museum of
science+industry
chicago

One but Not the Same:
Non-Science Art in Science Education

A CONFERENCE REPORT

Overall Report Authorship:

Hee-Sun Lee
Concord Consortium

C. Aaron Price
Museum of Science and Industry, Chicago

L. Applebaum
Museum of Science and Industry, Chicago

Amber C. Coleman
Arizona State University

J. DeWitt
IOE, UCL's Faculty of Education & Society, London

Ms. Alexa Miller
Arts Practica, Brandeis University

Meg Moorman
Indiana University School of Nursing

Dr. Jeffrey K. Smith
University of Otago, New Zealand

Christian Steciuch
Department of Psychology, Rockford University

Ann Tanner
People Experience and Technology, Amazon

Recommended Citation: Lee, H., Price, C. A., Applebaum, L., Coleman, A., DeWitt, J., Miller, A., … Tanner, A. (2023, January 7). One but Not the Same: Non-Science Art in Science Education. Retrieved from edarxiv.org/qghjv

Introduction

Dr. Aaron Price, *Museum of Science and Industry (MSI), Chicago*

STEAM, the inclusion of art as a critical companion to STEM, is a hot topic in science education.[1] In both research and practice, STEAM is often (or even primarily) manifested through science-themed art (e.g., visualizations of science subjects or art inspired by science). As such, it does not take advantage of the potential value of artistic output that does not focus on overtly scientific themes. Such art is ubiquitous in our lives and influences how we sense, interpret and think about the world. This includes so-called fine art with its disciplines and legacies, or art writ large – the creation of something through personal or group expression.

The relationship between art and learning has been studied for centuries. Arts education researchers have synthesized this history into an always evolving system of best practices for using art in educational settings (Eisner, 2004; Winner, Goldstein, & Vincent-Lancrin, 2013; Bowen & Kisida, 2019). And they continue to press the field by incorporating advances in neuroscience (Solso, 2000; Belkofer, Van Hecke & Konopka, 2014) and cognitive modeling (Pelowski, Markey, Lauring & Leder, 2016). With these advancements in mind, how can we apply a growing understanding of the cognition of art to support learning about science through and alongside art?

The National Academies of Sciences, Engineering and Medicine recently called for more research to expand the "limited but promising" evidence that integrating arts and humanities with science education leads to better learning (NASEM, 2018; Root-Bernstein, 2018). A 2013 survey of 225 scientists and engineers found that most could cite a direct impact of arts, humanities and design experience on their work; even more suggested it be a requirement of science education (Root-Bernstein, Lamore, Lawton, Schweitzer, Root-Bernstein, Roraback, Perusk, et al. 2013). The question then becomes: *how?*

The question behind this conference is:

"How might we use non-science themed art to support science education?"

Art educators and researchers have their own unique ecosystems for sharing and collaborating, as do science educators and researchers. For the most part, these communities do not overlap, except in the world of STEAM, where art is almost always inspired by and in direct support of science. Outside of STEAM, the art world finds science in highly focused areas such as artwork conservation. Within each domain, the other is not treated as equal and thus not truly integrated. One is always subservient to the other.

The goal of this conference was to bring together representatives of art and science groups for a discussion of how non-scientific art can influence science education and how we can apply empirical results to the theory. It involved a combination of researchers who focus on art and science education and practitioners, including museum interpreters, exhibition designers and science educators.

For this report, we define **"non-science themed art"** as art that was not inspired by science or intended by the artist (or programmer/ curator) to be used in any form of programming related to science education or science communication.

[1] "For the purposes of this report, we use the term *science education* to refer to science engagement, teaching and learning by and for everyone, anywhere and at any time."

Conference Context

Located on the culturally-rich south side of Chicago, the Museum of Science and Industry, Chicago (hereafter: MSI) is the largest science center in the Western Hemisphere. For 50 years, MSI has hosted Black Creativity, the longest-running annual exhibition of juried art by African American artists in the United States. At the height of the Black Arts Movement, the Museum was approached by a local community group, Black Aesthetics, to host an exhibition and celebration of African American creativity. The works showcased are selected by a jury of Black and African American art experts and include pieces by Black and African American artists in a variety of media.

Figure 1. 2019 Black Creativity Juried Art Exhibition, Museum of Science and Industry, Chicago

Historically, the artwork was neither science themed nor formally tied into the Museum's programming. However, the gallery is surrounded by scientific exhibitions that must be navigated to reach the art. In recent years, guests had to pass through the *Extreme Ice* exhibition, which centers on the effects of climate change on glaciers. The genesis of this conference proposal began as Museum staff pondered the question: *How does the Black Creativity exhibit affect the guest experience as they pass through Extreme Ice?* Pilot studies (summarized in the next section) suggest some impacts that may help and hinder the learning experience outside the Black Creativity gallery.

*The genesis of this conference proposal began as Museum staff pondered the question: **How does the Black Creativity exhibit affect the guest experience as they pass through Extreme Ice?***

To design subsequent studies that delve deeper and more rigorously into this, we turned to the literature and the community. We found some discussion about the potential of combining non-science art with science, but very little research about what actually happens (see *Literature Review* section) in practice. Additionally, we lacked partners with whom we could collaborate or even discuss the idea. The players in these fields rarely cross paths. The STEAM world benefits from numerous studies about the use of science-themed art and artistic practices to engage people with science, but there is very little about the use of non-science-themed art programs and exhibits to support or enhance science education.

This lacuna in the research could simply be due to the cultural separation of the fields. When we have brought up this concept to anyone (artists, educators, scientists, researchers, etc.), we've encountered tremendous interest in the idea. We've also found some scholarship in medical education literature, albeit of limited scope and rigor, and we've identified position pieces in the literature calling for more work on this topic (but, again, not much in the way of empirical research per se).

Summary of Conference Agenda

Although it was originally scheduled for August of 2020, the convening was postponed to April 2022 because of the pandemic. Held in Chicago, at MSI, the conference opened with a literature review to establish the field and standardized definitions for participants. This was followed by a practitioner session during which two expert practitioners shared insights from their decades of experience using non-science art for educative purposes (primarily in the world of medical training). Then came a lunch session, which featured a discussion of the history of the Black Creativity exhibit, followed by a tour of the exhibit. During the tour, the expert practitioners gave demonstrations of a technique they used to engage medical trainees with art. Because attendees came to the conference from a wide and diverse range of professional backgrounds, the two-afternoon sessions were designed to introduce core concepts related to how people think about art and how they think when learning about science. These sessions were meant to give a basic overview to these two fields of study so participants could start thinking about how the fields can complement one another.

The second day of the conference began with a brief recap of the previous day. Then the morning was dedicated to two sessions. The first was a presentation and discussion about known biases in the fields of science and education. The second session centered on a discussion about biases in art and how they should be openly addressed and, ultimately, how progress in one area can be used to promote progress in the other. The lunch break was spent discussing those topics further; it also featured an exploration of *Art of the Brick*, an exhibit at the Museum that used Legos to recreate famous works of art.

Participants spent the afternoon in conversation about potential research agendas and questions related to learning more about the impact of non-science art on science education. These conversations were led by two researchers on site, as well as two additional researchers who joined remotely to provide commentary. Attendees also had the option to attend the 2022 Expo Chicago, an international exposition of modern and contemporary art, which took place the following day in downtown Chicago.

Day 1. Session 1.

