felt it improved their overall project and they wanted even more scaffolding to improve collaborative relationships.

4. Discussion

This study demonstrates how participation in an art–science CURE may enhance key science inquiry skills such as making observations and planning experiments, expand career goals and options, develop science communication talent, and provide opportunities for meaningful collaboration between students across a variety of disciplines. Our findings support those of other college-level art–science educators who have noted similar enhancement of students' science inquiry and communication skills [19,20]. In addition to these findings, this study provides further evidence that these specific impacts are possible even if the course only enrolls science students. At some institutions, it is challenging to cross-list courses that will fulfill requirements for both art and science students, which may lead to issues with enrolling both art and science students. Student awareness of the importance of collaboration across disciplines, however, was enhanced only in the course sections that enrolled both art and science students. As discussed by Mejias et al. [3], students benefit the most from art–science curriculum when "both are equally in play" such that the curriculum and the research practice are informed by both art and science principles. Therefore, it is important for both science and art programs to include interdisciplinary courses as part of their degree, providing an incentive for students from each major to make time to engage in the interdisciplinary coursework that they might otherwise not make time for.

Students in the course noted that many connections between science and art exist—as one student said, they are "two sides of the same coin.". Some students came into the course recognizing these connections, while others gained an appreciation for this connection during the course. Art and science students alike noted the creativity associated with science inquiry, and its importance to this process, as has been noted by past researchers [1,4,56]. Furthermore, they appreciated the feelings of excitement and satisfaction that have been noted to be a driving force for scientific discovery [41–43]. This study adds that students also appreciated how these connections helped them to consider a wider variety of potential careers, especially those that work at the intersection of arts and sciences. They felt that they had more "real-world" practical experience as a result of working on the project as a collaborative art–science team, and that the experience enhanced their communication skills. Similarly, the science-only teams learned how to collaborate on art projects and gained confidence in experimentation with an artistic endeavor. Art and science students learned that science research can be conducted in a variety of ways, by a diverse field of practitioners, and that cross-disciplinary opportunities exist to communicate science, as has been noted by STEAM education researchers [39,40].

Student self-efficacy with critical skills of posing research questions and collecting experimental data was enhanced through participation in the project. Student participation with CUREs has been shown to increase student involvement with science research [32], especially for students who may not otherwise have access to research experiences due to life constraints [31,33]. The CURE in this study was unique by employing two strategies to increase accessibility to non-traditional and low-income students. It provided funding for students to travel abroad, thereby eliminating a major hurdle to participation for low-income students. Also, by offering the field-based CURE during a short summer session (travel abroad group) and as a regularly scheduled lecture/lab course (local group), the course was accessible to students who had families and/or had to work to support themselves. However, the authors argue that the art–science collaborations during the CURE made the experience even more impactful, as has been noted by some others [7,19,20] by changing the way that students think about science inquiry and discovery. The interdisciplinary art–science research component provided a unique construct that helped students to conceptualize the scientific method as a more flexible set of rules that could be applied in a somewhat circular fashion to allow for adjustments, rather than a strict linear process that does not allow for refinement of a process. By working with an artist, or as an artistic team with other scientists, the students learned the benefits of experimenting WITH the scientific method. They became more creative thinkers, which can lead to scientific innovation, as discussed by Draper and others [3,6,16,22,56]. Additionally, as argued by Mody [56], the messier, more flexible conceptualization of science research that these students developed better prepares them for situations they will encounter in the workforce.

Students in the program noted many similarities between the scientific and artistic process, similar to those observations by Zhu and Goyal [2], "At their core, art and science are both about observation and interpretation". Furthermore, Forget [8] noted that by emphasizing the similarities between practices in the arts and sciences, it can mitigate gender stereotypes and engage girls with STEM in a meaningful way. Students from historically excluded groups are also more likely to feel welcomed in creative and flexible STEM environments that are created through interdisciplinary art–science collaborations [3,6,10]. The students who participated in this project were not "traditional" STEM students in many ways. Many of them identified as being from a historically excluded group (African American, Hispanic/Latino, Pacific Islander, Native Alaskan, Native American) and/or were from low-income families. Further, other researchers [57] have demonstrated that the use of drawing or sketching out science processes helps to engage Latino students in science, particularly when their parents do not speak English as their first language.

