

Purposeful Pursuits: Leveraging the Epistemic Practices of the Arts and Sciences



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The object of art is to give life a shape
Jean Anouilh

1 Introduction

Decades of research make clear that purpose and meaning are essential to learning (NRC 2012a). Purpose and meaning drive our interests, questions, and persistence; they urge us to branch out and go deeper. They are central to both being and becoming: reflecting and also shaping our identities as individuals, or as members of communities, who value and know a place, a practice, a domain of objects, a body of knowledge.

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Purpose is highly personal, cultural, and contingent. It can ebb and flow over time. It develops from opportunity and it also creates opportunity. Purpose emerges when individuals recognize, and are recognized for, opportunities to participate in, contribute to, and transform social activities that have meaning and value to the learner (Stetsenko 2017). Implicit in this vision is the idea of entering into and becoming an integral part of communities of practice, with opportunities to observe expertise, to practice one's skills, to develop and float one's ideas, while becoming more and more central participants in the valued activity, including coming to re-define or reinvent the activities themselves (Lave and Wenger 1991).

For decades, research on the arts and education has documented the ways in which the arts create personally meaningful contexts for young people to develop a sense of purpose and therefore of self (e.g., Greene 1977). At the heart of these arts activities are opportunities for the creative production of something—whether temporal, virtual, performed, displayed, or gifted to an authentic audience. The value of creative production with authentic audiences has been explored, for example, in theatre (Heath 2000), gallery exhibitions (Smith 2014), community arts projects (Kafai and Peppler 2012), storytelling and poetry (Soep 2006), and, more recently, in maker communities (Bevan 2017).

Purpose also sits at the heart of current science educational reform movements in the USA. State science standards, adapting the National Research Council's consensus volume *K-12 Framework for Science Education* (NRC 2012b), emphasize the practices of science, such as identifying questions, using computational thinking, creating and using models, and arguing from evidence. These reforms hold that engaging students in science, technology, engineering, and mathematics (STEM) practices creates authentic and purposeful contexts for deeper engagement in and with STEM—driven by questions or needs identified by the learners—leading to greater STEM learning as well as to the development of productive STEM learning identities (Berland et al. 2015).

But many young people face significant economic, cultural, historical, and/or social obstacles that distance them from STEM as a meaningful or viable option—these range from under-resourced schools, race- and gender-based discrimination, to the dominant cultural norms of STEM professions or the historical uses of STEM to oppress or disadvantage socio-economically marginalized communities (Philip and Azevedo 2017). As a result, participation in STEM-organized hobby groups, academic programs, and professions remains low among many racial, ethnic, and gender groups (Dawson 2017). One solution to this imbalance has been to reposition STEM as STEAM—integrating the arts and design in ways that can have wider appeal to a broader cross section of young people. Integrating the arts and sciences is not only a strategy for broadening appeal, it also reflects the ways in which participation in civic, academic, and professional activities is becoming increasingly hybridized, requiring communication, design, and technological skills. A STEAM approach to broadening participation or inclusion can be relevant across the four distinct “discourses of equity” that Philip and Azevedo (2017) posit underpin research on equity in out-of-school STEM. They argue that equity in informal STEM education is seldom articulated but variously conceptualized as (a) supporting student achievement in school STEM, (b) building student STEM learning interest

and identity through more authentic engagement with STEM, (c) democratizing STEM by locating its presence and uses in everyday life, or (d) understanding how STEM can be taken up by social justice movements as a tool for achieving transformation and change. How informal STEM programs advance equity can thus vary widely, depending on their conceptualization of equity.

As STEAM becomes more deeply theorized, it may be valuable to consider the evidence base that suggests that engaging in the epistemic practices of a discipline will lead to deeper disciplinary learning and more productive learning identities (e.g., see NGSS or Common Core in the USA). In other words, integrating purpose and meaning into engagement with the disciplines links epistemological and ontological processes of development. Further, an epistemic approach (unlike a concepts-based approach) is potentially relevant across the four distinct discourses of equity articulated by Philip and Azevedo; i.e., it can enrich programs focused on STEM school achievement as well as those concerned with broader social transformation. But what are the epistemic practices of the “discipline” of STEAM?

2 Background and Rationale

In this section we briefly describe what research says about epistemic practices in science and art and explore what these findings might mean for theorizing and enacting STEAM programs that can advance youth purpose and agency.