Literature Review

Presented by Dr. Aaron Price, *Museum of Science and Industry (MSI)*

Science and art museums are typically separate institutions. In the rare case that science and art content are combined in one setting, individuals tend to visit either for the science content or the art content, but not both (von Roten & Moeschler, 2007). However, the integration of art and science tends to be appreciated when it does happen (von Roten, et al., 2007; Turkka, Haatainen, & Aksela, 2017). Indeed, according to a 2019 internal evaluation, guests who visited the Black Creativity exhibition said that the Museum exceeded their expectations at a higher rate compared those who did not view the exhibition.[2]

In an e-mail dialogue with Dr. Jen DeWitt about the literature on learning in art and science museums around London, they pointed out a tendency among researchers to conceptualize art and science as distinct and separate domains. Art in science environments poses a challenge to visitors and evaluators alike because of the persistent differentiation between the "two cultures" of art and science (Casini, 2010). Pollio (1996) studied the pedagogies of these two cultures and suggested the idea of "signature pedagogies" and variable habits of mind in different disciplines. Following influential work by Snow (1959, 1993) on the separation of those two cultures, there have been subsequent discussion of a more varied and sophisticated distinction (van Dijck 2003; Jacobs 2011). This continuum is what is more often described as "interdisciplinary," referring to work that "draws on disciplinary perspectives and *integrates* their insights through the construction of a more comprehensive perspective" (Klein and Newell, 1998). It is important because "they support basic skill sets for the analysis and integration of difficult problems that require knowledge and cooperation from different groups" (Harp, 2007), a common practice in modern science.

The notion of disciplinary and pedagogical distinction raises questions about learning in both art and science museums. While similar constructivist and co-constructivist techniques are often found in both museum and science education settings, the concept of signature pedagogies and habits of mind—as well as the legacies of the "two cultures" debate—indicate that there are further routes of inquiry into learning in art and science museums. We hoped to lay the foundation for one such route with this workshop.

How has non-science-themed art been used to promote science education so far?

In short, not much. And there is relatively little research on the topic. One study of engineering education found that an arts-based lesson increased communication skills (Osburn & Stock, 2005). Most of the existing research and practice comes from the medical field. As a pioneer in the field, Moorman conducted a 2015 study of nursing students who viewed and interacted with artwork using a technique, Visual Thinking Strategies (VTS), built on a stage theory of cognitive aesthetic development (Housen, 2002). VTS encourages the viewer of art to talk about it and provide details to support their reasoning. They found nursing students felt more empowered to speak up to their superiors, which addresses a significant known problem in nursing (deference to authority). Students also reported that the particular way they were introduced to the art, through the VTS dialog process, encouraged them to notice detail they would not normally see. A review of VTS-based arts education studies found evidence that art observation practice can promote the development of observational skills, communication, and tolerance of ambiguity (De Santis, Giuliani, Staffoli & Ferrara, 2016). Other studies have found that VTS-based arts experience increased medical and dental students' ability to describe physical findings (Naghshineh, Hafler, Miller, Blanco, Lipsitz, Dubroff, Khosbin, et al., 2008) and offered more objectivity (Pellico, Friedlaender & Fennie, 2009). Dr. Moorman and her colleague, Alexis Miller, describe this strategy and these results in more depth in a subsequent section of this report.

Anderson (2018) studied the impact of a three-part arts workshop on students and administrators at Dell Medical School. The workshop was designed to support students' visual literacy, self-care and empathic communication with patients. However, what the attendees saw as valuable differed from the original goals of the program. Students raved about how the workshops helped them express and experience greater humanity and motivation. An inductive analysis of interview data found the specific aspects students connected with were aligned with well-known theories about the impact of art education. They valued the workshops "precisely for the features that the arts, and the arts alone, added to the learning experience" (Anderson, 2018). These results are important to show that exploratory studies are

Day 1. Session 1.

still needed and that we need to be ready for results that are new. The field may not yet be ready for highly targeted assessment strategies regarding the impact of art on learning.

The dialog between artists and scientists should be equitable and bidirectional, but the focus of such dialog often centers on how art can serve science and not vice versa. "If we're talking about how one can use art in engineering… as an artist, it seems we're missing the point and devaluing, or not realizing, art's purpose and importance. We have it backward." (Jolly, 2014). But there is a trend toward more equal integration: "The growing insight that some scientists have gained in recognizing the work of artists as co-investigators of reality has led them to conclude that while their approaches differ, artists and scientists strive toward a common goal in their quest for knowledge." (Huang, 2009).

> *"It's easier to 'bridge' science and art when you don't really think there's a gap between them in the first place, as I don't. The boundaries between subjects are really artificial constructs by humans, like the boundaries between colors in a rainbow."*
>
> **› Dr. Eugenia Cheng, scientist-in-residence at the School of the Art Institute of Chicago (New York Times, 2020)**

Arts integration & science education

Arts integration is the idea that arts instruction can be used "as a means of enriching the teaching of other subject matter" (Burnaford, Brown, Doherty, & McLaughlin, 2007, p. 5), a pedagogy that can be traced to the beginning of the twentieth century. In 1934, American philosopher John Dewey described the experience of art as one that does not belong solely to professional artists but, instead, can also be used as a foundation for meaningful learning within education in general (Rieger, Chernoma, MacMillan, Morin & Demczuk 2016). In helping students to perceive works of art, they become more adept at perceiving the world and themselves and drawing multiple meanings from their perceptions (Bresler, 1995). The development of these "imaginative capacities" (Eisner, 1983, p.60) allows one to take information perceived by one's senses and explore the possibilities, meaning, and potential of this information.

The most prevalent forms of arts integration are those in which the arts are subservient to other subjects – for example, singing a song about the solar system or painting a portrait of a historical figure. These types of activities use the arts to make other subjects more engaging but are usually not designed to develop aesthetic awareness, critical review, or specific artistic skills (Bresler, 1995). The least common type of arts integration—though perhaps the most effectively integrated—is the co-equal or cognitive interpretation style. This approach is designed to engage higher-order cognitive and aesthetic skills; allow students to observe, perceive, and develop their own interpretations; and provoke students to engage in higher-ordered analysis, synthesis, and evaluation. It excels in encouraging active perception and critical reflection. As such, it is generally the most difficult to implement because it requires an educator with a background in the arts.

In more recent years, this latter style of arts integration has become known more generally as Arts-Based Learning (ABL), in which the emphasis remains on significant learner engagement with an art form (Rieger & Chernoma, 2016). It is distinguished from traditional pedagogy, in which art is merely injected into a subject to engage students; rather, "the arts are viewed as the basis, means, and threshold for student learning" (Davis, 1999, p.4). Students either observe another's art or actively engage in the artistic process (Rieger & Chernoma, 2016).

ABL provides a starting point for the ways in which non-science art can be used to promote science education. A review of ABL literature reveals more robust empirical support for "learning experiences that use reflective observation of visual art" (Rieger & Chernoma, 2016), particularly within professional fields. One study of engineers found an ABL lesson increased communication skills of their students (Osburn & Stock, 2005).

Beyond professional training, the integration of arts within K-12 science curriculum has seen a resurgence within the STEAM movement. The STEAM movement expands upon a US national push for STEM (Science, Technology, Engineering, Mathematics) education, which came into popularity during the 1990s and its explosion of tech-based job opportunities within the private sector (Gunn, 2017). In the early 2000s, Georgette Yakman, along with fellow proponents of the movement, proposed adding the "A" to STEM to emphasize that the arts are a critical component to innovation (Yakman, 2010; Concordia University-Portland,

Day 1. Session 1.

2019). In 2013, a resolution was introduced to the U.S. House of Representatives that proposed incorporating art and design into Federal programs that target the STEM fields (H. Res, 51, 2013-2014). Studies focusing on STEAM-inspired interventions of art and science integration have indeed been on the rise, however, a recent survey of how science teachers integrate art show that it is incorporated infrequently and in minor roles, such as asking students to draw a scientific model (Turkka, 2017). Furthermore, art is consistently seen as enhancing science education, with little discussion of how the reverse can be accomplished, for example – how can the tenets of science exploration enhance achievement within the arts? The relationship remains one that is hierarchical, with science consistently at the top.

