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Why create SciArt? An investigation into science artists' goals and professional journeys

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Abstract

Although Science Art ("SciArt") is increasingly used in science communication as a way to make content more engaging or accessible, little is known about why artists pursue this practice or what they hope to achieve through their work. This project addresses these questions through a thematic analysis of interviews with 131 practicing science artists. We identify a diversity of goals for creating SciArt, only some of which involve communicating science.

Keywords Science and technology, art and literature; Visual communication

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Introduction

Science art (or *SciArt*) is a fast-growing mode of creative visual expression that draws inspiration from science. Heralded for its ability to engage audiences at a deep, emotional level, it has captured the interest of the scholarly community. This interest in SciArt has resulted in a wealth of creative projects — produced by individual "science artists" or through collaborations between scientists and artists — aimed at broadening the public impact of research.

Despite a rising interest in SciArt within science and science communication, relatively little is known about the perspectives of the creators themselves. This lack of knowledge limits the potential for supporting science artists' work and ensuring collaborations between science and artists are productive and mutually rewarding. This qualitative study seeks to fill this gap by identifying and documenting the self-described creative journeys and goals of practicing science artists. Using a rich dataset of 131 interviews with SciArt creators that were published on the blog of Art the Science (ATS),[1] we conducted a qualitative analysis of these creators' journeys, or paths, into the creation of SciArt, external or audience-focused goals, and internal or creator-focused goals. We present and compare our findings with those found in existing literature and discuss

[1] https://artthescience.com/magazine; ATS changed the title of its publication to *Polyfield Magazine* in September, 2021.

implications for both research and practice. We see this study as a necessary first step towards better understanding SciArt creators and forging more egalitarian and effective partnerships between SciArt creators, scientists, and science communicators.

Literature review

The mutual practices of science and art have a long history, dating back to the interdisciplinary work of Renaissance thinkers such as Leonardo da Vinci [Agostinho & Casaleiro, 2015; Fuller, 2020; Rock & Howard, 2019] and perhaps even earlier. More recently, however, the practice of SciArt — visual art inspired by science — has gained popularity among science and science communication practitioners and scholars [Gewin, 2013; Parks & White, 2021; Rödder, 2015]. At least some of the rising interest in SciArt may be attributed to its ability to help audiences relate to science on a personal, emotional level [Lesen, Rogan & Blum, 2016; Pirrie, Jackett, Jones & Lyon, 2018] and to spark creative thinking among both artists and scientists [Swanson, 2015]. Scholars argue that visual arts-based approaches boost interest and engagement with science by targeting the affective aspects of learning, rather than only the cognitive ones [Agostinho & Casaleiro, 2015; Grushka, Hope, Clement, Lawry & Devine, 2018; Pirrie et al., 2018]. More broadly, SciArt is celebrated as a way to disseminate science beyond the scientific community [Lau, Barriault & Krolik, 2022; Prem, 2019], especially to hard-to-reach or disinterested audiences who would not otherwise seek out science information [Rosin, Wong, O'Connell, Storksdieck & Keys, 2021]. For these and other reasons, collaborations between scientists and artists continue to attract attention within the academic community [Nature, 2021; Oliveira, 2015; Swanson, 2015].

Despite this growing interest, however, the goals of visual SciArt initiatives are often not fully understood, even to those involved in them [Lesen et al., 2016]. This lack of knowledge does not bode well for scientists and communicators interested in working with SciArt creators. Interdisciplinary science communication projects are known to suffer when goals and values of collaborators are unacknowledged or misunderstood [Halpern & O'Rourke, 2020]. The risk of such misunderstandings is high in SciArt collaborations, as scientists and visual artists can sometimes see project goals differently [Rödder, 2017]. There is danger that the goals of the scientific community will be privileged over those of other collaborators [Halpern & O'Rourke, 2020]. In addition to harming SciArt creators, such unequal collaborations may prevent scientists from engaging publics in reciprocal ways. A recent *Nature* poll found that, while most scientists who had collaborated with artists described the experience as valuable, artists reported that their own goals were often deprioritized [Nature, 2021]. The article concludes: "The reach of art-science tie-ups needs to go beyond the necessary purpose of research communication, and participants must not fall into the trap of stereotyping each other" [p. 528].

In this study, we seek to address this disconnect in how the scientific community views and understands the work of visual science artists by exploring how these creators describe their creative journeys and goals in making SciArt. Developing a better understanding of science artists' professional priorities is a necessary (though not sufficient) step toward fostering productive and mutually rewarding collaborations among scientists, artists, campaign managers, and other science communication professionals. Productive and mutually rewarding collaborations

that equally combine the perspectives and work of scientists and creators may also result in SciArt products and experiences that are more inclusive and engaging for broad audiences.

Journeys into SciArt

One way that we can better understand SciArt creators is by listening to their origin stories — how and why they got into SciArt — especially as many academic systems do not support simultaneous study of science and art. There may be commonalities in journeys into SciArt that help us understand the perspectives of SciArt creators. Below, we review literature related to these journeys.

Scholars have noted that many higher education systems privilege disciplinarity and academic specialization, despite the demonstrated value of interdisciplinary research and research communication [Buyalskaya, Gallo & Camerer, 2021; MacLeod, 2018]. Still, interdisciplinary degrees and educational programs have started to emerge in some parts of the world, some of which offer training in both arts and sciences. While a review of global SciArt education is beyond the scope of this paper, several relevant programs exist within our home countries. For example, Canada's Convergence Initiative offers year-long collaborations between artists and neuroscience graduate students, offering a window into SciArt careers [Zaelzer, 2020]. Other Canadian examples include Queen's University's Cultural Studies[2] and Environmental Studies[3] programs, which allow students to work with supervisors from different departments. In the U.S., some universities have interdisciplinary courses[4] or summer programs[5] that combine science and art, or offer programs, like the MIT Media Lab,[6] that train students in science and arts disciplines.

Other attempts to build connections between science and art have taken the form of funding initiatives, most notably the U.K.'s Wellcome Trust's SciArt program, which financed collaborative projects between artists and scientists for 10 years [Glinkowski & Bamford, 2009; Sleigh & Craske, 2017]. More recently, universities, research institutes, and nonprofits have invested in SciArt "residencies" [e.g., Lau et al., 2022; Prem, 2019], which place artists into research labs where they engage with scientists, explore scientific techniques, reflect on new findings, and produce art informed by these experiences. Initiatives such as SciArt Exchange[7] or Lifeology SciComm University program[8] also provide opportunities for building skills or knowledge of SciArt via online courses and training opportunities. SciArt workshops, such as the one described in Parks and White [2021], are also becoming more common at universities and research institutions, as are multi-week training initiatives, such as the Baltimore SCIART Consortium.[9]

While these initiatives provide opportunities for SciArt training and development, most are relatively new. It seems likely that many of today's working science artists

[2] https://www.queensu.ca/culturalstudies/.
[3] https://www.queensu.ca/ensc/.
[4] https://arts.stanford.edu/for-faculty/art-science/.
[5] https://sciart.umbc.edu/.
[6] https://www.media.mit.edu/graduate-program/about-media-arts-sciences/.
[7] https://www.sciartex.net/about-us.html.
[8] https://lifeology.io/lifeology-univ-scicomm/.
[9] https://chemistry.umbc.edu/sciart/.

have found their own way into their craft. As, to our knowledge, no existing studies have examined the nature of those journeys into SciArt, a first goal of this study is to understand:

RQ1: How and why did SciArt creators first become involved in making SciArt (i.e., their creative journeys)?

