Artists' Work Process:
STEM Topics & Art-Science Collaboration

Project: **Indianapolis: City as Living Laboratory**

NSF Award #DRL-13-23117

March 6, 2018

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NewKnowledge Publication #NSF.097.115.05

Executive Summary

This report describes the results from an exploratory study of how artists approached collaboration with earth scientists to foster the public's science learning and engagement with a city's waterways. Data from phone interviews, surveys, and reflection on the artwork produced for this collaboration were compared with observations of roundtable discussions with community-based artists and scientists grappling with these ideas in a dialogue format.

The researchers found that personal connections with the waterway sites and professional interest in and experience with art–science collaborations influenced artists' perceptions of science. Artists' experience with art–science collaborations further determined how and where they gathered scientific information. All artists prioritized experiential and emotional engagement with science topics for their audiences, rather than attempting to create instructional pieces about scientific process or facts. In general, the artists and scientists who participated in the study desire more opportunities for meaningful and equal partnerships in art–science collaboration. Reflecting on art and scientific process, artists and scientists saw both similarities and differences in the processes and priorities that characterize their fields. The results of this study reveal characteristics of artist-led processes that may complicate efforts to advance public STEM literacy. The results also point to opportunities for further experimentation, as well as specific strategies that might improve the process and outcomes of future collaborations among art and STEM professionals.

INTRODUCTION

In 2013, the Center for Urban Ecology at Butler University was awarded a National Science Foundation grant (#DRL-1323117) to explore informal science learning opportunities on public lands in Indianapolis, Indiana. The five-year project, entitled *Indianapolis City as a Living Laboratory: Science Learning for Resilient Cities* (I/CaLL), project investigates how different types of art can be used as conduits for informal science learning on a citywide scale. The project set out to explore art and art process as a new strategy for enhancing informal science education for environmental sustainability. As a collaborative endeavor, the project brought together earth science researchers, artists committed to exploring environmental issues, and social scientists who sought to explore cultural phenomena related to these professional collaborations and public encounters with the art products.

Butler University collaborated with Indiana University - Purdue University Indianapolis (IUPUI), Mary Miss/City as Living Laboratory, Reconnecting to Our Waterways (ROW), and New Knowledge Organization Ltd. (NewKnowledge), in addition to individual artists and curators on the project.

I/CaLL leadership selected five sites adjacent to waterways in a range of Indianapolis communities where artists were invited to create installations, performances, or art works based on these sites to support an experiment in advancing public informal earth science literacies in the greater Indianapolis region. The five waterways were considered particularly useful for this experiment because they are found within a twenty-minute walk for most residents in the central Indianapolis area. Ultimately, the project's outputs aimed to increase the connections between people and their environment.

I/CaLL social science researchers are studying how artistic installations and programs at Indianapolis waterways can promote community engagement and science learning among city residents. The key questions guiding this research are: 1) How do art experiences prompt science reasoning?; 2) How can we measure and define scientific literacy, growth, and vectors for science learning in a community?; and 3) How does informal science learning happen as part of family and civic life outside the home? This study of approaches to and perspectives on art–science collaboration focuses on the first and second research questions. Specifically for the second research question, we focus on how art-science collaborations can serve as a vector for increasing science literacy. However, we do not address how to define and measure the public's science literacy and growth.

We used interviews with artists and roundtable discussions with artists and scientists to gain insight into our research questions. Specifically, findings examine how three factors – Perceptions of Science, Science Knowledge, and Artists' Intentions – affect how an artist works, particularly on artwork involving environmental issues. We also discuss themes important to artist–scientist collaboration, as well as opportunities and barriers for integrating artists into informal science learning initiatives.

Background

Artists and scientists have collaborated on initiatives that focus on public engagement for over fifty years (Snow, 1961), particularly in STEM education and conservation biology (Bagdassarian, 2009; Barnett & Whittle, 2006; Jacobson, McDuff, & Monroe, 2007; Mandelbrojt, 2006; Rubin, 2008; Tolisano, 2007; Vitulli, Pitts Santoli, & Fresne, 2013; Samsel, 2013). These collaborations have been suggested to offer multiple benefits, including promoting advocacy, furthering disciplinary knowledge, and advancing art and science literacy. Despite these claims, few studies have quantified or documented real-world impacts of such collaborations.

From a rudimentary communications perspective, professional artists have skills that can be used to illustrate and convey scientific information in an accessible and engaging manner. As a result, their work has the potential to demystify environmental issues and create more visceral connections that influence public understanding, which may increase the likelihood that audiences engage in positive environmental attitudes and behaviors (Mills, 2007; Bunting, 2009; Curtis, 2003; Jordon, 2007; Born & Barry, 2010). This type of science communication emphasizes the artist's instrumental communication skills, rather than the potential intrinsic societal value of the artwork.

From a disciplinary perspective, artists and scientists both benefit from interaction across boundaries, and such

experiences have sometimes led to technical and innovative discoveries and visualizations (Webster, 2005; Rubin, 2008; Blakeney, 2009; Samsel, 2013). For example, the invention of the microscope at the turn of the nineteenth century played an integral role in the exploration of themes and forms that characterized Art Nouveau (Blakeney, 2009). Conversely, art has influenced scientific discovery and practice. Artists have played key roles in creating tools that advance medical training from the time of Leonardo da Vinci to the present (Andres, Himsworth, Weber, & Scott, 2016). Artists such as Paddy Hartley helped facial surgeons create bioglass facial implants, and artist and heart imaging specialist Philip Kilner collaborated with a heart surgeon to create intricate models that led to new surgical approaches for rare and critical congenital heart malformations (Webster, 2005). These examples should be considered disciplinary scaffolds, though, because the artists interacted directly with learners rather than creating art works to support an informal science literacies agenda.