Art in science museums

Science and art museums have largely been seen as separate institutions. The field of science during this time period is often characterized by the development of specialized disciplines and, concurrently, the development of more specialized public museums of science, emerging largely separate from art galleries (MacDonald, 1998). However, beginning in the 1960's, museums began to grapple with the ways in which art and science complement each other. In 1966, a New Jersey-based series of exhibitions titled *9 Evenings: Theatre & Engineering* involved artists working with engineers to create a series of projects on view at different locations around the world (Mcdougall, Bevan, & Sempter, 2012). This experience led to the founding of the organization Experiments in Art and Technology (E.A.T.), which continued to develop collaborations between artists and engineers. At the same time, the Exploratorium, founded in 1969 in San Francisco as a public lab and museum in which scientific inquiry is fostered through personal exploration, soon established an artist-in-residence program to help foster inquiry-driven investigations of the world by artists (Mcdougall, et al., 2012). By 1970, the art/technology movement had spurred the Los Angeles County Museum of Art to similarly found its Art and Technology program, which aimed to place artists-in-residence within leading technological and industrial corporations in California (Los Angeles County Museum of Art, 1971). These various collaborations worked to engage artists and scientists in investigations of both of their respective worlds.

At the MSI, the presence of the aforementioned *Black Creativity*, a long-standing, annual art exhibition, provides an opportunity to study the ways in which the viewing of fine art in a science context impacts the ways in which guests engage with science thereafter. Often, when science museums integrate art and vice versa, the two disciplines are combined in a single experience or exhibition. For example, a science museum hosts an exhibit of artistic visualizations of human anatomy (Royal College of Physicians, 2019), or an art museum hosts a gallery talk on how different artists' works were inspired by scientific processes (Museum of Modern Art, 2019).

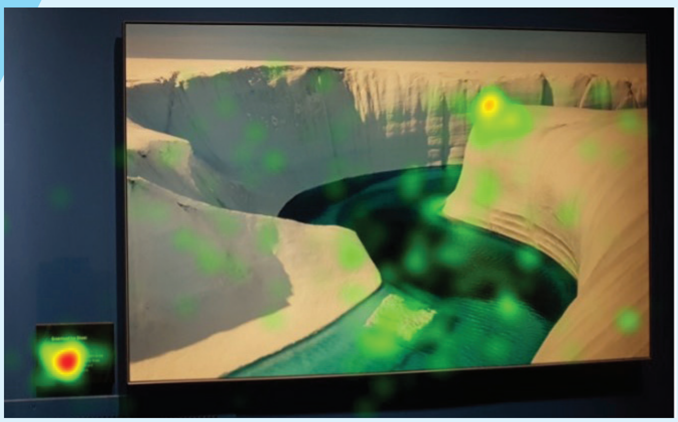
Black Creativity at MSI, however, is unique in that it is a fine art exhibition without any overt ties to science content. The only eligibility requirements for submissions are that artists identify as African American, and, as a result, its pieces cover a variety of topics, such as history, identity, or the natural world. Internal evaluations of the exhibition in 2018 and 2019, on its day of highest attendance, have shown that between 70–80 percent of attendees had not heard of the exhibition before coming to the Museum that day. Its presence at MSI is often a surprise to guests and likely subverts their expectations for a visit to a science museum.

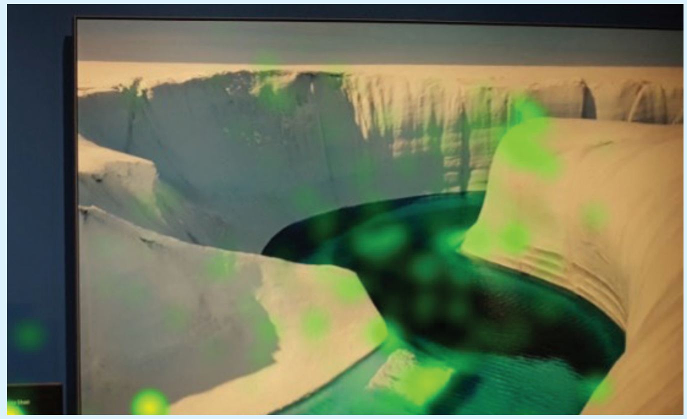
This juxtaposition between art and science content that *Black Creativity's* presence creates is ideal for studying the ways in which the experience of viewing art may prime a visitor's mind to engage with science content. It should also be noted the exhibition is unstaffed. Guests are free to engage with the content as little or as much as they would like without the presence of staff who are trained in art pedagogy or gallery engagement techniques. Typically, studies of ABL within science fields focus on programs led by a trained facilitator (Naghshineh et. al, 2008; Pellico, Friedlaender & Fennie, 2009; Moorman, 2015; Anderson, 2018). This exhibit allowed for the study of *free-choice* art engagement on science education, an avenue of research that is largely unexplored. Our first evaluation of how this kind of engagement impacted guest emotions found that it increased feelings related to peacefulness and personal growth during subsequent experiences engaging with a science exhibit, but had little impact on other emotions (Applebaum & Price, 2019). Our follow up study used some of the same measures combined with timing, tracking and mobile-eye tracking methodology. We found guests who went through *Black Creativity* paid more attention to the details of photographs and visual imagery in the exhibit than those who did not (Figure 2) (Greenslit, Price & Malone, 2021). Those guests spent less time at interactive portions of the exhibit.

While limited, there are other examples of non-science art being present in science education spaces. The Oakland Museum of California has separate science and art history

Day 1. Session 1.

Figure 2. On the left is a heat map of the visual attention of guests who attended *Black Creativity* and the *Extreme Ice* exhibit. On the right are those who only attended Extreme Ice. For guests who attended *Black Creativity*, increased attention was given to a portion of the photograph that included a human being standing on the glacier. (Background photo by James Balog/Earth Vision Institute. Reprinted with permission.)





galleries. The Exploratorium has an artist-in-residency program, and the School of the Art Institute of Chicago has a scientist-in-residency program. The Wellcome Collection in London probably has the closest example of an institution integrating science and non-science artifacts in its galleries, which feature art on the walls and natural science exhibitions in the center (Figure 3).

Figure 3. ‘Medicine Man’, one of the galleries at Wellcome Collection, London.

(By Osama Shukir Muhammed Amin FRCP(Glasg) - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=56678808)

Day 1. Session 2.

Perspectives from Practitioners

Presented by Ms. Alexa Miller (Arts Practica, Brandeis University) and
Dr. Meg Moorman (Indiana University School of Nursing).

Ms. Miller and Dr. Moorman shared insights from their extensive practical experience of using non-science art in science education settings. Ms. Miller began by introducing HSSP 160A (Looking with Uncertainty), a course at Brandeis University based on Miller's fellowship research with the Society to Improve Diagnosis in Medicine. Designed to develop medical students' capacities to identify and respond to uncertainty, the course is focused on the challenge of uncertainty in medicine and specifically in diagnosis, and builds on Miller's previous research with a team at Harvard Medical School suggesting that formal art observation training improves medical students' capacities for observation, a skill central to diagnosis (Naghshineh, Hafler, Miller, Blanco, Lipsitz, et al., 2008). Miller's presentation ended with a discussion of Visual Thinking Strategies (VTS)—a methodology for teaching with art that is used in both the Brandeis and Harvard courses—and made links between VTS skills and researched needs for better diagnosis shown in public health. Skills such as careful observation, listening, tolerance of ambiguity and integration of diverse perspectives are needed in diagnosis and across domains in medicine since they support disciplined information processing to minimize potential bias, complexity, and ambiguity. Dr. Moorman's presentation further casts light on VTS in the training of nurses. Dr. Moorman described the three VTS questions—"What's going on in this picture/painting? What do you see that makes you say that? What more can we find?"— and their relevance to nursing practice. Using interpretive phenomenology, Moorman's 2015 study revealed that VTS training could make students feel safe in their own learning and enable them to make different and unique observations, all while facilitating critical thinking, teamwork and collaboration, open-mindedness and ethical reasoning and competence.