External goals in SciArt

To understand the work of artists who create SciArt and to foster successful collaborations between scientists and artists, it is also important to understand the goals of artists who create SciArt. For example, do most artists who create SciArt have specific outcome-based goals, or are their goals focused on the process and creation experience? Existing research into the goals of science artists is limited — composed mainly of commentaries and small case studies of specific artists or SciArt initiatives. For example, scholars have explored the use of comics to promote public health [Kearns, Kearns et al., 2021], engage minority communities [Kearns, Baggott et al., 2021], or spark students' interest in science [Spiegel, McQuillan, Halpin, Matuk & Diamond, 2013]. Others have studied SciArt courses and workshops within higher education settings, finding that science artists in these contexts are often motivated by public education goals [Parks & White, 2021] or a desire to communicate facts effectively [Zaelzer, 2020]. Still others have examined the goals of specific initiatives, such as the *Waiting for Water* exhibition in Australia, which had an explicit ecological focus and a goal of inviting "a collective discourse around our environmental future of waiting for water" [Pirrie et al., 2018, p. 10]. While such studies offer a taste of the many external goals that can motivate SciArt creators working within specific settings, we still lack insight into whether there are overarching goals shared by creators working across formats and contexts. In this study, we seek to address this research gap.

While there is limited research on the goals of artists who create SciArt, there is a growing body of research investigating the goals of individuals or groups who practice science communication. Given that SciArt is often seen as a way to engage broad audiences with science, we review the literature on science communication goals below in an effort to provide a foundation of goals against which to compare and contrast our own findings related to the goals of artists. In doing so, we recognize that while some SciArt creators may have goals that overlap with those of scientists and science communicators, they may also have goals as artists that have nothing to do with communicating science. In the following paragraphs, we highlight potential overlaps and differences wherever possible.

Whether they are internal or external, a creator's goals can affect how they approach their work and what they create. If we assume that a SciArt creator is ultimately seeking to communicate or express something (which may not be the case — we explore this in our results section), we can use science communication literature on goals to begin to explore the potential goals of SciArt creators. A communicator's goals can be defined as the long-term desired outcomes of their communication efforts [Besley, Dudo, Yuan & Abi Ghannam, 2016; Kendall, 1996]. Some of these goals may be *external*, or focused on producing change in the real world, for example, increasing audiences' awareness, interest, understanding, or enjoyment of science, or enabling someone to form or change a science-related

attitude [Burns, O'Connor & Stocklmayer, 2003]. Whether or not communicators achieve these goals determines the effectiveness of their communication efforts [Besley et al., 2016; Hon, 1998]. Even if goals are not accomplished, they guide various aspects of the work that an individual produces.

In science communication, the goals of scientists, science writers, or other content creators are often primarily to help people understand science, take interest in science, or see the value of science [Besley et al., 2016]. Scientists may also feel a sense of duty to communicate the results of their publicly-funded research [Besley et al., 2016], which may lead to efforts to communicate research in more accessible formats. This external goal seems to be shared by some SciArt creators as well. In one study, science comic artists described their work as an approachable way to communicate and clarify scientific ideas to audiences, particularly to those who "might not normally engage with science" [Collver & Weitkamp, 2018, p. 8]. Some of these creators were also motivated to instill a "sense of wonder" in readers, and to inspire curiosity and appreciation about seemingly uninteresting or "dreary" things. Similarly, Rosin et al. [2021] propose that SciArt can be used as a form of "Guerilla Science", embedding scientific information or ideas into an unexpected but approachable context with the goal of "empowering people with scientific ideas — helping them to see the relevance of science to their lives and in being able to meaningfully use this knowledge" [p. 2]. Recent SciArt collaborations have also featured partnerships between Western scientists and Indigenous artists to "communicate… across science and art, and across cultures, with great success" [Tingay, 2018, p. 3].

Importantly, however, not all creators of science art see their work as fulfilling science communication aims. Some may even actively resist having their work labeled in this way [Sleigh & Craske, 2017]. As Ball and Ede [2017] argue, "the artist is not (or should not be, although the misconception still occurs) there to illustrate, explain or make the science accessible. That is the job of educators, explainers, journalists, illustrators" [p. 309].

External communication goals can also focus more on promoting dialogue and conversation as opposed to simply imparting information. Getting citizens engaged in science through dialogue or actively involving citizens in discovery are goals that a growing number of science communicators and artists have in mind [Marizzi & Bartar, 2021; Zaelzer, 2020]. However, scholars have argued that this explicit goal of engaging publics in dialogue and mutual listening is sometimes used to pursue an unstated, underlying goal of maintaining science's authority position in society [Wynne, 2006]. In contrast, science artists often express this dialogic goal in a way that invites true criticism of science, for example, using art as a way to raise awareness about scientific failures, present an alternate view of the "hype" around new discoveries, and encourage audiences to question biotechnological innovations [Born & Barry, 2010; Catts & Zurr, 2018]. For example, many artists involved in the Wellcome Trust-funded SciArt projects described their role as "independent scrutiniser" — they created artwork with the aim of asking questions and provoking insights about science that might otherwise be overlooked [Glinkowski & Bamford, 2009; Sleigh & Craske, 2017]. The independent scrutiniser is a unique and important role that is not often filled by science communicators [Brown Jarreau, 2015b], but is related to the role that science journalists have played historically in critiquing and investigating science.

A related goal of uncovering hidden connections or alternative possible realities has been identified by Benjamin [2020] who writes: "Art's creation of perceptual experiences beyond everyday existence brings the seemingly impossible into contact with the possible, a magical act of revealing" [p. 510].

Given the broad range of external goals that have been identified among science communicators, and, to a lesser extent, SciArt creators, we ask:

RQ2: What are creators' external goals in creating science art?

Internal goals in SciArt

Internal motivations and goals also guide the work of communicators and SciArt creators. In fact, achieving internal goals may determine how sustainable one's work as a communicator or creator is. Previous research has found that experiential activities, or activities pursued with a focus on the intrinsic experience of the activity as opposed to external goals, are more enjoyable and sustainable [Fishbach & Choi, 2012]. In other words, "often the intrinsic incentives create the positive experience of pursuing an activity, and further increase pursuit" [Fishbach & Choi, 2012, p. 106].