This study was unique in its comparison of artist-scientist and scientist-only collaborative groups. The importance of collaboration was discussed by many of the students who worked in art–science teams. Indeed, it was a major theme throughout the interview and survey data for this group. They were more likely to agree with statements that collaboration (between scientists, between artists and between artist-scientist groups) is important for sharing ideas and findings, especially when they have widespread, global societal impacts. Thus, while the students in scientist-only groups gained an appreciation for art and the scientific method while working on their projects, they did not gain as much appreciation for the importance of collaboration and sharing of ideas with others outside of the traditional science community. On the other hand, the scientist-only teams were forced out of their comfort zone to engage more with the creation of the art to practice these skills, because the scientist–artist teams reported a tendency to split the work based on their major. Why and when this split occurs is an interesting phenomena worthy of further study, and a mechanism to prevent students from splitting the work according to expertise would benefit interdisciplinary scientist–artist teams. These communication and collaboration skills are even more essential for research that has urgent societal impacts that may lead to social inequities, such as studies related to human and environmental health, climate change, growing crops/food, and (clean) water access [3,39].

This study unveiled some interesting findings about the impact of remote field experiences, and how they uniquely help students to embrace their scientific identity quickly. Students in the travel group mentioned that the remote environment isolated them from their usual social circles and distractions, and this was an important aspect of their experience. It expanded their horizons such that they were more interested in pursuing science research, and they were more comfortable traveling to more exotic locations for future research jobs. It is not always economically or environmentally feasible to take students on a study abroad field trip for their CURE experience. Luckily, the aspects of the field-based study abroad group that the students found most redeeming (collaboration between artists and scientists, time to plan out and work on an authentic research project, and access to art materials) can also be replicated in a local setting.

In an effort to promote art–science projects, the materials generated for and by this program are publicly available online. The second author created a virtual gallery for the student posters and works of art from this project. Thus, the scientific and artistic material is freely available to the general public who desire to learn about the research topics studied by the students in the course, even when they are not able to visit a physical venue displaying BioArt (such as a museum or gallery). The virtual gallery is available at this website: https://sites.google.com/asu.edu/bioart/virtual-exhibit (accessed 6 June 2024). Additionally, to aid dissemination of the art–science curriculum used in our program, the curriculum for the college-level course, and adaptations of this curriculum for elementary and secondary audiences is also available publicly at this website: https://sites.google.com/asu.edu/bioart/teaching-materials (accessed 6 June 2024).

Future studies would be helpful to examine these findings with a larger number of students, especially including more art and science student pairs. As stated by Gurnon et al. [7], scheduling conflicts present a challenge with recruiting students from the arts, which require significant studio time, and from the sciences, which require significant time in the laboratory and/or field. This challenge was also an issue for this study, as it was only possible to recruit art students for the summer travel abroad offerings of the course. Additionally, it would be helpful to learn whether the travel aspect was so impactful because the experience took place in a different country with new cultures, or if traveling regionally to somewhat isolated research stations with different ecosystems and new professional influences, but relatively stable cultural influences, would lead to similar shifts in student career goals. Finally, the curriculum developed for this course is publicly available for college educators, and it has been adapted to primary and secondary (K-12) classrooms. One local elementary (K-8) school adopted the curriculum, and we continue to work on dissemination to other schools. Future studies may examine the benefits and potential challenges associated with implementation of this curriculum with younger audiences. It will also be interesting to learn which lessons translate well to the K-12 audience.

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Appendix A

The guiding interview questions used in this study are as follows:

1. Before the course, did you see connections between science and art, and if not, has that changed after the course?
2. Has this course changed how you conceptualize the scientific method? Do you think it is a necessary part of the scientific process, or does it limit creativity?
3. Do you see any similarities between the processes that artists use to create a work of art and scientific research?
4. As a result of participating in the course, has your identity as a scientist (or artist) changed in any way? Has your career path changed?
5. How was your experience developing the presentation for the exhibit/installation? The poster and the work of art? And collaborating with your partner?
6. Do you have any feedback about the course?
7. For the travel abroad students ONLY. Was travelling abroad an important part of your course experience?

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