The session, and subsequent discussion among the audience, highlighted these emerging ideas on how non-science art can promote science teaching and learning:

- **Interactive experiences** with visual art provides participants with learning opportunities, such as: eliciting curiosity, dealing with uncertainty and complexity, discovering implicit prejudice, inviting and facilitating collaboration and valuing different perspectives. These capacities align precisely with key features of learning of science as a process: i.e. questioning situated in the student interest, carrying out investigations, collecting and analyzing data, interpreting results for the community context, and making proper conclusions.
- **Visual Thinking Strategies** has been repeatedly shown to enhance observation skills in learners. VTS encourages to think critically for themselves while further encountering different and diverse perspectives (Housen's "reasoning in a social context"). Such experience can help students recognize that their experiences and ideas matter while engaging productively in the knowledge-generation process.
- **Art-viewing** is a unique experience that calls upon aesthetic intelligence as well as careful language skills. Drawing from body language, facial expression, emotion, perspectives, purposes, and framing in context, it asks learners to find patterns and contrast viewpoints.
- **Uncertainty is inherent** in science and cannot be avoided in scientific research or medical diagnosis. Uncertainty in science originates from theoretical, methodological, analytical, interpretive, and communicative limitations. Addressing uncertainty requires understanding complexity in contexts where simple, straightforward solutions can be error-prone, inappropriate, or ineffective. The idea, origin, and appreciation of uncertainty can be addressed experientially in arts training.
- **Discussions of "non-science art"** should recognize that art is not a simple illustration but a generator of ideas and reflection. It is produced in a cultural context and reflects the values shared by the community. Artists make art for a wide range of reasons, conscious and unconscious, and respond to the world around them and the truths they see. Art brings attention to many current socio-scientific issues such as climate change, pandemic responses, an epidemic of misdiagnosis, and inequitable distribution of resources in future hazards and risks. Ethical considerations can begin by incorporating such perspectives, which can be experienced through the perspectives of artists.

Day 1. Session 3.

Your Brain on Art

Presented by Dr. Jeffrey K. Smith (University of Otago, New Zealand).

Dr. Smith started by sharing Van Gogh's painting of "Cafe Terrace at Night" by asking what the audience was seeing. He used the audience's ideas about the painting to demonstrate parts of the brain responsible for the various senses, emotions, and thoughts elicited from the painting. Eye-tracking studies on how experts and novices viewed the images showed that experts tend to scan the whole image while novices focus on main characters in the same image and show enthusiasm by describing the details of an image. Experts tend to focus on colors and shapes, followed by the overall appreciation. He discussed his experience working with astrophysicists who study supernovae in galaxy photographs. Several fMRI studies have captured regions of the brain activated when viewing the paintings with different degrees of aesthetics. While promising for testing a wide range of hypotheses, Dr. Smith mentioned limitations of current fMRI studies such as lack of authenticity (viewing paintings inside the fMRI machine vs. museum setting), sample size, and artistic materials that can be tested (2d vs. 3d artwork).

The session, and subsequent discussion among the audience, highlighted these emerging ideas on how non-science art can promote science teaching and learning:

- **Art viewing** engenders an aesthetic experience involving knowledge-meaning, sensory-motor, and emotion-valuation. The knowledge-meaning aspect includes expertise, context, and culture; the sensory-motor aspect involves sensation, perception, and motor system; the emotion-valuation aspect manifests in reward, emotion, and wanting/liking. Each aesthetic experience can be analyzed or interpreted as a different manifestation of these three aspects.
- **An art piece can generate a wide range of reactions:** perceptual (lines, curves, symmetry, contrast, consonance, etc.), affective (feelings such as pleasure, awe, sadness, outrage), experiential (memories, etc.), and so on. Art can provide a safe haven for aesthetic experience to amplify. The viewer can control the degree of engagement with aesthetic appreciation, allowing a vicarious experience that could not be had otherwise. Aesthetic experience can be internal and external as well as vary from person to person, from setting to setting, and from culture to culture.
- **While there are common aesthetic standards established** in the world of art, i.e. realistic vs. abstract vs. impressionist, there are multitudes of endless possibilities how an artwork engages viewers with diverse knowledge bases, experiences, and socio-cultural backgrounds.
- **fMRI can show the activated region** by sorting out signals from noise using the two-dimensional view of three-dimensional phenomena in the brain. If particular regions of the brain are activated by aesthetic experiences, it is possible to identify science activities that use the same regions of the brain. In turn, artistic training experiences can benefit science learning indirectly by means of the enhancement of brain functions in the same region. The connection between aesthetic experience and science activities can be tested in the brain imaging studies using fMRI methods.
- **Learning science** involves not only carrying out cognitive and analytic tasks but also sense-making from experiences, proposing creative solutions, playful engagement with material setups, and pursuing epistemic rigor. Art training can enhance many of such elements critical in learning to do science.

Vincent van Gogh's Café Terrace at Night (1888).

Photo via: Kristoff

The audience's ideas about the painting were used to demonstrate parts of the brain responsible for the various senses, emotions, and thoughts elicited from the painting.

Day 1. Session 4.

Your Brain on Science

Presented by Dr. Ann Harvey Tanner (People Experience and Technology, Amazon).

Dr. Tanner characterized quality science learning as a positive experience that addresses emotion (making it feel good), ease (making it easy), and effectiveness (making it work). Dr. Tanner introduced three cognitive strategies such as spacing of tasks, interleaving instructional materials, and using dual coding methods involving audio- and visual channels of information processing. With regard to addressing emotion, factors including personal motivation, self-efficacy, identity, values, autonomy, personal connections, and relationships were identified. In particular, self-efficacy derives from mastery experience, vicarious experience, social persuasion, and physiological states can lead to science achievement, science activities choices, motivation, effort, and perseverance. Intrinsic motivation is based on value, utility, and connection to science as well as the perception that real science/scientists can increase interest, motivation, and learning. Effectiveness can manifest in terms of critical thinking, problem-solving, curiosity, creativity, persistence, open-mindedness, managing uncertainty/ambiguity, etc. Curiosity, as a drive state for information that motivates learning, increases as uncertainty increases from 0 (total uncertainty) to 0.5 (half-and-half) and then declines as uncertainty further increases to 1.0 (total certainty).

In real-world problem solving, a focused mode occurs through memory retrieval, targeted observation, and solution execution. When an impasse is encountered, new solutions are sought through a defocused mode, characterized by an expansion of the range of associations, observation of environmental cues, access to new memories, and the visualization of new outcomes. Dr. Tanner illustrated these concepts through examples taken from product and behavioral research.

The session, and subsequent discussion among the audience, highlighted these emerging ideas on how non-science art can promote science teaching and learning:

- **From the perspective of student experience,** what constitutes science learning can be broadened beyond the simple acquisition of disciplinary ideas or skills. For meaningful learning to occur, students must be motivated and readily engaged; ambitious goals for learning science through practical applications and experience can promote this kind of motivation and engagement.
- **Learner-centered approaches** should take into account the authentic experiences, feelings, and behaviors of artists and scientists in ways that educators can implement and support. Researchers can test and validate design principles for the development of learning experiences in art and science. These principles can serve as guides for the future development of curricula, exhibits, and materials.
- **By considering science learning** as a student experience, the learning context should consider what enables students to learn and do science.
- **At the juncture of art and science experiences,** exciting opportunities exist to articulate, design, and implement experiences that facilitate
  - Processes of creating art and process of doing science
  - Understanding of whole-part relationships to manage complexity
  - Maturation as artists and scientists
  - Creation of visual artwork that captures artists' real-world experience and scientific inscriptions that model real-world phenomena
  - Material interactions in art and in science
  - Seeing oneself as an artist vis a vis as a scientist, especially as it relates to continuing curiosity, reducing uncertainty, being open-minded, and comfortable in oneself

Day 2. Session 1.

Broadening Opportunities

Presented by Dr. Amber Coleman (Arizona State University) and
Dr. Aaron Price (Museum of Science and Industry, Chicago).