Internal goals might include enjoyment, self-improvement, and other personal benefits such as becoming a better communicator [Besley et al., 2016; Brown Jarreau, 2015a]. These goals might be particularly pertinent for communicators or creators who are working primarily on an unpaid basis. However, internal goals can also yield external outcomes. For example, science communicators may use an internal goal or motivation [Moravcsik, 1974], such as personal enjoyment, creative self-expression, or finding beauty, to help them create work that others will enjoy [Brown Jarreau, 2015a]. Internal goals as well as personal interests, experiences, and intentions may be particularly important to the artist's creation process [Yokochi & Okada, 2021].

For science artists, goals of enjoyment or self-expression may be supplemented by internal goals that are not often discussed in science communication literature, such as personal exploration and reflection [Benjamin, 2020; Glinkowski & Bamford, 2009]. SciArt creators use art to explore boundaries between natural and unnatural [Oliveira, 2015], reflect on humanity's place within a larger ecosystem [Catts & Zurr, 2018], and gain self-insight and understanding [Benjamin, 2020]. Some describe their work as being process-focused rather than outcomes-focused — often in direct conflict with the results-oriented goals of the scientists they collaborate with [Sleigh & Craske, 2017]. Root-Bernstein, Siler, Brown, and Snelson [2011] similarly argue that work bridging art and science is about exploration and reflection, "not embodied in its products so much as it is expressed through the convergence of artistic and scientific processes and skills" [p. 192]. Understanding SciArt creators' internal, process-focused goals as well as more external, outcome-focused goals is thus essential for supporting and working effectively with science artists. As such, our final research question asks:

RQ3: What are creators' internal goals in creating science art?

Methods

Data were collected from the blog of Art the Science (ATS), a Canadian nonprofit organization that facilitates cross-disciplinary relationships between artists and scientists. ATS's blog posts fall into five different categories — *Features*, *Bits*, *Spaces*, *Works*, and *Creators* — all of which highlight SciArt or science artists from around the world. This study relied on the *Creators* posts,[10] each of which features a Q&A with a different SciArt "creator". Creators either submit responses independently or are invited to do so by a blog editor, but all answer the same six interview questions:

1. Which came first in your life, the science or the art?
2. Which sciences relate to your art practice?
3. What materials do you use to create your artworks?
4. Artwork/exhibition you are most proud of:
5. Which scientists and/or artists inspire and/or have influenced you?
6. Is there anything else you want to tell us?

To compile the research dataset, interviews with 131 creators spanning a five-year timeframe (Nov 20, 2015–Nov 20, 2020) were manually extracted from the blog and loaded into NVivo 12 software for analysis. Detailed demographic information about these creators is unavailable, as ATS did not collect demographic information from the artists featured on its blog. However, we were able to glean some information about their background and professional practices from answers they gave in the blog posts. Responses to the first interview question suggest that most of the creators had experienced early exposure to art ($n = 55$) or came from a mixed background that combined art and science ($n = 41$). Only 20 participants reported engaging in science before exploring art. An additional 15 creators did not provide a clearly categorizable answer to this question. While creators were diverse in their use of artistic formats and techniques, the sample included creators predominantly focused on visual art (rather than performance or sound art). Common artistic approaches included photography, microscopy, digital art, painting, illustration, and sculpture. Creators engaged with many different scientific disciplines, but environmental sciences, life sciences, and psychology and neuroscience were among the most frequently mentioned. Creators appeared to differ in their level of professionalization, with some participants identifying as full-time artists and others describing their art as a side job, personal passion, or hobby. However, almost all creators said that they had exhibited their work publicly in some way, and about a third of them reported that they had collaborated on projects with scientists in the past.

Two main coders applied thematic analysis to the interviews, although all three authors contributed to the development of the themes and subthemes. Coding began with a close reading of the posts and a preliminary analysis using open coding and constant comparison [Braun & Clarke, 2012]. Using an emic, iterative approach, codes were identified and grouped together to form larger subthemes, which were, in turn, grouped into several overarching themes. Following Manyweathers, Taylor, and Longnecker [2020], themes and subthemes were

[10] https://artthescience.com/magazine/category/creators/.

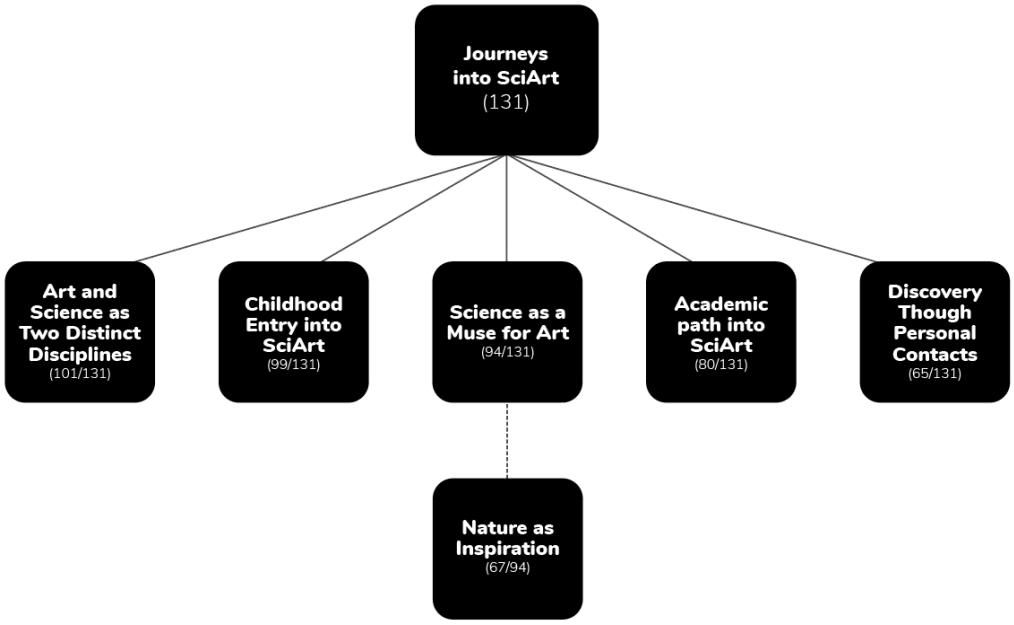

Figure 1. Thematic map of "journey" themes. Note that themes and subthemes often overlap.

data-derived, but informed by existing research into creator journeys and goals. Themes were not exclusive, in recognition that an individual might have multiple reasons for creating SciArt. The two main coders met frequently to discuss challenging codes and themes. The third author — a science artist and founder of the ATS blog — was involved in these discussions. The results of the final coding are summarized in Figures 1, 2, and 3, and discussed in further detail below.