From an educational perspective, research has conceptualized the artistic process as a pathway for advancing content literacy through sustained interest and exploration (Burnaford, 2007 offers a review). Furthermore, creating art tends to be a hands-on process of physical engagement with a specific medium to achieve a representational end product, during which those tools are used to explore ideas at a conceptual level. Advocates of Experiential Learning Theory propose that this type of dual integration (i.e., conceptualizing/experiencing and acting/reflecting) increases learning (Kolb, 1984; Kohl, Potter, & Dery, 1993; Roberts, 2011; Delacôte, 1998; Kolb & Kolb, 2005; Duke, 2010). Studies in formal education suggest that benefits related to student-created art include improved grades, standardized test scores, critical thinking skills, reading comprehension, motivation, and engagement (Vitulli et al., 2013). Again, though, these products become instrumental scaffolds because the art products themselves are not situated as a central focus for advancing literacy.

Long-term art–science collaborators Wright and Linney (2006) note that developing a common language, being creative, taking risks, and having public endorsement are important aspects of collaborative initiatives that transcend disciplines. Despite these claims, there is a dearth of documentation about the impact of these factors, and much to be learned about the components of truly successful art–science collaborative projects that contribute to public science literacies and are perceived as valued art in their own right.

METHODS

Participants

I/CaLL featured four core art disciplines: visual art, dance, music, and poetry. Each discipline was represented by one or more artists. As is typical of large-scale sculpture and installation, the visual artist had the support of an extended studio team and contractors to execute their vision.

The music and poetry were commissioned in 2013 through a curatorial process to select artists producing original work (music) or compiling both non-original and original work (poetry). The selected musicians and poets also had to have prior experience interpreting place and an interest in environmental and science topics. Curator Michael Kaufmann commissioned the musicians and curator Stephen Motika commissioned the poets. The choreographers worked with a large dance company to develop and perform a series of place-based pieces.

Seven of the artists included in this study were based in the state where the work was displayed (Indiana), three were based in New York City, one in Los Angeles, and one in Seattle, and one was a US artist currently working in Europe. Table 1 describes the artists, their disciplines, and the associated I/CaLL sites.

The artists themselves chose to convene monthly group calls. A researcher listened in on these calls and took informal notes to stay abreast of how the artists engaged with each other and the science content.

Simultaneous with the implementation of the I/CaLL project, the da Vinci Pursuit, an Indianapolis-based organization, began hosting monthly roundtable conversations in March 2014; over 135 occurred during the I/CaLL funding cycle. These conversations brought together local artists, scientists, educators, and community representatives to discuss topics

of mutual interest and explore varying perspectives. Participants were not limited to the I/CaLL artist team.

Table 1. Artists' project role and site focus.

Artist	Role	I/CaLL Site
Mary Miss[a, c] & City as Living Laboratory	Landscape Artist/ Sculptor	Multiple Sites
Cynthia Pratt & Larry Attaway[a, b]	Dance Choreographers	Multiple Sites
Michael Kaufmann[a]	Music Curator	Multiple Sites
Matthew Skjonsberg	Composer	Central Canal
Roberto Lange	Composer	Little Eagle Creek
Hanna Benn	Composer	White River
Olga Bell	Composer	Pleasant Run
Stuart Hyatt	Composer	Pogue's Run
Moses Sumney	Composer	Fall Creek
Stephen Motika[a]	Poetry Curator	Multiple Sites
Catherine Bowman	Poet	Multiple Sites
Alessandra Lynch	Poet	Multiple Sites
Adrian Matejka	Poet	Multiple Sites

Notes.
[a] Core artist
[b] The 110+ members of the dance company that participated in the project, Butler Dance, were not included in the study because of the time-intensive nature of the interview research methodology.
[c] City as a Living Laboratory (CaLL) is a non-profit organization led by artistic director Mary Miss. CaLL staff supported content development and production of materials for the I/CaLL project.

Instruments

Every two months from September 2014 to June 2015, a NewKnowledge researcher conducted semi-structured phone interviews with the five core artists/curators. Interviews were designed to provide insight into the artists' thinking and process. Scripts varied slightly depending on the interviewee's role in the project and when the interview occurred (see Appendix for a sample script). The general topics were:

- Creative efforts and decision-making processes;
- How sustainability and water-related science issues are incorporated into their work;
- How community concerns and issues are incorporated into their work; and
- Interactions and collaborations with other artists and scientists involved in I/CaLL.

During the same period, the core artists also completed monthly reflective surveys, which served as an alternative or supplement to the phone interviews. The survey asked these artists about their:

- Creative process;
- Relationship to the science content of I/CaLL; and
- Engagement in art–science collaborations.

During their engagement with the project, the commissioned poets and composers completed the same monthly reflective surveys as the core artists and participated in one phone interview. We used these data as a point of introduction to the study and to learn their initial thoughts about I/CaLL. The number of surveys each artist completed ranged from two to nine months, depending on how long they were involved in the project.

Analysis

A NewKnowledge researcher took notes for each bi-monthly interview and recorded the conversations when possible. Recorded conversations were used as a reference and for transcription when needed. Notes from all interviews and the data from the email surveys were entered into an Excel file and coded to highlight these themes:

- **Perceptions of Science** – views on science, including values and formative experiences with science or scientists;
- **Science Knowledge** – how the artists gathered information about science and used science resources, and their confidence in their own science knowledge; and
- **Intentions of Work** – what the artists hoped their work would accomplish, as well as foci of their work.