Amber C. Coleman has a Ph.D. in Art and Visual Culture Education from the University of Arizona and is now a post-doctoral fellow at Arizona State University. She identifies as a Black queer woman from the South and as an educator/researcher/artist. Aaron Price has a Ph.D. in Science Education from Tufts University. He identifies as a white, cis-male scientist with a settler background and roots in Texas, New England, and the Midwest.

First Presentation: Broadening Perspectives in Science with Art

Dr. Aaron Price

Art, in general, can be used to highlight socio-cultural and political issues that are salient in science museums but often ignored. Such issues include inequities in the history of science, bias in scientific perspectives, the mixing of science and politics, and much more. Art may prime guests to assume a more open position when thinking about what science is and who can be scientists. Non-scientific art exploration has been shown to increase flexible thinking (Pellico, et al. 2009) and can be used to reach audiences historically not comfortable attending museums (Rosin, Wong, O'Connell, Storksdieck & Keys, 2021).

Art may prime guests to assume a more open position when thinking about what science is and who can be scientists.

Raising political issues in science domains, especially museums, can be difficult (DeWitt & Archer, 2017; Garibay, 2017; Bevan, Calabrese Barton & Garibay, 2018). But art can bring a political and socio-cultural perspective that is often missing in science (Casini, 2010). For example, the *Black Creativity* Juried Art exhibition at MSI often includes art covering important social and political issues not found elsewhere in the museum. Sometimes those issues stand apart from other museum content (at least on the surface, we recognize complex interdependencies in reality) and, sometimes, they can be linked to museum content. For example, environmental justice is a common theme in the juried art. If viewed before walking through our climate change exhibition, it could broaden how people think of the unequal impact of the latter. Guest feedback after viewing *Black Creativity* often includes stories and quotations from people who didn't expect to see the exhibit at a science museum but who were moved (and sometimes offended!) nonetheless by what they saw.

In the United States, science is mainly taught as being a product of western civilization. Yet science historians can chart paths that predate the very existence of modern, western culture. For examples, thousands of years ago, Polynesian sailors staked their lives on the observation and prediction of stars, winds and tides to navigate their epic voyages. And non-western societies continued to make scientific progress during the European dark ages (at that time, Islamic astronomers were among the first to doubt the Earth's position as the center of the Universe). The misperception of science as a product solely or primarily of western civilization is mainly due to the Eurocentric portrayal of scientists and science endeavors that centers white male protagonists. Modern media and consumer culture continue to perpetuate this by creating artificial dichotomies among "western science" "eastern philosophy," "indigenous ways of knowing," and other investigations of the natural world. In reality, these approaches are integrated in such complex ways that they wouldn't exist without each other, and, in the best research, they are used to support each other in a common exploration of a problem or curiosity.

"When we enter the world of science, we do not shed our cultural practices at the door."

› Medin, Lee & Bang (2014).

Day 2. Session 1.

Second Presentation: The Need for Radical Imagination

Dr. Amber C. Coleman

Visual art and visual culture have the ability to impact our ways of knowing and being in the world. As Klebesadel (2006) reminds us, "The diversity of art you see....matters. It matters which artists are held up as examples for you to emulate. It matters whose visual representations are displayed—and validated—for society as large." While there are various definitions for art and visual culture, inclusive of (but not limited to) fine art, folk art, craft, textiles, social media, film, and television. The terms visual art and culture emphasize sight and visuality but often include engagement with our other senses.

Visual art and visual culture are tools of *radical imagination*. People create art and cultural products to reflect the things they imagine. These creations are things that we can respond to, critique, challenge, and re-envision. With this context of art and visual culture in mind, how might we use them to think more broadly about cultural identities and assumptions Art and visual culture in relation to the concept of race provide a useful example.

"The fact that we are here and that I speak these words is an attempt to break that silence and bridge some of those differences between us, for it is not difference which immobilizes us, but silence. And therefore so many silences to be broken."

› Audre Lorde

Race is a social construct; it is an identity, a constantly evolving entity where we name, experience, and understand our bodies and beliefs (Dewhurst, 2018). Identity formation is ultimately impacted by who we think we are and who others think we are (Kirk & Ŏkazawa-Rey, 2010). Following *social constructionism*, people develop knowledge of the world in a social context, and much of what we perceive as reality depends on shared assumptions (Vinney, 2019). Socially-constructed identities, such as race, are dependent on context, perpetuated by institutions (schools, government forms, etc.), and can impact how we construct knowledge. With these identities, people may also be subject to real or imagined divisions that inhibit our ability to connect with others. In the United States, for example, the effects of the social construction of race include bias, prejudice, discrimination, microaggressions, anti-blackness, White privilege, racism, Whiteness, and hegemony.

With this understanding of race in mind, it is important to consider how identities, power, and privilege are interconnected. Crenshaw (1989) conceptualizes this phenomenon as **intersectionality.** As Love (2019) states, "Intersectionality is not just about listing and naming your identities—it is a necessary tool to explain the complexities and the realities of discrimination and of power or the lack thereof, and how they interact with identities." As people work toward combating oppression, they search for liberation strategies that take intersectionality into account. Liberation theories and strategies such as Critical Race Theory, anti-racism, abolition, and transformative justice support the notion of *collective liberation,* which posits that *everyone* deserves to be free from oppression (Carruthers, 2018).

To achieve this freedom for everyone, one might engage in **Black radical imagination**, thinking of possibilities and creating alternatives that exist beyond what we currently see and know. This imagining inspires acts of **freedom-dreaming** (Kelley, 2002), which supports creatively work toward collective liberation for all people. Therefore, Black radical imagination and freedom-dreaming are inextricably linked. This movement between thinking and action can be seen in social movement-building. As such, these collective enterprises necessitate tools for cultivating stories, healing, creativity, and joy (Carruthers, 2018).

One of these tools can be art. Art can challenge traditional assumptions in many ways, including the process of *visualization*. Defined as "the representation of an object, situation, or set of information as an image" (Wilson, 2019), the purpose of visualization is to actively communicate the information obtained by sight. It is also a way to rethink traditional art skills, works of art, and artistic habits of mind in the context of visually dominant cultures (Kraehe, 2019). Considering the nature of visual culture, visualization education supports exploring images, imagination, image-making, and the relationships between them. The visual is an educational tool that conveys historical and contemporary knowledge and practices (Kraehe, 2019).

Day 2. Session 1.

"[Black radical imagination is].... about how black people have imagined real freedom....[it] tells us a great deal about what people dream about, what they want, how they might want to reconstruct their lives. After all, the history of black people has been a history of movement – real and imagined."

› Kelley (2002)

Visualization education necessitates an acknowledgment of power dynamics, which are inherent in the process of creating and sharing visuals (Wilson, 2019). What happens when we analyze these visuals? It creates opportunities for empowerment. The kind of empowerment that encourages us to create the futures we would like to be a part of (Womack, 2013). We can resist, reclaim, and re-envision the dominant ideas and practices we have been taught in favor of ones that value and support who we are and what we desire. When we examine various points of the creation process (from production to consumption), it prompts questions such as: Who has the ability to create visuals? Whose gaze impacts how we make meaning of what we see? How can we create our own images?

To answer these questions, arts-based research is a useful approach for examining visuals. Rolling (2013) describes arts-based research as both an art and a science. It focuses on the affective, engaging interaction between the ways of thinking, feeling, and doing of the researcher (or facilitator) and the audience (Barone & Eisner, 2011). It also prompts us to question the ability to participate in the inquiry process (Wilson, 2018), to think critically and analyze our realities (Freire, 1970), and to engage in meaningful dialogue (Hilton, 2013). Here, the emphasis is placed on meaning-making and how art can bridge our understanding across varying concepts and experiences. The use of art and the form of art help to shape this understanding as the researcher/facilitator transforms the artistic experience into something meaningful (Finley, 2012). Using this approach, we can interrogate how knowledge is created and shared and decide how we can respond to the world and create new knowledge.