Results

Journey themes

By analyzing creators' responses to the question "Which came first in your life, the science or the art?", as well as other relevant references throughout the blog posts, we identified several major themes in how and why creators first became involved in SciArt, many of which overlapped with one another. We summarize these themes and subthemes in Figure 1 and describe them in detail below.

Art and science as two distinct disciplines. The most common theme ($n = 101/131$) addressed in creators' journeys implicitly or explicitly reflected, critiqued, or discussed the idea that the sciences and arts are often seen as two distinct, disconnected ways of knowing. Several creators shared experiences of times they had felt they had to make a choice between pursuing science or visual art. Many of these reflections were rooted in the limiting nature of the education system, such as Rob Kesseler's[11] remark that "Given the inflexibility of the British education system at that time, I had to choose between art and biology. It wasn't possible to study both and so I pitched for biology", or Katrina Vera Wong's[12] comment that, "artistic creativity isn't really valued in Singapore's education

[11] http://www.robkesseler.co.uk.
[12] https://www.furiebeckite.com.

system (unless it directly affects your grades) so there was some pressure for me to stick with science". Others similarly noted a pressure to focus on science because they were told that it would open up more career opportunities. For others, the choice of which discipline to pursue was a question of practicality, such as Louise Mackenzie,[13] who said, "At school, even though I absolutely loved art, I also loved the sciences, and in the end had no room for art in my timetable".

However, creators expressing this theme also found ways to connect their two passions, either by pursuing alternative educational opportunities later in life or by experimenting with intersections of art and science in their spare time. This journey from having to choose to integrating science and art is reflected in comments such as:

> Somewhere along the line I realized how interested I was in biology because it was the subject of all my paintings. This led me to a major in biology as an undergrad, where I discovered both my interest in evolutionary questions and SciArt. Since then, I've embraced the integration of science and art in my career. (Bridget Vincent[14])
>
> I realized over time that I had a serious passion for making art, that there was some kind of inherent need within myself to create that I just couldn't ignore, so I decided to go back to school to pursue a career in the arts. (Angela McQuillan[15])

Whether they discovered their passion for SciArt later in life or learned to integrate both passions from an early age, most creators expressing the two disciplines theme said that they now saw art and science as complementary ways of knowing. This feeling is reflected in comments such as, "I view the sciences and art as not being separate, but as being in a symbiotic relationship with one another. I find art to be a free-flowing and abstract way to experiment, see, and understand the natural world", or Michelle Anderst's[16] comment that, "Science and art have been inextricably entangled from my very first memories, therefore one has never existed without the other".

Importantly, comments relating to *Art and science as two distinct disciplines* may, in part, be influenced by the phrasing of the interview questions themselves. In particular, the question "What came first, the science or the art?" includes an implicit suggestion that these two disciplines are, in fact, distinct.

Childhood entry into SciArt. About three quarters ($n = 99/131$) of the creators traced their SciArt origins back to childhood. Many comments under this theme expressed a sense of innate curiosity that spurred experimentation or exploration from a young age. For example, Greg Dunn[17] stated "I was definitely a kid who liked to experiment, and I think it's easier and more accurate to say that I'm a pretty curious person all around. That led me through many random obsessions".

[13] http://www.loumackenzie.com.
[14] https://bridgetavincent.wixsite.com/bridgetavincent.
[15] http://www.angelamcquillan.com.
[16] https://www.michelleanderstshop.com.
[17] https://www.gregadunn.com.

Similarly, Suzanne Anker[18] felt that "The curious condition of a child's imagination provided me with the opportunity to express my interest in world-making".

The childhood theme often overlapped with other journey themes (discussed below), especially *discovery through personal contacts* and *nature as inspiration* (a subtheme of *science as muse*). In comments that intersected with *discovery through personal contacts*, creators recounted early experiences with parents, other family members, teachers, or friends that inspired them to explore science, art, or both. For example, Owen Fernley[19] stated: "I have an artistic background, my mother is an oil painter, my father an art director and musician. Science came later when I realized I enjoyed physics".

Also common were childhood comments relating experiences with nature that creators viewed as encouraging their journey into SciArt, such as this one:

> As a child, I was always out in nature, collecting things, obsessively drawing and visiting quarries and dig sites, and collecting and cataloguing natural specimens. My fascination with nature established my connection to both fine art and the natural sciences. (Stefan Herda[20])

Science as a muse for art. Unsurprisingly, almost three quarters ($n = 94/131$) of the interviews included comments about how science acted as a source of inspiration for their art. Some of these comments described scientific phenomena that had sparked a passion, such as this reflection from Vance Williams:[21] "In my early teens, I was captivated by the images of science, especially photographs of planets, galaxies, and nebulae". Even more common, however, were comments that fell under the subtheme *nature as inspiration* ($n = 67/94$) — experiences with the natural world that sparked an interest in science, art, or both. This subtheme is exemplified by Jenni Ward's[22] comment that "Biological sciences probably influence my work the most. I love looking at structures in nature, finding out how things work and what is happening on the insides".

Although, as described above, these experiences with nature often began in childhood, many creators portrayed nature as an ongoing source of inspiration. For example, Sharl G. Smith[23] related that "I don't incorporate biology in a literal way; it's more that I am inspired by the relationship between nature, beauty, and geometry. I think of my work as organic geometry".

Academic path into SciArt. More than half of the creators ($n = 80/131$) mentioned experiences with formal education that were important for their journey into SciArt. Many of these comments focused on the importance of inspiration or support received from personal contacts developed during academic studies (discussed below). However, in other comments, the value of academic training appeared to be less about personal connections and more about

[18] http://suzanneanker.com.
[19] https://owenfernley.com.
[20] https://stefanherda.com.
[21] https://www.instagram.com/vance.williams.
[22] https://www.jenniward.com.
[23] https://www.sundropsstudio.com.

uncovering a creative passion. This was the case for Jennifer Willet,[24] who recalled working as an AV technician in an anatomy lab: "I think these experiences sparked my desire to work in other highly specialized institutional scientific laboratories as an artist, cultural critic, and observer".

Discovery though personal contacts. About half of the creators ($n = 65/131$) felt that the role of personal relationships had been important to their SciArt journey. In addition to childhood memories of influential role models or loved ones, creators also related experiences with personal contacts they made later in life, such as Laura Bundesen,[25] who emphasized the importance of connecting with other science artists:

> I'm incredibly inspired by a handful of scientist-artists who work in both spheres and who have been very generous in sharing information. They include Greg Dunn, Christine Liu, and Tahani Baakdhah to name just a few. Their generosity is just amazing, and their art is inspiring.