The same NewKnowledge researcher who conducted the artist interviews coded the notes from these interviews. A second researcher checked the codes and summarized themes across the artists.

Additionally, we listened to the audio recordings from five roundtable conversations that took place between March 2014 and June 2015, identified topics common to every discussion, and explored these patterns through analysis of:

- **Exploring Artist–Scientist Collaboration** – artists' and scientists' explorations of partnering. As mentioned, the artists and scientists who participated in the roundtable discussions were not necessarily part of the I/CaLL project team.

Our analysis of the interviews and the roundtable discussions included factual descriptions of the dialogues, the language used in conversation, and what meaning we could infer behind those words based on syntax and prior information. Sennett's (2012) sociological approach was used to distinguish between *dialectic* and *dialogic* discussion. Dialectic interpretation refers to face-value understanding of a conversation, which is used to highlight explicit and factual meaning. Dialogic interpretation draws on the skill of listening and hearing implicit meaning behind the words. Our analysis acknowledges both levels of interpretation and attempts to include explicit and implicit interpretations of discussions between the researcher and the artists.

Survey responses were synthesized and coded using grounded theory analysis. Findings reflect the four themes that emerged from the surveys: Perceptions of Science, Science Knowledge & Content Exploration, Intentions, and Working with Scientists.

RESULTS

Perceptions of Science

One of the key factors that determined artists' perceptions of science – and the earth sciences related to Indianapolis waterways, in particular – appears to be a sense of personal connection to the water sites and the city itself. Artists had different relationships with the landscape and its communities. Over half of the I/CaLL artists who participated in the interviews and surveys were born in or currently live in Indianapolis. These artists spoke about a personal investment in this project that was not a factor for non-resident artists.

The music curator, for example, travels through numerous areas of the city every day. His commuting path leads him through many of the neighborhoods adjacent to the waterways and waterway sites associated with the I/CaLL project. When selecting the six musicians who would compose site-specific pieces, the curator deliberately chose artists likely to align with his personal vision of the corresponding neighborhoods or qualities he identifies with the waterways. For Pleasant Run, for instance, he recognized the importance of the surrounding community's expectations for the music. He wanted a composer who would be able to create a beautiful, accessible piece celebrating this community. The curator envisioned a composition with emotional gravitas that could tap into the collective psyche of the neighborhood. Given his approach, project-related artistic and curatorial decisions sometimes reflected less focus on science topics in a traditional, empirical sense, and more on emergent community issues.

Prior professional experiences emerged in the surveys and interviews as the second key factor that influenced artists' perceptions of science for this collaborative initiative. Some artists entered this project after decades of work on environmental art, whereas others noted that this was their first environmental art effort. With 40 years of experience as an environmental and landscape artist, Mary Miss professed a deep interest in using art to speak about the environment. She envisioned the I/CaLL project as a logical next step to build on her legacy of exploring environmental science content in public arenas (Bendel, Kirn, & Gupta, 2013; Fraser, McDonald, & Ardalan, 2015; Fraser & Miss, 2012).

Musician Stuart Hyatt also felt that he was deeply involved with the project because it built on his prior work. A local resident, Hyatt has done sound mapping of different parts of Indianapolis as part of interdisciplinary media projects for much of his musical career. Hyatt felt this project was an ideal opportunity for him to continue to sound map the city and expand his interdisciplinary repertoire. He created a seven-track series of recordings and published a digital and vinyl album about Pogue's Run waterway. He explained that his work explored both science and community issues.

According to interviews and surveys, a third factor that seemed to influence artists' perceptions of science was prior

experience working in art–science collaborations or other interdisciplinary work. Landscape artist Mary Miss and composers Stuart Hyatt, Olga Bell, Matthew Skjonsberg, and Roberto Lange had experience participating in cross-disciplinary projects, some specifically with scientists. Those artists working on their first interdisciplinary science project fell into two camps: some felt less connected to the science and some felt excited about rethinking their process by engaging with scientists in subjects they found unfamiliar. In the latter group, observations and interviews showed that poet Alessandra Lynch and choreographers Cynthia Pratt and Larry Attaway embraced the interdisciplinary process, anticipating that new information would help them discover something new in their own work. Reflecting on discussions with scientists, for instance, Pratt remarked, ***I never left these conversations where I didn't feel stimulated and inspired.***

Lastly, practical issues such as location and available time also played a role in artists' perceptions of science and their willingness to engage with science content and scientists associated with the project. Whether an artist was local to Indianapolis and whether they had conflicts with other commitments resulted in varied levels of engagement with the science relevant to the specific site each artist was assigned as a point of focus.

It must be noted that the different art forms received varying amounts of funding that impacted the resources and time different groups of artists were willing and able to contribute to the project. The sculptor, Mary Miss, received the greatest amount of funding and contributed the most time and resources. The dance team received the second largest amount of funding, though the amount was substantially smaller than that received by the sculptor, while the musicians and poets received similar or markedly smaller amounts than the dance team. Aside from Stuart Hyatt, who used this project as an inspiration and challenge to grow his own repertoire, the time and resources invested generally reflected the artists' respective levels of funding.

Science Knowledge & Content Exploration

I/CaLL was intentionally designed as an experiment that would allow artists to lead the process of working with science topics and scientists, rather than situating artists in a default instrumental role that asks them to simply explain and visualize science topics. To support the artists as they began what was, for most of them, an unfamiliar process of engaging with science concepts and science reasoning, project scientists shared a list of 22 earth science concept topics that impact river ecology in the Indianapolis region. In parallel, the social scientists (and authors of this report) offered their expertise in informal science learning as another resource the artists could draw on.