2.1 *Epistemic Practices in STEM*

In STEM fields, there is a long history of promoting hands-on, problem-based, and inquiry-based learning (Driver et al. 1994). More recently, improvement efforts in the USA have begun to focus on the epistemic practices of these disciplines (NRC 2012b). These reforms emphasize the ways that professional scientists, mathematicians, technologists, and engineers use disciplinary practices, such as evidence-based reasoning, to answer specific questions or solve specific problems. The reform movement posits that students can develop deeper understanding of and about science by using these same practices toward purposeful ends. For instance, students develop conceptual understanding as they engage in epistemic practices to explore local environmental problems, understand community patterns of health and wellness, or design computer games or mobile applications.

Implicit in this approach are two ideas. One is that purposeful learning provides opportunities for deeper learning (NRC 2012a), and another is that by engaging in STEM practices, young people may come to value STEM in the same ways that practicing STEM professionals do—not by reading about it, but by doing it for an authentic purpose (NRC 2012b). This strategy may be especially important for STEM programs that seek to engage learners from communities that have been historically excluded from STEM.

The National Research Council's (2012b) *K-12 Framework for Science Education* identified eight practices related to science and engineering. These practices describe how scientists and engineers build knowledge about the natural and designed world. To help educators, researchers have organized these practices into three conceptually manageable clusters of activities: investigating, sense-making, and critiquing practices (McNeill et al. 2016). A critical distinction between practice-oriented approaches to STEM learning and prior instantiations, such as inquiry-based learning, is an emphasis on the critiquing phase of STEM learning (Engle and Conant 2002). Prior inquiry-based reform efforts focused on the investigating and sense-making phases, but often were organized in ways that, intentionally or not, omitted explicit attention to scientific argumentation—i.e., negotiating between competing explanations through critiquing the nature and validity of evidence marshalled to support explanations—as well as to connecting explanations with a larger scientific discourse related to the scientific phenomena being explored. This key aspect of STEM sits at the heart of peer review processes.

2.2 *Epistemic Practices in the Arts*

Three broad concepts are important to epistemic practices in the arts: (1) active engagement in the learning process; (2) youth's personal connection to their work, which is posited to inspire a general love of learning and build upon their prior experiences; and (3) the creation of projects that are of value to a larger community. These concepts connect to both sociocultural theories of learning and theories of the arts and aesthetics (Greene 1995; Dewey 1934/1980). Arts learning focuses, on one level, on the design of artifacts rather than on the use of artifacts and tools, and, on another level, it focuses on the bidirectional relationship between an individual and a community of learners. According to Dewey, "[a]rt denotes the process of doing or making," and provides a tool by which we search for meaning (1934/1980, p. 47). Being active in the learning process is important to current conceptions of what it means to be motivated and to engage deeply in the content.

Kafai and Peppler (2011) have investigated the epistemic practices of youth's creative production, illuminating how youth engage in multiple literacies and diverse forms of authentic participation as they engage in interest-driven projects (New London Group 2006; Guzzetti and Yang 2006; Lankshear and Knobel 2011). Their work provides a holistic vision of visual/media culture, new technologies, and traditional art making, and identifies ten practices relating to full participation in communities built around creative production. These ten practices are organized into four clusters of activities: technical, critical, creative, and ethical practices. Technical practices in the arts relate to crafting within the medium selected for a piece, which determine medium-specific skillsets such as coding, debugging, and repurposing of materials. Artists engage in critical epistemic practices—observing and deconstructing media, evaluating or reflecting (i.e., critique), referencing and reworking—as they strive for originality or to thoughtfully break from tradition.

Creative practices, perhaps the most well known in the arts, involve making meaningful and artistic choices (e.g., pertaining to color theory, shape and contour, musical instrumentation, etc.) to transform the intended “meaning” of a piece, or to forge connections between various modalities in contemporary work. Lastly, a range of ethical practices has emerged in the arts around ownership and information. This expanded palette of previously conceptualized practices surrounding participation in the arts includes a broader spectrum of design activities important to contemporary practice, as well as youth culture.

2.3 STEAM: Intersections Between the Arts and Sciences

The promise of STEAM approaches is that by coupling STEM and the arts, new understandings and artifacts emerge that transcend either discipline. Evidence of this potential can be seen through fundamental shifts in both fields. The infusion of the arts into STEM has shown to be transformative, for example, with the emergence of tools and communities that not only engender new content understandings but also invite participation from populations historically underrepresented in STEM fields (Peppler 2013). Similarly, the use of STEM tools and data in the arts have created important bodies of work for artists exploring intersections of the natural and social worlds.