As mentioned above, this theme also overlapped with the theme of *academic path into SciArt*, as many creators felt that the role of graduate supervisors, university instructors, and other academic influences had been important to their creative development. For example:

> Dr. Adam Summers is a fish biologist at the University of Washington who became renowned for creating beautiful images of fish using clearing and staining. He actually taught me that research technique, and inspired me to make my own cleared and stained images to decorate my walls. (Noah Bressman[26])

External goals themes

Creators expressed a range of external goals of creating SciArt, falling generally into three overlapping themes and several subthemes, summarized in Figure 2 and described below.

Reach and connect. The most common external goal, expressed by more than half of creators ($n = 74/131$), was to *reach and connect* with audiences. This theme captured a diversity of subthemes that all centred on impacting the audience's experience in some way — be it emotionally, intellectually, spiritually, or behaviorally. Creators who shared this goal made comments such as, "I always tell people to reach out and touch my work, as I believe art should be a multisensory experience", and "I am most proud of pieces that encourage viewers to discuss the underlying science and consider how the data might impact their thinking".

More specifically, creators sharing the reach and connect goal reported using SciArt for one or more of the following subgoals: *engage or invite participation* ($n = 35/74$),

[24] https://incubatorartlab.com.
[25] https://www.laurabundesen.com.
[26] https://noahbressman.wixsite.com/Noah.

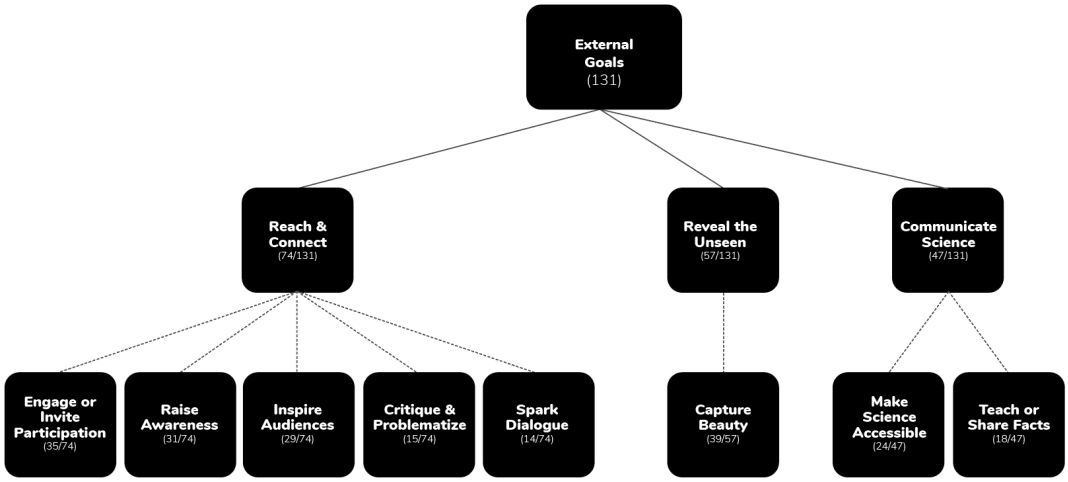

Figure 2. Thematic map of external goals. Note that themes and subthemes often overlap.

raise awareness about an issue ($n = 31/74$), *inspire audiences* ($n = 29/74$), *critique and problematize* ($n = 15/74$), and, finally, *spark dialogue among audiences* ($n = 14/74$). We describe each of these goals in more detail below.

Engage or invite participation: the most common reach and connect subtheme focused on bringing the audience into SciArt itself. While creators in our data set mostly used visual artforms, many found ways to incorporate a participatory element into their SciArt, allowing the audience to become a part of the creative process. For example, Tracey M. Benson[27] shared that, "At times, my work has also been performative in nature, not just by me performing a part but also through engaging the audience as active participants as part of the work". In other cases, the goal of inspiring audience participation was purely aspirational, such as one creator, who said, "I dream of co-creating (with the participants) out-of-doors, hands-on community science-art. The creations would be made of the natural objects we looked at and the intangible collaborations among the participant-science-artists". Whether or not they had acted on this goal, creators reflected that audience participation could change the art, the way it was interpreted, and even the audience members themselves. As one creator expressed:

> Each viewer brings their own history, interest, and knowledge to the work. A circle may be read by one viewer as a planet, while another viewer may perceive it to be a particle. The ambiguity of these forms enables the viewer to experience the work on a deeply personal level. My intent is that these familiar repeating patterns used in my paintings will activate the viewers' inner knowing. This awareness and recognition of these commonalities can allow for the viewer to experience an epiphany through this interconnectivity.

To *raise awareness* was another common goal among creators. This goal often had an environmental focus, with several creators reporting that they used SciArt to make audiences "think about what the environment will be like in the future" or to "foster a stronger, more sustainable, and empathetic relationship with each other and our ecosystem as a whole". Others aimed to raise awareness about less

[27] https://traceybenson.com.

obviously scientific issues, such as "global peace and love". Still others, such as Okunola Jeyifous,[28] used their art to address equity issues within science:

> I am a Nigerian-Black American man. I have lived on the south side of Chicago longer than anywhere else; however, I am a research scientist in an academic and professional world characterized by a severe lack of BIPOC representation. These experiences have reinforced in me the importance of chronicling and documenting Black stories and lives, the profound and the mundane. I have a particular interest in the latter because I think there is an under-appreciated power and complexity in the representation of these particular moments; they are humanizing and provide depth and nuanced complexity to everyday life.

In addition, several creators reported aiming to *inspire audiences* through their SciArt. Much like the *raise awareness* subtheme, the inspirations that creators hoped to evoke in others touched on a wide range of social and scientific issues. For example, some creators said they aimed to "inspire a shifted perspective on the way we view the natural world" or to "spark curiosity for soils in others". Others, such as Luciana Haill,[29] however, were more focused on inspiring people to consider venturing into art, science, or both: "I would like to work with sleep laboratory scientists and researchers with VR, Photic stimulation, MRI and mystics exploring dream telepathy in an art practice with a wide public outreach, to inspire new generations of consciousness artists and explorers".

Other creators said they aimed to *critique and problematize* the status quo, encouraging audience members to think differently about the world around them. These creators often had an "inherent desire to challenge mainstream perceptions" and felt that art was a useful tool for getting others to do the same. The questions they aimed to raise often related to the issues that they themselves were reflecting on, such as the state of the environment or the role of technology in society (as outlined in the Internal Goals section). In other cases, however, this goal had a broader focus of inspiring a different way of looking at the world. This was the case for Jody Rasch,[30] for example, who said: "There are multiple dimensions that I am trying to communicate in my work, but mostly I want the observer to begin to question what he/she believes".