After the science concept topics list was shared with each of the participating artists at the start of the project, there was general agreement that one of the topics was too abstract to be of use. Subsequently streamlined to 21 concepts, the list did not include definitions; it simply noted phenomena that impact Indianapolis waterways.

Interviews showed that the artists found the list (Table 2) too vague or intangible to engage with in a meaningful way. Listing these concept topics without explanations did not position the artists to develop an approach to these issues in their work or establish a strategic point of reference from which they could develop affinities with science collaborators.

To guide assessment of informal science learning impacts among the public, a biologist developed and published a more detailed overview of these 21 science concepts and outlined relevant levels of general, functional, and operational literacy for each topic (Danoff-Burg, 2015). This substantially more comprehensive resource was shared with each artist, and while some said they were able to use it, many had already completed their work before it was published.

Though not all topics were addressed by the artists, the final topic list (Table 2) was considered the basis for this project's aims to increase public science literacy in Indianapolis.

Table 2. Earth science issues impacting Indianapolis waterways.

	Topic
1	Brownfields
2	Toxic chemical pollutants
3	Water contamination by harmful bacteria
4	Pharmaceutical pollutants
5	The Deep Rock Tunnel Connector
6	Riparian habitats
7	Invasive species
8	Nutrient cycling in an urban environment
9	Material flow analysis
10	Urban water cycle
11	Urban heat island effect
12	Storm water management
13	Human impacts on groundwater
14	Water distribution and loss
15	Integrated urban water strategy
16	Physical impacts of urbanization on waterways
17	Urban stream restoration
18	Health of urban waterways
19	Politics of urban watershed management
20	Sustainable urban water supply
21	Urban water engineering

Interview and observation data showed that the freedom to lead the collaborative effort was liberating for some artists and challenging for others. Though prior fascination with science topics did not seem to have a direct influence on a path to understanding, prior experience with science collaborators did seem to have an impact on the art production process.

Not surprisingly, and as occurs among the wider public, the artists pursued self-directed online research, including general web searches and reviewing documents offered by the project scientists. Many contributed their discoveries of useful resources to an online shared project folder. Artists said they also read popular science books such as *The great animal orchestra: Finding the origins of music in the world's wild places* (Krause, 2013).

Artists' approaches to integrating science knowledge in their work varied, according to observation, interview, and survey data. As mentioned, some individuals joined I/CaLL with a long history of art–science collaborations. Experienced collaborators demonstrated a degree of confidence in researching science concepts and were excited to engage with scientists and science materials. Those with a self-described science affinity also exhibited a more structured approach in describing their work process. They relied more heavily on engaging natural scientists in discussions, explored phenomena first-hand at assigned waterway sites as part of their development process, and supplemented their work with online explorations to delve more deeply into specific aspects of earth science.

Artists who felt more confident approaching science topics reported initiating and scheduling their own calls and meetings with different types of natural scientists, not only those scientists affiliated with the project. They tended to focus on earth science research, environmental management, and health topics related to environmental issues. Over the course of this project, artists worked with ecologists, climatologists, social ecologists, biologists, science educators, earth scientists, hydrologists, naturalists, sociologists, historians, urban designers, land managers from the Department of Environmental Management, county health department officials, and experts from an energy group. Since many of these scientists were not part of the project team, most of the relationships that emerged between the artists and the scientists listed here might be most accurately described as consultative, rather than collaborative.

We observed that the science-confident artists' engagement with science seemed to stem from a search for facts and information to incorporate into their work, rather than an attempt to replicate the scientific process. These artists thus appear to have engaged with scientists for the instrumental use of information rather than as a collaboration of equals. While we highlight this instrumental approach, each of the artists felt that their role went beyond conveying information. They defined their role as using new information to help them create conditions that would provoke thinking or reasoning by those who experienced the final art product.

Interview, survey, and observation data indicated artists with less experience working with science topics were more likely to gather information in a much more targeted way. These artists focused on prolonged contact with several science advisors associated with the project, rather than independently searching for a wide range of information from many types of scientists. One artist, for example, sought out a science expert who communicated in a narrative form that she found accessible, informative, and engaging. She explained that she needed a guide who could help her carefully explore unfamiliar science information.

Self-Directed Science Content Exploration

Observations suggested that some artists seemed to focus more narrowly on environmental science, while others used broader scientific and science-related perspectives associated with several types of science. Artists who focused almost exclusively on environmental science were clear about their research topics, which one researcher identified as stream flow, infrastructure, watersheds, habitats, urbanization, climate, runoff, geomorphology, food webs, and decomposition. Artists who explored content more broadly also engaged in additional information-gathering in disciplines such as urban studies, sociology, and anthropology when amassing or deepening knowledge about their sites and the surrounding communities. None of the artists explored psychology despite the presence of a psychologist on the leadership team.

We also observed that artists differed in the degree of science focus they used in their work. Some perceived their work as very representative of current science research, while others felt science was implicit in their work. This latter group tended to intuitively use their senses to guide the way they created or compiled their work, seeing themselves as vectors whose ability to represent natural and science phenomena was sufficient to achieve their goals.

Artists' Intentions for their Work

While artist intentionality has been generally debunked as not necessarily relevant to the user or viewer's experience (Marková, 2003), inferred artist intentionality has been linked as a path to user of viewer understanding (Housen, 2007). For the most part, artists in this project tended to approach site-specific and science topics by creating art they felt would be experientially and emotionally engaging for their audiences. Based on interview data, there was consensus among the artists that they were instigators for learning but would not attempt to be instructional, nor would they seek to ensure that audiences came away understanding new scientific facts. It is therefore not surprising that none of the artwork was overtly didactic or factual in nature. Most artists were interested in using art as a means of visualizing science in emotive and personal ways that viscerally engaged the public. It seemed that they hoped to instill the *feeling* of the science concepts addressed at each site. This strategy was described in their personal reflections and interviews as intentionally provoking the public to reflect, question, or talk with each other. Most thought their work would motivate people to pursue personal research into associated earth science issues.