Conclusions

Amber C. Coleman & Aaron Price

Art and visual culture enable us to rethink what we already know and what we can learn. They offer space for reflection, challenge, critique, and change. As educators, researchers, practitioners, and artists, we must realize that visuals play a role in how we understand our identities and the world. We have the ability to decide how we engage with visuals and to create our own.

Many of the limits of scientific progress lie in a science education paradigm that continues to promote limited viewpoints of what science is, who can be a scientist, and who science is for. Art, arts-education, and arts-based research can be used to challenge existing limitations and to promote more flexible approaches to finding new answers.

Day 2. Session 2.

Further Research Ideas and Methods

Presented by Dr. Jen DeWitt (IOE, UCL's Faculty of Education & Society) and Dr. Aaron Price (Museum of Science and Industry, Chicago) with contributions from Dr. Martin Storksdieck, (Oregon State University).

Price had a professor in graduate school who coined a phrase: "If it exists, it can be measured. If it cannot be measured, it does not exist" (Ludlow and Alvarez-Salvat, 2000). Although somewhat reductionist, it is in many ways an optimistic statement. The MSI research team refers to it often when struggling with complex research questions, such how to measure the impact of non-science artistic experiences on science learning and engagement.

As described in the literature review, MSI has run pilot studies using a variety of tools and methodologies, including surveys with various item formats, mobile eye tracking, timing and tracking, and more. They have used both experimental and quasi-experimental designs. Hints of impacts and outcomes exist in the data, but the researchers believe that they have not succeeded in truly measuring what is occurring in the spaces.

Does this mean nothing is occurring? Possibly, but our human and professional experience suggests that is not the case. For most people, art does something. And, for most people, learning about science is contextual, especially in museums (Falk and Dierking, 2016). It's hard to believe that when they occur back-to-back, artistic experiences don't impact scientific experiences (or vice versa).

Bringing the above two propositions together, the final session of the conference focused on articulating and developing research questions emerging from the previous two days. In launching the small group discussions, participants were encouraged to connect to their practice as educators or researchers. They were asked to consider what made them curious in their own experience or practice, as well as to be mindful of issues of power and balance, thinking about whose knowledge "counts" and what even might count as research. As is common in evaluation brainstorming, the discussion quickly turned to methodology. The group was particularly excited about broad, flexible approaches such as co-research and participatory action research. But, ultimately, they were reminded that methods needed to follow the research questions. A discussion followed about how to look for questions that are answerable, inspiring to the field, relevant for all, and of personal interest.

From there, the workshop discussion continued along the trajectory established by the Broadening Opportunities session, going beyond the previous day's emphasis on how art might support or enhance science education, to thinking about, for example, how art can broaden opportunities for engagement in and with science, broaden perceptions of who belongs in science (or in science education), broaden what counts in science education and whose voices count – or have 'rightful presence – in science education (Calabrese Barton & Tan, 2020). The discussion was particularly inspired by Amber Coleman's presentation, which led to questions about how art can support agency and radical imagination and how art can help individuals and their communities to imagine a better future (perhaps one in which both art and science could be leveraged towards desired ends). Such issues and questions are well aligned with the turn towards a deeper focus on equity in the informal science education field, and these concerns underpinned the kinds of questions that were mooted and considered. It was generally agreed that research questions must address such issues to be relevant for today.

The discussion also drew upon other points raised in the conference, including that of respect for and valuation of different perspectives and experiences as part of a shift away from the notion of science as fixed and science-related questions as having a single right answer. Participants recognized the importance of making space for multiple epistemologies, noting that canonical science is one way among many of knowing about the world (art is another). This tenet coheres well with the epistemological and axiological underpinnings of VTS, which build on experiences and orientations that a viewer brings, without judgment, and is open to multiple perspectives and interpretations.

Day 2. Session 2.

The discussion led to the articulation of further questions that could start to form the basis of an art+science research project or projects, including:

- How might we use art to expand what people think science is?
- What messages does art (or the presence of art) give in different settings (e.g., in science museums, art museums, community settings, makerspaces)?
- What happens when a VTS approach is used in different settings and beyond art museums? It has extra flexibility since it requires neither prior expert knowledge nor a focus on content on the part of either the facilitator or the audience.
- Science museums are spaces loaded with cultural and political energy. How might they learn from the practice of art to begin to mitigate this?
- What might art bring to community science?
- Can we use characteristics of the discipline and practice of art (e.g., how uncertainty and ambiguity are inherent features; how there is room for multiple perspectives) to design science learning experiences that are more inclusive and accessible?

In considering these questions, we acknowledge that they may reflect a false dichotomy between art and science. For instance, many scientists would argue that uncertainty and ambiguity are features of their work as well. However, in these questions, we are considering the perspectives held by many in the (non-scientist) public, as it is their learning and engagement with science that is our primary concern.

Although the discussion in this final workshop revolved around question generation, there was broad agreement that the methodologies used to explore such questions should be participatory and collaborative. They should involve audiences/communities to ensure a research focus on issues of interest to them. Challenge-centric thinking also arose as a way of framing the research—an imperative to begin by asking "What is the problem, concern, or issue?," followed by "What can be brought to bear on this? By whom?" —as well as the notion of supporting individual and community agency, providing scaffolding for them to use their experience and passion to solve problems. Indeed, this may be one reason MSI's studies, which had not been broadly participatory, have not detected much. Preliminary ideas around places to start exploring such questions and themes, include:

1. With respect to existing community programs run by a science museum, can non-science art be introduced into the mix? What might it bring? What happens?
2. New program pilots, such as community science infused with art, exploring the issues a community wants to address and inviting them to co-design the research, bringing in both science and art.

There are clearly many lines of research that could emerge from bringing together non-science art and science. The direction that emerged in the final discussion could sit alongside other, sometimes more quantitative or psychology-based work, focusing, for instance, on visitor experience in the gallery (such as MSI's pilot studies or efforts to measure individual differences). While such studies may seem disparate, they can be mutually informative. For instance, it is not difficult to imagine how studies such as MSI's pilot or Steciuch & Price's ideas (sidebar) could provide guidance as to how art might open up science or possibilities to consider in making a science experience more engaging. Together, these different kinds of research will likely all be required to advance and deepen the field's understanding of how art can broaden opportunities for engagement with and learning in science.

Day 2. Session 2.

Measuring Individual Differences in Museum Settings

Drs. Christian Steciuch & Aaron Price

In a museum setting, it can be challenging to determine what leads visitors to engage with an exhibit. Despite an exhibit designer's attempts to make information accessible, visitors may walk through, simply glancing at the objects without further contemplation (Bauer & Schwan, 2018). Even when they do pause, Smith and Smith (2001) noted that 75 percent of viewers spend less than 30 seconds looking at an artwork and its label. To fully understand the potential for learning at an exhibit, it is essential to document the complex interaction between motivational, cognitive, and social factors that inform a guest's propensity to engage with it.

Currently, there are few individual difference measures that have been, or can be, employed to better understand a visitor's experiences in a museum setting (Myszkowski & Zenasni, 2020). In informal learning settings, experimenters have manipulated the prior knowledge of exhibit facilitators (Eberbach & Crowley, 2017) or accompanying text (e.g., Swami, 2013) to enhance engagement and appreciation. Prior art expertise has also been shown to influence eye movements for representational paintings. We can also measure where guests direct their attention. For example, experts have been shown to look at relationships between multiple objects, while novices look at specific objects (Nodine, Locher, & Krupinski, 1993).