Spark dialogue: finally, several creators were motivated to facilitate discussion among audience members, often as a way to foster deeper reflection or connection about the topic at hand. This motivation can be seen in comments such as, "It is essential for us to engage in the cultural issues involved with new scientific information and have all people (not just scientists) participate in an open dialogue about what it means to be alive in the world today". In some cases, sparking dialogue allowed creators to simultaneously pursue other *reach and connect* goals, such as *inspiring audiences, inviting their participation*, or encouraging them to *critique and problematize* the world around them. For example, Dana Simmons[31] reported, "My goal is to use these images to inspire people to wonder about neurons and brains. I aim to promote curiosity, questioning, and discussion".

[28] http://www.okjey.com.
[29] http://www.lucianahaill.co.uk.
[30] http://raschart.com.
[31] https://www.dana-simmons.com.

Similarly, Okunola Jeyifous[32] said: "My practice is rooted in a STEAM-based approach to visual storytelling. I view this as a novel mode of visual narrative construction, and a novel way to engage and enhance public discourse and awareness of scientific principles and research".

At times, *reach and connect* subthemes overlapped with a larger goal of *communicate science* (discussed below), with artists explaining that they used dialogue, inspiration, or other forms of engagement to share science. However, many creators who shared these goals did not mention any explicit science communication goal, as exemplified by Amy Rae Hill's[33] comment that "While I value the scientific accuracy in my work, I make choices in my work first and foremost in service of the art". That is, although scholars have often conceptualized *reach and connect* goals such as *engage or invite participation, inspire audiences*, or *spark dialogue* as science communication goals [Burns et al., 2003; Kappel & Holmen, 2019; Metcalfe, 2019], this appeared to be true for only a minority of creators in our dataset.

Reveal the unseen. Another common goal identified was *reveal the unseen*. Discussed by just over two-fifths of creators ($n = 57/131$), this theme reflected a desire to shed light on hidden aspects of reality, either literally or metaphorically. For example, Amie Esslinger[34] remarked, "In my role as artist, I… attempt to reveal hidden intricacies of our objective world, but by doing so, I manipulate the inhabitants of that world, imposing my own subjective order upon it". Neuroscientist and science artist Hannah Warming[35] similarly stated that:

> Seeing the patterns that occur naturally in the brain, like the cell layer organisations in the hippocampus or cerebellum, is a huge inspiration for my art. I want to share with people the beauty of the brain, from the perspective of someone who works with it on a single-cell level.

Also implicit in Warming's words is the subtheme *capture beauty*, which was found within 39 creator posts (30% of total dataset). Comments reflecting this subtheme emphasized a desire to use SciArt to uncover beauty, often in unexpected places. For example, Adam Cohen[36] reported:

> My favorite pieces are those that show aspects of internal anatomy since that is often hidden and considered grotesque by most people. Once it is presented as art in this indirect form it is somehow much more palatable for most viewers and in my opinion beautiful. Many people don't [or can't] see the beauty in the guts and gore, but somehow our art makes that beauty evident.

Communicate science. *Communicate science* was the least common external goal we identified, voiced by just over a third of the creators ($n = 47/131$). Creators sharing this view made comments such as "I would have never dreamed that one

[32] http://www.okjey.com.
[33] https://amyraehill.com.
[34] http://www.amieesslinger.com.
[35] https://twitter.com/NeedlesNeurons.
[36] https://www.inkedanimal.com.

day I'd be able to combine my passions to communicate science in creative ways and spark fascination for biology" (Beata Mierzwa[37]), or "My trusty laptop and the internet are my tools for research and translating peer-reviewed data into knittable pieces" (Rickie van Berkum[38]).

Within this larger theme of communicating science were two subthemes: *make science accessible* ($n = 24/47$) and *teach or share facts* ($n = 18/47$). Creators who expressed the first subtheme described SciArt as a way to invite a wider audience to engage with, relate to, or understand science in some way. For example, Tahani Baakdhah[39] reflected: "I then branched out, crocheting many science and medical models outside my field with the aim of communicating science with the public and science lovers everywhere. I want to make science accessible to everyone".

The second subtheme, *teach or share facts*, was more educational. This external goal refers to a desire to disseminate information or help audiences learn about a specific scientific topic. This can be seen in Rozan Vroman's[40] comment, below:

> I have now developed a website to showcase my work and also hopefully educate people about the structures and processes within the brain… I realized that through art I can enthuse people about science concepts and help to educate them through images. To facilitate this I provide explanations for every work on the site to reveal the science behind them and/or show how the images were made.

Internal goal themes

Creators expressed a range of internal goals related to their SciArt practice, falling generally into four overlapping themes, summarized in Figure 3 and described below.

Art as a process. Most creators ($n = 106/131$) reported that the *process* of creating SciArt motivated their practice in some way. In stark contrast to Allen Hirsh's[41] belief that "The final product is the proper measure of artistic validity, not which tools produced it", creators who expressed this theme valued the practice of art-making in its own right, irrespective of the art it produced. Responses falling under this theme were often expressed through two, inter-related subthemes: *experiment and explore* and *joy experienced while working creatively*.

Most creators for whom the *process* was an internal goal reported valuing how SciArt allowed them to *experiment and explore* ($n = 96/106$). Many of these comments included references to scientific techniques or modes of inquiry, such as Xiaojing Yan,[42] who said that "Being an artist provides me the chance to explore science". Other comments overlapped with the *art and science as two distinct disciplines* theme, such as Louise Mackenzie's[43] reflection that "…what

[37] https://beatascienceart.com.
[38] https://www.vanberkumfiberart.com.
[39] https://sciencecrochet.wordpress.com.
[40] https://wee-aye-aye.com.
[41] https://www.theabstractgardener.com.
[42] https://yanxiaojing.com.
[43] https://www.loumackenzie.com.

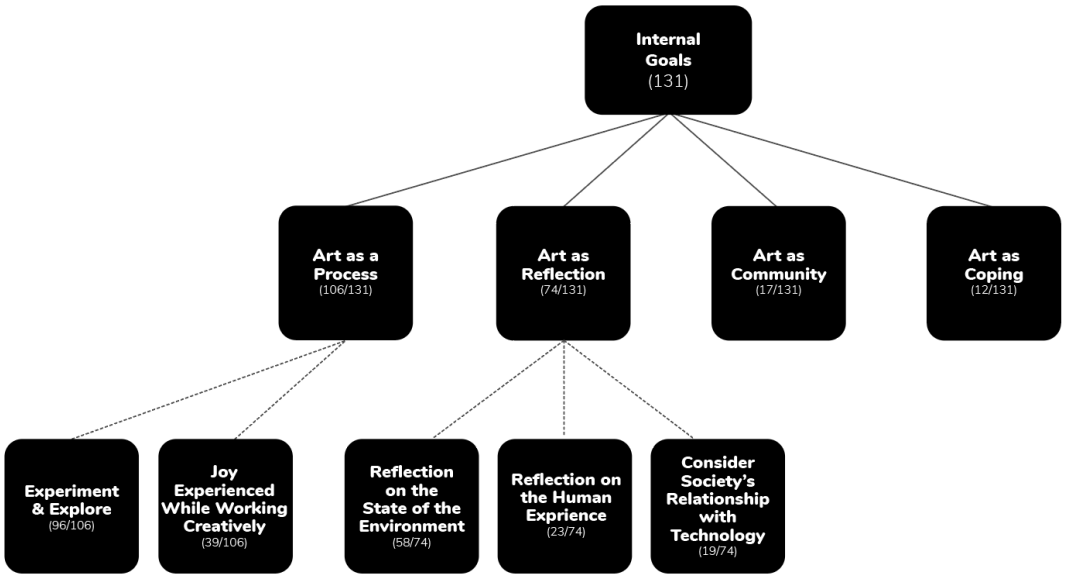

Figure 3. Thematic map of internal goals themes. Note that themes and subthemes often overlap.

distinguishes art and science are primarily different methods of learning and researching. The initial research motivations and even lines of enquiry can be similar, I think".