Overall, artists' surveys and interviews showed they intended their work to be a stepping point that might encourage the public to seek factual scientific information elsewhere. Artists hoped this information would eventually be available on the project website, and found through self-directed Internet searches or community resources such as universities and libraries.

Mary Miss, for example, attempted to foster connections between the environment and the public with her installations, rather than teach scientific facts. She aimed for a juxtaposition of text and large red lines to direct the gaze in ways she thought would provoke reasoning about environmental phenomena that could be observed at the site.

Figure 1. Mary Miss's installation at the Central Canal; red lines and mirrors aim to direct the viewer toward specific environmental phenomena.

Figure 2. Riverrun Revisited was a series of site-specific public performances about the city's waterways, led by choreographer Cynthia Pratt.

Likewise, choreographer Cynthia Pratt envisioned a series of events in which the public would participate in the dance movement experience. She saw this type of active involvement as an opportunity for kinesthetic learning through body movement, possibly linked to discussion about the meaning of those movements. Unfortunately, the Institutional Review Board regulations for human subject research and university safety policies prohibited public participation in dance events led by the I/CaLL project choreographers. Instead, they worked with the Butler University dance company (Butler Dance) to lead a set of public performances focused on raising awareness about the waterway sites and observable environmental phenomena, to activate community interest in use of these sites and ongoing observation of site conditions.

In one interview, the choreographers speculated that co-presenting their work alongside more traditional science presentations would probably result in a larger impact on the public audience. They explored this idea in their final choreographed event, Riverrun Revisited, which layered movement, poetry, music, and didactic science content to connect with viewers in multiple ways.

The poets were interested in the power of words to conjure images and create connections between the public and local landscapes. One poet said, ***I have been interested in more directly inviting people ... to meditate on these beautiful, damaged sites, to come closer to these essential, somewhat hidden or seemingly inaccessible parts of their environs—where they live, the water they drink.***

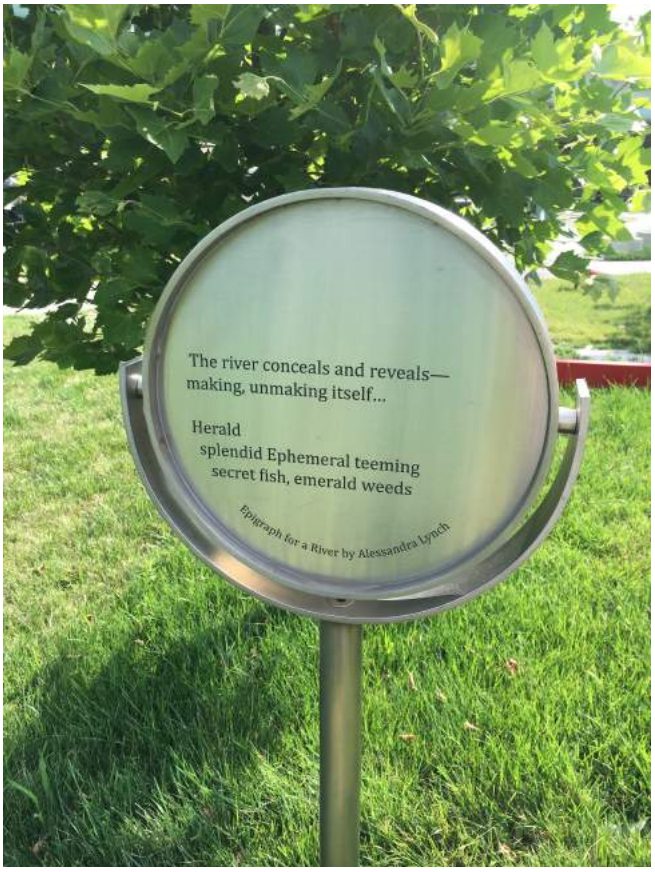

Figure 3. Project poet Alessandra Lynch wrote original poems that were integrated into Mary Miss's site installations.

For the most part, the musicians interpreted the science in experiential and affective ways and used the structure and content of their work as metaphor for specific science issues they felt they addressed. Roberto Lange, for instance, explored ***physical impacts of urbanization on waterways*** and ***health of urban waterways***, abstracting his experience of the waterways into sounds that he felt could metaphorically represent the waterways to listeners. He described his process this way:

Runoff, garbage, and buildings became distinct visual landmarks, which I translated into sounds. There was a quiet and stoic quality to the buildings. They represented a drone quality that I interpreted into the string sounds but also let the buildings fall into the background until they were reactivated by other environmental sounds.

The infrequent human coming out of one of the buildings added the untimed variable of sound. Footsteps echoing quietly down the corridors as they walked out and down cement steps onto pavement created real subtle rhythms and tempo.

Matthew Skjonsberg took a different approach to his musical composition. One of his intentions was to directly affect the composition of the water through a public performance of the 61 bells of the carillon played near the Central Canal on the Butler University campus. He seemed less concerned with the public's experience of his composition or their ability to relate these sounds to water science. Rather, Skjonsberg felt his composition was itself a direct intervention that would have positive impacts on pollution, water health, and stream restoration. He got this idea from research suggesting that water can be affected by sound vibrations (Emoto, 2011). However, Skjonsberg did not appear to draw directly on this emerging theory or existing evidence with respect to how specific tones, but not other tones, are understood to impart a potentially healing impact on waterway systems. His work was based on his intention to transform the Central Canal, rather than a research-informed formulated structure of musical notes that might transform the waterway.