In psychological research, a trait-level characteristic describes something a person brings to the experience that is inherent in who they are. This is different from a state-level characteristic that can be manipulated and is based on the situation in which they find themselves in at that time. For example, a trait characteristic would be feeling general anxiety while taking a test because the person hates tests of all types. A state-level characteristic would be feeling anxiety while taking a test because the person did not study for it. There is very little museum research that looks at how to use or improve trait-level differences to enhance learning; this kind of research, though, could be essential to understanding how building on a person's innate interest in art could impact their state of mind and openness to learning about non-art topics (e.g., science).

The recently published Aesthetic Processing Preference Scale (APPS) measures three trait-level cognitive processing preferences when viewing aesthetic objects (Kopatich, Steciuch, Feller, Millis, & Siegesmund, 2021). These measures include:

1) Appreciation for complexity: preference for conceptually and visually challenging content
2) Intolerance for ambiguity: comfort with ambiguous artworks, in which no correct 'answer' or interpretation may exist
3) Propensity to contextualize: likelihood of relying on background information presented with the artwork

Identifying museum visitors' processing preferences might give researchers an indication of who may be struggling with initial engagement, guest's ability to cope with perceived ambiguity, and their tendency to rely on information from sources outside the artwork.

Researchers can use the three processing preferences described in the APPS combined with cross-sectional measures, such as eye movements and objective ratings of comprehension and affect, to better capture engagement in informal learning settings. For example, in a science museum exhibit a student with a high appreciation for complexity may mimic eye movements similar to an art expert (inferring relationships between objects). Alternatively, a student with a high propensity to contextualize may demonstrate information-seeking behaviors, such as asking questions in a group setting or spending more time exploring the exhibit space. Combining the APPS with situational measures of engagement can potentially bridge the gap between arts-based and science education research in informal learning settings.

The APPS can be a tool used in studies that examine the impact of non-science themed art in science education by providing a trait-level description about how guests interact with the art. It may reveal previously undefined relationships between viewers and their subsequent interactions with art and science content.

Conclusion

Dr. Aaron Price, *Museum of Science and Industry (MSI), Chicago*

The conference was a special time. In addition to bringing together groups of people who normally do not cross paths at such events, it was also the first conference of its type for many attendees since the start of the COVID-19 pandemic. This fostered abundant discussion and collegiality. One of the benefits of that was the discussion quickly transcended the technical in favor of the philosophical, animated by important questions regarding the nature of art and the nature of science, how to truly keep them equal when power dynamics pull one way or the other, and how to make the research truly participatory and focused on the need for art and science research to grow in equity and ambition. Further discussions on these topics will be needed to advance this overall agenda. If we want to know how non-scientific art and science education can work together, we'll need to spend more time defining the frameworks while also accepting that the research methods are going to need to be quite complex and innovative. The magnitude of the challenge is immense, but it is nonetheless dwarfed by its potential impact.

Acknowledgments

The conference was supported by the National Science Foundation (DRL#1939342). We acknowledge contributions to this report from Priscilla Yee and Martin Storksdieck. We appreciate all of the artists of the 2022 Black Creativity Juried Art Exhibition.

References

Applebaum, L. & Price, C. A. (2019). Black Creativity Juried Art and Extreme Ice Study Research and Evaluation Executive Summary. Retrieved from https://www.msichicago.org/fileadmin/assets/educators/research/BC_Juried_Art_and_Extreme_Ice_2019.pdf

Anderson, C. C. (2019). *The art of medicine: A narrative case study of an art museum workshop series for first-year medical students* (Doctoral dissertation).

Barone, T., Eisner E.W., (2012). Arts based research. *Sage Publications, Inc.*

Bevan, B. B., Barton, A. C., & Garibay, C. (2018). Why broaden perspectives on broadening participation in STEM. *Center for Advancement of Informal Science Education.*

Brentjes, S. (2015). Relationships Between Early Modern Christian and Islamicate Societies in Eurasia and North Africa as Reflected in the History of Science and Medicine. *Confluence: Journal of World Philosophies, 3.*

Bauer, D. & Schwan, S. (2018). Expertise influences meaning-making with renaissance portraits: Evidence from gaze and thinking-aloud. *Psychology of Aesthetics, Creativity, and the Arts, 12*(2), 193-204. doi: 10.1037/aca0000085

Belkofer, C. M., Van Hecke, A. V., & Konopka, L. M. (2014). Effects of drawing on alpha activity: A quantitative EEG study with implications for art therapy. *Art Therapy, 31*(2), 61-68.

Bowen, D. H., & Kisida, B. (2019). Investigating Causal Effects of Arts Education Experiences: Experimental Evidence. Houston's Arts Access Initiative. Research Report for the Houston Independent School District. Volume 7, Issue 4. *Houston Education Research Consortium.*

Bressler, S.L. (1995). Large-scale cortical networks and cognition. *Brain Research Reviews, 20*(3), 228-304. doi:10.1016/0165-0173(94)00016-I

Burnaford, G., Brown, S., Doherty, J., & McLaughlin, H. J. (2007). Arts Integration Frameworks, Research Practice». *Washington, DC: Arts Education Partnership.*

Calabrese Barton, A., & Tan, E. (2019). Designing for rightful presence in STEM: The role of making present practices. *Journal of the Learning Sciences, 28*(4-5), 616-658.

Calabrese Barton, A., & Tan, E. (2020). Beyond equity as inclusion: A framework of "rightful presence" for guiding justice-oriented studies in teaching and learning. *Educational Researcher, 49*(6), 433-440.

Carruthers, C. (2018). Unapologetic: A Black, queer, and feminist mandate for radical movements. *Beacon Press.*

Casini, S. (2010). Art in science centres: A challenge to visitors and evaluators. In *Science Exhibitions: Communication and Evaluation* (pp. 51-76). Museums ETC.

Cazan, A.-M. & Indreica, S. E. (2014). Need for cognition and approaches to learning among university students. *Procedia – Social and Behavioral Sciences, 127,* 134-138.

Crenshaw, K. (2018). Demarginalizing the intersection of race and sex: A Black feminist critique of antidiscrimination doctrine, feminist theory, and antiracist politics [1989]. In *Feminist legal theory* (pp. 57-80). Routledge.

Davis, J. H. (1999). Nowhere, somewhere, everywhere: The arts in education. *Arts Education Policy Review, 100*(5), 23-28.

De Santis, S., Giuliani, C., Staffoli, C., & Ferrara, V. (2016). Visual Thinking Strategies in nursing: A systematic review. *Senses and Sciences, 3*(4).

Dewhurst, M., & Hendrick, K. (2018). Decentering whiteness and undoing racism in art museum education. In T*he Palgrave handbook of race and the arts in education* (pp. 451-467). Palgrave Macmillan, Cham.

DeWitt, J., & Archer, L. (2017). Participation in informal science learning experiences: The rich get richer?. *International Journal of Science Education, Part B, 7*(4), 356-373.

Eberbach, C. & Crowley, K. (2017). From seeing to observing: How parents and children learn to see science in a botanical garden. *Journal of the Learning Sciences, 26*(4), 608-642. doi: 10.1080/10508406.2017.1308867

Eisner, E. W. (1983). Teaching as art and craft. *Educational Leadership, 40*(4), 4-13.

Eisner, E.W. (2004) What can education learn from the arts about the practice of education? *International Journal of Education & the Arts, 5*(4), 1-13.

Elias, S. M. & Loomis, R. J. (2002). Utilizing need for cognition and perceived self-efficacy to predict academic performance. *Journal of Applied Social Psychology, 32*(8), 1687-1702. doi: 10.1111/j.1559-1816.2002.tb02770.x

Falk, J. H., & Dierking, L. D. (2016). The museum experience revisited. New York: Routledge.

Finley, S. (2016). Ecoaesthetics: Critical arts-based research and environmental advocacy. In *Qualitative inquiry and the politics of advocacy* (pp. 205-220). Routledge.

Garibay, C., & Teasdale, R. M. (2019). Equity and evaluation in informal STEM education. *New Directions for Evaluation, 2019*(161), 87-106.