In addition, more than a third of creators expressing the *art as a process* theme reported that the *joy experienced while working creatively* was an internal goal ($n = 39/106$). These creators made comments such as, "Now that I'm retired I can finally go back to the joy of creating my own work" [Miles van Yperen] or, "I am always exploring new ways of creating. New methods seem to stimulate the evolution of novel ideas" (China Blue).

Art as reflection. The second most common theme relating to creators' internal goals was *art as reflection*. Expressed by more than half the creators in the dataset ($n = 74/131$), this theme reflected an appreciation for the personal questioning and reflection that creating SciArt made possible. Creators who shared this internal goal reported that they were "fueled by a fierce curiosity about the world, human nature, and how it all works together" and used "science, art, music, and literature as a means to examine human experience, the nature of opposites, and the spectrum in between". While creators sharing this goal used art to question a wide range of topics, most reported that they were motivated to reflect on at least one of three subthemes: *reflection on the state of the environment*, *reflection on the human experience*, or *consider society's relationship with technology*.

Reflection on the state of the environment was among the most common, voiced by more than three quarters of artists who valued *art as reflection* ($n = 58/74$). Comments in this subtheme often addressed topics such as climate change and environmental destruction, the role humans play in the larger ecosystem, or the interconnectedness of the natural world. For example, creators reported "exploring the intersections of nature and spirituality and the abundance of ways in which naturally occurring shapes and patterns overlap with those of sacred geometry…

seek[ing] to examine our connection to nature and emphasize our place in the cyclical and circular nature of all things". Others described "creating art reflecting the negative effects of humans on the environment" and exploring solutions for how to overcome them. While some of these reflections were critical, others were celebratory:

> The first scientific images I painted were dividing cells, and I still love painting them. The fact that this simple, constant process underlies all of life fills me with amazement and awe. From there, I gradually branched out into microbiology. I love the idea that there's this whole hidden world in us, on us and around us, and that, although the individual components are extremely tiny, together they have tremendous power. (Michele Banks[44])

Next most common subtheme was *reflection on the human experience* ($n = 23/74$). Creators who used SciArt for this purpose often drew inspiration from psychology and neuroscience, with comments such as, "I also endeavor to recreate an internal landscape, one of dreams and introspection. My images, while realistic, depict an inner reality or alternate space, inhabited by emotion as much as reason" (Michael Frank[45]). Others were fascinated by the physicality of human existence, valuing the opportunity SciArt provided to "bring our internal biological world to the forefront" (Trinley Dorje[46]). Still others were motivated to explore humanity's larger purpose, using SciArt as "a constantly evolving search for understanding who we are as humans and our relationship to the world around us".

Finally, a quarter of creators who expressed the internal goal of *art as reflection* also appreciated that their practice let them *consider society's relationship with technology* ($n = 19/74$). Many of these comments reflected concerns about planned obsolescence, artificial intelligence and other forms of machine learning, or the growing role of biotechnology in daily life. For example, Angela McQuillan[47] related, "I think that biotechnology is advancing so quickly that it is really important for artists to interpret these developments in order to create a dialogue around what our collective future holds". Others described "explor[ing] how interactive technological systems can relate to human beings and their sensory capabilities, behaviors, and communications". Still others shared that "Biology, genetics, microbiology, biotechnology, and genetic engineering all relate to my art practice. My art uses materials and techniques, explains, and looks at ethical concerns in these areas of science".

Art as community. A more minor theme, 17 creators (13%) described developing community support or connection as something they valued about creating SciArt. This theme was, in many ways, the extension of the journey theme of *discovery through personal contacts*, which, as described above, relates to the powerful role that community members can play in motivating an individual to start creating SciArt. However, for creators expressing the *art as community* theme, the opportunity to connect with other science artists did more than inspire them to start their creative practice; it motivated them to *continue* creating SciArt in the long term. As Julio

[44] https://www.artologica.net.
[45] https://www.behance.net/MichaelFrank.
[46] https://www.instagram.com/tdorjeart/.
[47] http://angelamcquillan.com.

Lacerado[48] said, "ever since I became involved [in paleoart], I've had the pleasure of seeing new names pop up every now and then. They keep inspiring me and showing how our community is evolving".

Art as coping. Finally, about a tenth of the creators ($n = 12/131$) described SciArt as a coping mechanism. These creators reported that SciArt helped them deal with difficult experiences, such as Yamina Pressler,[49] who "started painting with watercolour in 2019 in an effort to reduce my plane anxiety", or Lia Pas,[50] who became ill with myalgic encephalomyelitis and "started embroidering my neurological sensations of pain and paresthesia as a way of both better understanding them and as a practice of 'exquisite attention', which made them feel less disruptive and less painful in my day to day". As exemplified by the quotes above, the difficulties that creators coped with using SciArt were broad ranging, spanning physical, mental, an emotional challenges.

Discussion

In an introduction to a special issue on art and science, Ball [2018] highlights the diversity of goals associated with SciArt, arguing that it is futile to "make broad generalizations about the purposes, procedures and value of interactions between science and art" [p. 2]. This argument is partially supported by our findings. Through a qualitative analysis of 131 interviews with practicing science artists, we identified a wide range of experiences that led these creators to pursue SciArt, and an even wider range of internal and external goals related to their work. However, we also identified common themes that were shared by many of the creators. While some of these themes overlap with those found in prior research — including science communication literature — others extend far beyond information dissemination. Some creators described SciArt as a valuable mode of communication, but many also focused on its usefulness as a strategy for coping with hard times, a tool for inspiring audiences, a space to reflect and ask questions, and an enjoyable creative process. Below, we highlight ways in which these findings align with and diverge from those found by other scholars, and identify implications for scientists, science communicators, funders, and others seeking to work with or support science artists.