Figure 4. Project musician Stuart Hyatt recording at Pogue's Run.

Exploring Artist–Scientist Collaboration

The da Vinci Pursuit is the previously mentioned initiative that convened roundtable conversations to bring artists, scientists, interpreters, social science researchers, and community representatives together to discuss topics of mutual interest and explore participants' perspectives on topics related to our research question about how art experiences can prompt science reasoning. Some participants in these discussions were affiliated with the I/CaLL research and artwork, others were not involved.

The five conversations NewKnowledge analyzed focused on four topics: sources of inspiration, balancing objectivity and creativity, how to combine art and science, and communicating with the public. Complete analysis of these discussions was addressed in a separate report (Norlander, Fraser, Kesling, Ardalan, & Flinner, in review), though salient points relevant to this report will be summarized here.

When discussing the process of creating a piece of art or developing a scientific study, artists and scientists alike emphasized that serendipitous observations often serve as their source of inspiration, planting the seed of an idea they then develop. One artist described her creation process as constantly observing the world from a personal perspective and waiting for something to catch her eye.

Both artists and scientists also highlighted the inspirational importance of cultural and historical context, as well as disciplinary precedents. All agreed that both disciplines rely on what has been done before, with one participant quoting Isaac Newton, ***If I have seen further, it is by standing on the shoulders of giants***. Artists and scientists did seem to differ in their approach to using pre-existing models in their own fields. While both artists and scientists use an iterative process to apply and adapt models in their work, several artists mentioned that they intend to break these precedents as quickly as possible; scientists rarely echoed this sentiment.

Some discussion focused on the balance between objectivity and creativity, and how both are integral to advancing scientific research and producing art. Scientists particularly emphasized the importance of objectivity; one noted, ***If you're the only one who can experience it and measure it and have access to it ... then it's not science***. Artists and other participants echoed this concept when describing their perceptions of science, positing that the goal of the scientific method is to obtain objective results. Some scientists also felt that creativity plays an important role in scientific research, though. One remarked, ***You strive for the objectivity in the collection of data. The interpretation of the data, that's where the art is. That requires creative thinking and ... the ability to perhaps see something in a way that people haven't thought about before***. In contrast, artists were more effusive when describing the role of creativity in their work and were particularly likely to mention play and fun as an important component of their process.

Artists and scientists alike agreed it is a good idea to bring art and science together. They shared anecdotes of collaborations in which an artist has represented a scientific concept or an engineer has constructed an art piece as outcomes they perceive to be effective. They felt that true collaboration between or across the disciplines relies on jointly developing an idea, rather than involving the other party in implementation only. Interestingly, though this type of collaboration was described as the ideal, the artists commissioned for the I/CaLL work did not ascribe to this approach, as previously described.

Roundtable participants noted that it is hard for true collaboration to happen organically. They identified challenges in disciplinary language, trust, commitment, and desire as potential barriers to collaboration. All emphasized the importance of identifying common points of intrigue and having mutual appreciation for the work of all parties to enable collaboration. Skillful facilitators, they believe, might be a key to making collaborations more common by drawing experts from different backgrounds together and creating space to develop a common language and build mutual respect.

Publicizing work can be an important part of both scientific and artistic pursuits. The two disciplinary groups tended to have different perspectives about the goals and the process for bringing their work to outside audiences. Scientists placed high importance on publicizing their work for the scientific community and tended to overlook the relevance of sharing their findings with members of the public. They felt that much

of their work was difficult to make accessible or interesting to a lay audience. They claimed it is a challenge to communicate how an individual study fits into collective scientific understanding without summarizing years or even decades of scientific research.

Artists were more likely to value public engagement. One artist said that she hoped to inspire and intrigue the audience by publicizing the work, and explained that publicity can give the public a sense of what it took to produce a specific work or exhibit of art. Artists echoed scientists' concern that the public often does not understand how a particular piece fits into the greater context of art and their artistic domain. Unlike scientists, the artists were less concerned with public education and did not feel compelled to correct incomplete understandings or misunderstandings about their work. For example, one artist noted that if they explain their work too much, artists do not leave enough room for personal interpretation.

OPPORTUNITIES & CHALLENGES IN ART–SCIENCE INITIATIVES

Artists had varying degrees of ease and difficulty in understanding how art–science collaborations might be of benefit. Overall, artists who had not previously participated in art–science collaboration were less able and less likely to engage with science in a structured and rigorous way. These artists struggled with how to incorporate science into their work and were less articulate about how science factored into their creative process.

Time, distance, and funding also influenced how well artists were able to participate in this experiment. Local artists appeared to be better able to connect with the unique details of the sites, perhaps due to their proximity and personal relationships with the city. Local artists committed more time to their work on the project and seemed more confident in their efforts to address project criteria. Non-resident artists with adequate funding, such as Mary Miss, made more trips to Indianapolis and felt they developed deeper connections with the sites than lesser paid non-local artists, who seemed to see their commission as a work for hire.

Some artists mentioned that pay discrepancies created an imbalance with respect to true and equitable collaborative opportunities. Due to the nature of the grant funding, not all artists were funded equal amounts, and this appears to have contributed to different levels of engagement with the project, as well as how various artists engaged with science content.

The effects of personal history and time and personal investment were evident when we compared the artists' work products. For example, local musician Stuart Hyatt used his commission as a direct extension of his artistic repertoire, as previously described. He dedicated a great deal of time to the project and created a large body of detailed and exploratory work to capture the soundscapes at his assigned site. One poet, on the other hand, struggled to balance the time and energy he spent promoting his recently published work, *The big smoke,* with his commission to generate a body of original and collected poetry for the I/CaLL sites.