In the UK, Ireland, and Europe, the evolution of the field of art-science (the field in which art and science overlap), particularly in the last 10 years, has been socially and culturally significant. Science now appears in places and spaces ranging from galleries like the Wellcome Collection and Science Gallery Dublin to culturally arts-oriented festivals such as Latitude and Secret Garden Party (Bultitude and Sardo 2012; Dowell 2014). Scientifically embedded arts programs ranging from Collide@CERN and a subset of science festivals (von Roten and Moeschler 2007) represent one end of a spectrum, while hybrid programs like Ars Electronica and Waag Society occupy a more central position. Growing out of the Wellcome Trust’s SciArt funding scheme started in the mid 1990s (Glinkowski and Bamford 2009; Born and Barry 2010), art and science programming has moved from a more academic realm into a public space. This work has not instrumentalized the arts or science, but rather sought out a rich, fertile space for producing compelling cultural events and programming through a collaborative-practices approach. Art-science approaches speak to contemporary social, political, and economic concerns demanding transdisciplinary platforms and methods of working that allow for professionals, particularly in science, health and technology, to conceptualize their subject expertise through a broad thematic approach, as opposed to a discipline-specific perspective. Art-science programs have demonstrated the strong effects that such approaches can have on learners—removing them from specific identities of the “artsy” or “mathsy” person and placing them in a context that is purpose driven, offering an opportunity for creative and flexible thinking that maps onto their key concerns.

Increasingly this work is being developed in the USA, supported by organizations such as the Sloan Foundation, the Simons Foundation, and others.

Despite the promising aspects of this work, practice is well ahead of educational research in the context of STEAM. As this volume illustrates, there are many examples of exceptional STEAM or arts-and-sciences programs for young people. But there are also many examples, not detailed in this volume, of programs that style themselves as STEAM but do not do so in any deeply theorized way: in these programs, science activities may have some decorative tasks attached, or arts activities may integrate scientific phenomena, such as color mixing or electrical circuitry. But the epistemological and conceptual aspects of the “added” discipline—for example, the use of evidence-based reasoning in science programs, or of performance and critique in arts programs—typically are left unexplored.

In the next section we describe an approach being taken by an international collaboration of educators and researchers to better understand and theorize the ways in which the thoughtful integration of the epistemic practices of the arts and the sciences enrich learning in both areas, while supporting ontological processes for young people from economically and racially marginalized communities (Bevan et al. 2018; Bevan and Scarff 2015; Peppler and Wohlwend 2017).

3 A Framework for the Intersection of Epistemic Practices in the Arts and Sciences

Funded by joint grants awarded by the National Science Foundation in the USA and the Wellcome Trust in the UK, our study sites include Science Gallery Dublin, a public museum space at the intersection of science and art that targets young adults; Guerilla Science, a program based in London and New York that stages art and science events in unexpected settings, such as music or arts festivals serving primarily young adults; Youth Radio in Oakland, a program serving older youth in which participants explore contemporary issues and produce nationally aired radio segments and various digital platforms; WacArts, a London-based secondary school specializing in the arts; and the Boys & Girls Clubs of Indiana’s summer Maker camps, serving young children and tweens. All of these programs are free and serve youth from marginalized communities. As such, they work with youth over time and collect demographic data about participants. Guerilla Science is an exception given its focus on situating programs in live festivals or street-corners.

The underlying sociocultural theory guiding our work conceptualizes learning as a process that develops in supportive and responsive communities in which youth’s cultural, intellectual, and emotional resources are recognized and leveraged as they participate in purposeful and consequential activities (Nasir et al. 2006). Under these conditions, youth exercise and expand their agency, key to the development of productive learning identities (Holland et al. 1998). As such, we are using a framework (see Table 1) that builds on the work of the National Research Council’s

Table 1 A framework for epistemic practices of the arts and sciences

STEM practices	Epistemic intersections	Arts practices
<i>Investigative practices</i>	<i>Exploratory practices</i>	<i>Technical & critical practices</i>
<ul style="list-style-type: none"> • Asking questions/defining problems • Planning and carrying out investigations • Using mathematical and computational thinking 	<ul style="list-style-type: none"> • Noticing and questioning • Exploring materiality • Defining the problem space/deconstructing components • Producing tentative representations 	<ul style="list-style-type: none"> • Looking closely • Deconstructing the parts of the text (at a literal level) and the meaning behind the text
<i>Sense-making practices</i>	<i>Meaning-making practices</i>	<i>Creative practices</i>
<ul style="list-style-type: none"> • Developing and using models • Analyzing and interpreting data • Constructing explanations/designing solutions 	<ul style="list-style-type: none"> • Principled iterations/revisions (responding to feedback) • Considering multiple approaches • Engaging multiple modalities • Finding relevance • Adopting a critical stance 	<ul style="list-style-type: none"> • Applying artistic principles to augment meaning • Designing interrelations within and across multiple sign systems • Referencing or combining existing works and ideas
<i>Critiquing practices</i>	<i>Critiquing practices</i>	<i>Ethical practices</i>
<ul style="list-style-type: none"> • Arguing from evidence/peer review • Evaluating and communicating findings 	<ul style="list-style-type: none"> • Sharing results • Hacking the ideas of others • Engaging in critical reviews • Cultivating dissent • Holding commitments to standards of the field 	<ul style="list-style-type: none"> • Negotiating what constitutes a “good” project • Given a particular artistic goal, evaluating how successfully this goal has been met