One takeaway from this study was the valuable role early life experiences and informal learning can play in motivating individuals to pursue SciArt. Although the creators in our dataset shared multiple and varied stories of how they first became involved in the craft, many of these narratives were united by a shared starting point: childhood. These SciArt journeys were often sparked by experiences with the natural world or by interactions with parents, teachers, and other influential personal connections. Previous scholarship has similarly found that personal relationships can be important sources of support and inspiration in SciArt projects [Oliveira, 2015], although some creators seek to supplement these personal resources with training or institutional support [Agostinho & Casaleiro, 2015].

Formal education in science, art, or both *was* important for many creators. Still, for others, academic experiences acted as barriers rather than facilitators of their

[48] https://twitter.com/JuliotheArtist.
[49] https://yaminapressler.com.
[50] http://liapas.com.

creative journeys. Several creators recalled having to choose between art and science upon entering university — most often due to rigid educational structures, social pressures, practical constraints, or some combination of these factors. Creators also said that, at some point in their life, art and science had been presented as two distinct, or even incompatible, disciplines, echoing Collver and Weitkamp's [2018] finding that science comic creators often feel trapped between "two worlds" and experience challenges working and learning at the "grey, blurry" intersections of their dual passions [p. 11]. While creators in this study eventually found ways to reconcile their interests, funders and universities wishing to support the development of SciArt could introduce more educational programs offering training in both art and science or provide additional financial support for science artists pursuing self-directed study (e.g., through grants, residencies). Our analysis suggests such opportunities for learning should not be restricted to the post-secondary level; workshops or mentorship opportunities could be introduced early in life, when interests in art and science appear to flourish.

In addition, our research identified a range of external goals, many of which align with those found in prior research, including goals to reveal overlooked beauty [Parks & White, 2021] and to critique and problematize [Catts & Zurr, 2018]. A subset of creators also expressed clear science communication goals, such as teaching or sharing scientific facts and making science more accessible [Burns et al., 2003], in line with some previous research into SciArt goals [Collver & Weitkamp, 2018; Parks & White, 2021]. Others shared goals that have traditionally been conceptualized as science communication-related, such as raising awareness, sparking dialogue, inspiring audiences, or encouraging participation [Kappel & Holmen, 2019; Metcalfe, 2019]. However, unlike many science communication initiatives, these more "dialogic" goals did not always have an underlying focus of promoting the cultural authority or value of science [Wynne, 2006]; instead, many creators seemed to see participation, conversation, inspiration, and self-reflection as ends in themselves. Whether or not audiences ended up with a better understanding, or more positive view of science was often an afterthought, if it was mentioned by the creators at all.

Importantly, this finding does not mean that all SciArt creators are unwilling to work on science communication projects. Indeed, about a third of the creators in our dataset shared warm memories of working with scientists or institutions in the past, and many expressed interest in participating in future science communication work. Rather, a key takeaway from this research is that different creators make SciArt for many different reasons, some of which may align with those of scientists or science communicators, but some of which may not. To ensure success in science communication initiatives involving artists, project managers would do well to start such collaborations with an honest conversation about the internal and external goals of all participants, including artists [see Halpern & O'Rourke, 2020]. Paired with ongoing efforts to ensure those goals are met, such conversations could pave the way for more mutually beneficial, successful collaborations.

Another important finding from this study was the rich and varied internal goals that motivated creators to produce SciArt. Among these, the value of the artistic process was a dominant theme, with many creators using it as a mode of exploration and experimentation, a method of inquiry and learning not unlike the scientific process. These goals echo findings from Sleigh and Craske [2017], who

similarly identified parallels between scientific research methods and artists' descriptions of their creative practice. They also align with results from other studies finding that many creators use SciArt to explore, learn, and reflect on themselves and the world around them [Benjamin, 2020; Catts & Zurr, 2018; Glinkowski & Bamford, 2009]. Just as in Sleigh and Craske's analysis [2017], many creators in our sample expressed joy and fulfilment in creative practice itself — valuing the artistic process equally, or perhaps more, than the outcomes it produced. Individuals or organizations who hire SciArt creators could support these goals by budgeting in additional time for creative exploration and experimentation. Doing so may not only lead to more mutually fulfilling collaborations; it could also produce SciArt that is more critical and unique than what is often possible under tight time constraints.

Finally, our results depart from those found in existing research by uncovering other important internal goals related to SciArt creation. Several creators described a sense of community with other science artists as motivating their creative practice; they used SciArt to connect with and learn from like-minded people. Others reported using art to cope with personal hardships — to deal with mourning, anxiety, illness, and other challenging experiences. Creators also used SciArt to reflect on the world around them and on themselves: to think critically about the changing environment and their role within it, the mysteries of the human mind and body, and the risks and opportunities of society's evolving relationship with technology. Scholars studying SciArt creators may wish to examine these and other internal goals alongside external goals, such as those often found in science communication literature. These internal goals could also be used to inform public outreach efforts, as they suggest that creating SciArt can be emotionally and socially rewarding.

Limitations

This study has several limitations that should be noted when interpreting the findings. First, although the sample of interviews we analyzed is much larger than seen in previous qualitative work on this topic, it is not necessarily representative of all SciArt creators. While we did not analyze the demographics of the creators we studied, the blog posts from which these interviews were drawn may be biased towards artists from particular backgrounds, which may have skewed our results. It should also be noted that ATS is non-partisan and non-political; activist artists (and their goals) are not represented in the dataset. Moreover, this study focused primarily on creators of visual SciArt. Science artists who use other types of creative expression, such a performance art, may hold different perspectives than those expressed by the creators in this study. In addition, because we did not conduct the interviews ourselves, we were not able to ask follow-up questions. As such, while we were able to measure the presence of certain themes in creators' responses, the absence of these themes for any creators does not necessarily indicate that they *did not* relate to the theme; rather, they may simply not have mentioned it in their interview with ATS. Future research using complementary methods, and more representative samples, is needed to confirm the extent to which the themes identified in this study are universal among SciArt creators or specific to the present sample and method.

Conclusions

SciArt intitiatives are increasingly recognized for their potential to engage publics in creative ways, encourage critical reflection and dialogue, and make scientific knowledge more relatable. This study aimed to support the work of SciArt creators by building deeper understanding of the creative journeys and goals that motivate them to pursue this interdisciplinary craft. We find that the paths that lead creators to start making SciArt, and the goals that encourage them to continue doing so, are as rich and varied as the art they produce. Scientists, institutions, funders, and other organizations seeking to support science artists or incorporate SciArt into public outreach efforts should ensure they offer opportunities for creators to fulfil both internal and external goals. Doing so could be an important step towards supporting more mutually rewarding collaborations and, ultimately, a more vibrant SciArt landscape.

Conflicts of interest statement

Both AF and JK are, or have, volunteered with Art the Science (ATS) in the past: JK as the founder and a former blog contributor, AF as a former research officer, board member, and blog editor. PJ declares no conflicts of interest.

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