In 2014, Co-Principal Investigator Mary Miss initially aimed to convene monthly dialogues for project artists across their range of artistic disciplines. These monthly calls were set up to discuss and support each other's work. The calls were discontinued after a few months, though, and artists who already had established relationships reverted to sub-disciplinary meetings. By the close of 2015, we observed that the artists were taking steps to reestablish group-wide dialogues, but these meetings were focused exclusively on event logistics related to programmatic planning for the I/CaLL artwork rather than the process of art–science engagement.

The notes and transcripts from these meetings demonstrate that some artists were more able to articulate their creative process than others. We raised the topic of creative process in interviews and the open discussions, but it remained unclear whether specific attributes led some artists to be more articulate than others about their work. Capabilities for this type of communication do not appear to be related to the form of their art. We observed that some artists struggled with the reflective nature of participation during I/CaLL evaluation and research; one said she felt burdened by discussing her process and work with the research team. Meanwhile, others took advantage of the reflective aspects of the evaluation to help them work through concepts related to the site and gain insight into their own process.

DISCUSSION

The I/CaLL project provided a rich platform for artists to explore science through site-specific research and artwork. Many of the artists took advantage of this unique context, delving into earth science and urban experience topics that they feel inform their ongoing work of describing the human condition. Many consulted with scientists and a few used this opportunity to build new relationships with scientists that both parties described as mutually beneficial.

This project was a catalyst that helped artists explore new types of expression and new ways of engaging the public. The site-specific nature of the work offered artists multiple entry points to their exploration. We observed that some of the artists were quite focused on scientific content, while others were more likely to explore the relational aspects of a waterway system and community life. A few combined these two approaches.

The project team, including project researchers and artists, spent a great deal of time trying to build relationships between individual artists and scientists. Many of the artists commissioned for this art–science public learning and engagement experiment were unsure of how science might inform their work. Most of the artists also found it challenging to identify or engage scientists as resources or partners, partly because they knew the scientists' art collaboration time was not funded by the grant. The project was led by a group of earth and social scientists, though, and some academics willingly stepped forward to support the project, even without funding. Artists described not feeling comfortable with the pay discrepancy, which they felt created an imbalance that made true and equal cross-disciplinary collaboration impossible. It seemed that once the artists took primary authorship for their commission, the default strategy was almost always to seek out scientific information for inspiration rather than collaboration, a pattern that, in most cases, resulted in only instrumental relationships rather than deep dialogue and two-way idea-sharing.

With a few exceptions, these artists gravitated toward finding positive framing for the public's experience of the waterways. They most frequently used their work to elicit learning by providing for audiences a fresh opportunity and way to observe, experience, and hopefully connect to a place through the senses, as opposed to encouraging scientific reasoning about the environment. In a few cases, they employed question prompts or models that mimic phenomena found in the waterways (such as currents) to inspire subsequent self-directed inquiry or synthesis about those phenomena and biophysical systems. One musician attempted environmental healing and reconciliation but did not feel it was necessary to engage scientists or scientific theory, or measure impact. His musical experiment, which seemed to engage the idea or spirit of scientific intervention as a thought experiment that might captivate an audience, functioned as the artifice of scientific intervention rather than an actual experiment.

In general, the project artists claimed they were interested in collaborative opportunities but could not find strategies to facilitate this type of engagement through their own process. For example, it seemed that some of the artists would benefit from a long-term partnership with scientists but, lacking such relationships, approached their interactions with scientists as a short-term collection of scientific information to inform or inspire their work. We therefore consider the resulting relationships to be consultant–client partnerships.

The roundtable discussions indicate that both scientists and artists are interested in a sustained level of meaningful collaboration but also acknowledge potential barriers. On one hand, many of the artists speculated that a collaborative relationship with a scientist might catalyze the creation of art experiences that could impact public science literacy. On the other hand, it seemed that the artists focused more on the aesthetic interpretation of self-in-place than on direct provocations that could result in demonstrable changes in the audience's literacy.

Some of the poetry did use descriptive content, however in a post hoc review of the descriptive narratives employed by some poets for their site based work, the juxtaposition of actual site conditions in association with emotional descriptors may not necessarily have invoked STEM literacy issues. That juxtaposition may serve as a different type of motivator that raises the specter of environmental systems degradation and human responsibility. For example, references to overturned and abandoned shopping carts, the

abrasion of water on rocks, and disregard for systems are all provocative questions that are also being studied by the river ecologists in the region. While we did not find direct evidence that these provocations were functionally valuable for promoting STEM inquiry, the poetic form and structure seem to imply that possibility.

In contrast to a majority of the artists invited to participate in and explore the art–science I/CaLL initiative, we note that the dance choreographers engaged in deep dialogue, public discussion, and active attempts to create embodied learning by exploring how landscapes form and riparian change occurs. As they undertook this process of discovery, they created a dance piece that reflected a literal interpretation of science concepts that the collaborating scientists agreed were readily evident through the performance.

This project focused on artistic process amidst the challenge of addressing science content through a Science Education for Environmental Sustainability approach. The experiment structure used a generative strategy for advancing STEM literacies and was driven by the processes of the participating artists. The results suggest that many artists have an established work process and tacit beliefs about their own learning that they feel audiences can interpret from their work products. While this approach offers unique opportunities that can be useful for advancing public science literacy through art-science collaborations, it seems that many artistic processes and collaborative efforts have difficulty achieving public impacts despite the desire of all collaborators to achieve that outcome (Mejía, Malina, & Roldan 2017).