Greenslit, J., Price, C. A., Malone, T. (2021). Aesthetic dissonance: The impact of viewing fine art in a science museum. *Journal of Museum Education, 46*(2), 202-215. doi: 10.1080/10598650.2021.1882178

Gunn, J. (2017). History and Evolution of STEAM Learning in the United States. *Resilient Educator.*

Harp, G. (2007). *Boundary Expeditions: Strategies for Creative Research at the Interface of Art and Life Science* (Doctoral dissertation).

Housen, A. C. (2002). Aesthetic thought, critical thinking and transfer. *Arts and Learning Research, 18*(1), 2001-2002.

Huang, M. (2009). The neuroscience of art. *Stanford Journal of Neuroscience, 2*(1), 24-26.

Jacobs, S. (2011). CP Snow's The Two Cultures: Michael Polanyi's Response and Context. *Bulletin of science, technology & society, 31*(3), 172-178.

Jolly, A. (2014). STEM vs. STEAM: Do the arts belong? *Education Week: Teacher.* Retrieved from http://www.edweek.org/tm/articles/2014/11/18/ctq-jollystem-vs-steam.html

Kelley, R. D. (2002). 'Roaring from the east': Third world dreaming. *Freedom dreams: The Black radical imagination.*

Kirk, G., & Okazawa-Rey, M. (2000). Neoliberalism, militarism, and armed conflict. *Social Justice, 27*(4 (82), 1-17.

Klebesadel, H. (2006). Reframing studio art production and critique. *New museum theory and practice: An introduction,* 247-265.

Klein, J. T. (2006). Resources for interdisciplinary studies. *Change: The Magazine of Higher Learning, 38*(2), 50-56.

Kopatich, R. D., Steciuch, C. C., Feller, D. P., Millis, K., & Siegesmund, R. (2021). Development and validation of the Aesthetic Processing Preference Scale (APPS). *Psychology of Aesthetics, Creativity, and the Arts.* Advance online publication. doi: 10.1037/aca0000449

Kraehe, A. M. (2019). Entrepreneurship as creative destruction. *Art Education, 72*(5), 4-7.

References

LaMore, R., Root-Bernstein, R., Root-Bernstein, M., Schweitzer, J. H., Lawton, J. L., Roraback, E., ... & Fernandez, L. (2013). Arts and crafts: Critical to economic innovation. *Economic Development Quarterly, 27*(3), 221-229.

Love, B. L. (2019). We want to do more than survive: Abolitionist teaching and the pursuit of educational freedom. *Beacon Press.*

Ludlow, L. H., & Alvarez-Salvat, R. (2000). The Man in the Mask, *Popular measurement, 3*(5-6).

Macdonald, S. (1998). Exhibitions of power and powers of exhibition. *The politics of display: Museums, science, culture,* 1-24.

McDougall, M., Bevan, B., & Semper, R. (2012). Art as a way of knowing. In *Conference Report. San Francisco: Exploratorium.*

Medin, D. L., & Bang, M. (2014). The cultural side of science communication. *Proceedings of the National Academy of Sciences, 111*(supplement_4), 13621-13626.

Moorman, M. (2015). The meaning of visual thinking strategies for nursing students. *Humanities, 4*(4), 748-759.

Myszkowski, N. & Zenasni, F. (2020). Using visual aesthetic sensitivity measures in museum studies. *Front. Psychol. 11*:414. doi: 10.3389/fpsyg.2020.00414

Naghshineh, S., Hafler, J. P., Miller, A. R., Blanco, M. A., Lipsitz, S. R., Dubroff, R. P., ... & Katz, J. T. (2008). Formal art observation training improves medical students' visual diagnostic skills. *Journal of general internal medicine, 23*(7), 991-997.

National Academies of Sciences, Engineering, and Medicine. (2018). The integration of the humanities and arts with sciences, engineering, and medicine in higher education: Branches from the same tree. Washington, DC: The National Academies Press. https://doi.org/10.17226/24988.

New York Times (August 7, 2020). To the Mathematician Eugenia Cheng, There's No Gap Between Art and Science. https://www.nytimes.com/2020/08/13/books/review/eugenia-cheng-by-the-book-interview.html

Nodine, C. F., Locher, P. J., & Krupinski, E. A. (1993). The role of formal art training on perception and aesthetic judgment of art compositions. *Leonardo, 26*(3), 219-227.

Osburn, J., & Stock, R. (2005). Playing to the technical audience: evaluating the impact of arts-based training for engineers. *Journal of Business Strategy, 26*(5), 33-39.

Pelowski, M., Markey, P. S., Lauring, J. O., & Leder, H. (2016). Visualizing the impact of art: An update and comparison of current psychological models of art experience. *Frontiers in Human Neuroscience, 10*, 160.

Pellico, L. H., Friedlaender, L., & Fennie, K. P. (2009). Looking is not seeing: Using art to improve observational skills. *Journal of Nursing Education, 48*(11), 648-653.

Pollio, H. R. (1996). The Two Cultures of Pedagogy: Teaching and Learning in the Natural Sciences and the Humanities. *Teaching Learning Issues.*

Price, A., Quinn, K. A., Greenslit, J., Applebaum, L., Krogh-Jespersen, S., Krenzer, W. L. D., & Ibtasar, R. (2019). Awe and epistemology in a science museum.

Rieger, K.L., Chemoma, W.M., MacMillan, D.E., Morin, F.L. & Demczuk, L. (2016). Effectiveness and experience of arts based pedagogy among undergraduate nursing students: A mixed method systematic review. *University of Manitoba, Winnipeg. Canada.*

Rosin, M., Wong, J., O'Connell, K., Storksdieck, M., & Keys, B. (2021). Guerilla science: mixing science with art, music and play in unusual settings. *Leonardo, 54*(2), 191-195.

Rolling, Jr., J.H. (2016). Arts-Based Research: Systems and Strategies. *Art Education, 69*(3), 4-5.

Root-Bernstein, R. (2018). STEMM education should get "HACD".

LaMore, R., Root-Bernstein, R., Root-Bernstein, M., Schweitzer, J. H., Lawton, J. L., Roraback, E., ... & Fernandez, L. (2013). Arts and crafts: Critical to economic innovation. *Economic Development Quarterly, 27*(3), 221-229.

Smith, J. K. & Smith, L. F. (2001). Spending time on art. *Empirical Studies of the Arts, 19*, 229-236. doi: 10.2190/5MQM-59JH-X21R-JN5J

Snow, C. P. (1959). Two cultures. *Science, 130*(3373), 419-419.

Solso, R. L. (2000). The cognitive neuroscience of art: a preliminary fMRI observation. *Journal of Consciousness Studies, 7*(8-9), 75-86.

Swami, V. (2013). Context matters: Investigating the impact of contextual information on aesthetic appreciation of paintings by Max Ernst and Pablo Picasso. *Psychology of Aesthetics, Creativity, and the Arts, 7*(3), 285-295,

Turkka, J., Haatainen, O., & Aksela, M. (2017). Integrating art into science education: a survey of science teachers' practices. *International Journal of Science Education, 39*(10), 1403-1419.

Van Dijck, J. (2003). After the "Two Cultures" toward a "(multi) cultural" practice of science communication. Science Communication, 25(2), 177-190.

Vinney, C. (2019). Social constructionism definition and examples. *ThoughtCo.*

von Roten, F. C., & Moeschler, O. (2007). Is art a" good" mediator in a Science Festival?. *Journal of Science Communication, 6*(3), A02.

Wilson, G. J. (2019). Visual (ization) education: Expanding possibilities of arts-based pedagogy. *Art Education, 72*(3), 50-53.

Winner, E., Goldstein, T.R., & Vincent-Lancrin, S. (2013). Art for art's sake?: The impact of arts education. OECD publishing

Yakman, G. (2010). What is the point of STE@ M?–A Brief Overview. *Steam: A Framework for Teaching Across the Disciplines. STEAM Education, 7.*