These results suggest that dichotomized expectations about how scientific information can be represented with and through artistic representation create perceived boundaries that are challenging for many contemporary artists to transcend. Furthermore, artistic exploration in the context of artist-driven collaborations that focus on environmental or earth science issues may be limited to consideration of physical science phenomena rather than the full range and inventive possibilities of science, technology, engineering, and math. Artists in this study also tended not to consider the social sciences that address human engagement with environmental systems as a domain of knowledge that was potentially relevant and applicable to their own work process or products.

Recommendations

We recommend the following strategies to promote productive art–science initiatives in the future:

- Recruit artists who have established track records of scholarly dialogue and engagement with scientists;
- Recruit artists who have established relationships and personal experiences with the topics or places where the literacy interventions are most relevant. We make this recommendation based on findings that those most closely connected to the relevant scientific phenomena are most capable of bringing and using interpretations that are more accessible for others. These artists are also more likely to devote time and experimentation to ensure their work is culturally true to the experiences of an audience.
- Due to many artists' limited familiarity with collaborative processes, it may be better to create artist–scientist pairs like those pursued in other informal science experiments, rather than individual artists who guide the process. Science expert advisors in artist-driven initiatives may enjoy the thought exercises and inspiration that occurs through their collaboration with artists, but artistic outcomes in these conditions are unlikely to be commensurate with the effort and time involved.
- If externally sponsored work seeks to advance STEM literacies through art–science collaborations, it is necessary to clarify how all participants define and understand science and the science topics before commencing the work. Team members who disputed definitions of science or the nature of science struggled to identify how the effectiveness of their work would be measured in the collaborative context.
- Create core reference materials prior to engaging artists. In this case, it appeared that artists without sufficient briefing on and familiarity with the focal scientific concepts moved quickly into making meaning through their own personal experience. Once pursuing that track, these artists were not interested in developing new understandings.

- Establish clear monitoring and deliverable expectations related to audience engagement by artists and their work. Artists' narrow focus on patronage for a completed work of art will remain a challenge in future projects unless the outcome of an engaged public that has demonstrably enhanced scientific literacy is emphasized as a priority deliverable.
- Recruit artists who are willing and interested in – and have a track record of – discussing their creative process. In a project exploring how art can impact public awareness with respect to environmental science issues, it is important to understand the variables that contribute to successful collaboration and artwork that helps advance learning and community engagement. Articulate dialogue about artistic and collaborative processes may also benefit future artist–scientist initiatives by identifying a roadmap.
- Based on the lack of capacity that can characterize artist-led collaboration, it seems that the most effective collaboration will incorporate external facilitators who are trained in group dynamics as project leaders and instigators. Establishing a third-party facilitator or organizer as a leadership authority is likely to help artists and scientists better negotiate and share power, ideas, and ways of knowing within the unfamiliar spaces between their disciplinary traditions. From this deeper, supported collaborative experience we might expect new ways of engaging with artwork and advancing understanding of natural phenomena. It seems that the highest opportunity for public engagement and advancement of literacy may exist in ongoing dialogue between artists and scientists rather than any work product either might create.

CONCLUSION

Indianapolis City as a Living Laboratory: Science Learning for Resilient Cities was an investigation into how four different types of art – sculpture, music, poetry, and dance – can be used as conduits for advancing informal science learning on a citywide scale. NewKnowledge conducted a study of the artists' work processes as they engaged with earth science topics. Results showed that experience with art–science collaboration, ability to reflect on creative process, ability to develop strong collaborative relationships with scientists, trust in scientific vocabulary as a communication device to use in combination with artistic representation, and a personal connection to the artwork's intended location were all factors that affected the relative success of the final work product as a science education strategy that can advance environmental sustainability.

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Appendix

INTERVIEW SCRIPT

Introduction

Thank you for speaking with me today.

[Only for first conversation] I'm glad we are getting this conversation started. And I'm excited about hearing how things have been going for you and also getting the chance to sharing where we are and how are work has been coming. First, can I ask, if you don't mind would it be ok to record the conversation? It is purely for my recollection purposes and everything you say will remain confidential. [Yes/No]- Ok Great/Ok no problem, I'll just take notes.

Very generally, how have thing been coming so far? I know it is still early in terms of the project, but have you started working on anything?

[If after the first conversation] I 'm looking forward to hearing how things are coming along. Just to situate the conversation, let me recap a little from our last conversation to make sure we are both on the same page. [Recap]. Does that seem correct to you?

Can you give me an update on how your work is coming and if anything changed over the past month in relation to the recap I just gave?

Connection to Communities & Environment

How do you feel your work relates to the communities surrounding the site?

- [Probe] And has any of the community data we made available to you influenced your decision making process and/or your thoughts about your work?

How do you feel your work relates to the environmental issues surrounding the site?

- [Probe] And has any of the science information we made available to you influenced your decision making process and/or your thoughts about your work?

Process

Are you working with a specific scientist and if so, how has that relationship been going?

- [Probe] What is the dynamic of that relationship?
- [Probe] Is it purely informational?
- [Probe] Collaborative?

Can you talk about how you feel you have been integrating the artistic and scientific aspects of your work?

Are you seeking information form other sources concerning the communities and environmental issues that are relevant to the project? If so, what?

- [Probe] Is there anything specific (such as lectures, conferences, events) that have influenced your work this month?

Have you been in touch with any of the other artists in considering your work this month?

- [Probe] If so, who and why?

Closing

What has ben the most fulfilling aspects of your work on this project thus far?

Are there any final thoughts or comments you have?

Thank you for your time.

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