(2012b) *K12 Framework for Science Education* and of Kafai and Peppler (2011). Through this framework, investigators can explore how engaging in the socio-historically purposeful epistemic disciplinary practices of arts, sciences, and arts-and-sciences (STEAM) advances purpose, agency, and learning for young people from communities historically excluded from STEM and other domains of privilege.

The intersection of these epistemic practices is central to many STEAM-based programs (Bevan and Scarff 2015). For example, Maker programs, involving activities such as e-textiles or kinetic sculptures, entail exploring materiality, producing tentative representations, collecting and responding to feedback, and revising plans and products (Peppler 2013; Bevan 2017).

Digital production programs, such as Scratch (www.scratch.mit.edu), integrate processes of planning and designing, deconstructing components, responding to feedback, and critiquing and explaining within the Scratch community (Resnick and Rosenbaum 2013). Media-related programs, such as Youth Radio, integrate noticing and questioning, collecting data, developing representations of understanding, responding to feedback and critique, and producing and communicating evidence-based explanations (Chávez and Soep 2005).

To illustrate: at one of our study sites, to mark the 60th anniversary of the desegregation of Central High School in Little Rock, Arkansas, a group of present-day Central High students contacted Youth Radio in Oakland, California, to create a

social media reenactment of that historic day. With interviews, hand-drawn illustrations, and archival tape and photos from the original Little Rock Nine (LR9), the young people issued this provocation: If Twitter had been available in 1957, how would the Little Rock Nine story have unfolded? Also, how do the themes and conditions of the original Little Rock Nine remain relevant to racial inequality and school resegregation today? With this premise as a starting point, the teams in Oakland and Little Rock designed and coded a website from scratch, programmed a live Twitter reenactment and produced a story that aired on National Public Radio. They went through several iterations for the design of the final site as well as individual assets—for example, using illustration software and data tables to meticulously match hand-drawn portraits of the original “Nine” to archival and contemporary photos. Youth members of the various teams reviewed and critiqued one another’s work and devised ways to showcase the strongest materials to bring the past alive while connecting that history to data on racial divisions and disparities in education today.

In another example, every quarter, Science Gallery Dublin transforms its entire exhibition and education programming to focus on a broad theme, such as HUMANS NEED NOT APPLY (artificial intelligence), SECRET (data, privacy and encryption), IN CASE OF EMERGENCY (global challenges through trope of apocalyptic literature). The future-facing topics are chosen so that they can be interrogated by artists, scientists, humanities scholars, and designers. As a part of this work, the museum invites groups of 17–18-year-old “Transition Year (TY) students” to spend a week at the museum developing public programs related to the new theme. These students are predominantly from second level schools that are traditionally under represented in undergraduate student intakes in Irish universities. Students engage with scientists and artists working on the theme, and begin developing their own project. For example, for IN CASE OF EMERGENCY, the museum created a Situation Room in which visitors were presented with a realistic, potentially catastrophic situation such as a viral outbreak or a tsunami. The TY students worked with the researchers and designers to develop, test and adapt the gameplay of the Situation Room. They started by looking at the established game “Cards Against Humanity,” critiquing and understanding the gameplay. This was followed by a deep immersion into the themes of the exhibition through Q&A sessions with curatorial advisors and researchers. In this process, participants came to grips with some of the global challenges we face, from viral outbreaks to climate change, and they began to develop scenarios based around these issues. This learning was then mapped onto critiquing and developing the gameplay developed for the IN CASE OF EMERGENCY Situation Room.

As these examples show, such approaches have authentic audiences and consequential purposes. They integrate a range of investigatory, sense-making, and critiquing processes in the context of the creative production of, in one case, a radio segment and website and, in the other case, a museum experience. We follow this overview with two short examples from our early work in the field that may better illustrate the ways in which epistemic practices emerge, interweave, and hybridize in arts-and-sciences programs. While we chose these examples because they high-

light a particular cluster of practices, we also note that other arts, STEM, or STEAM practices co-occur in these activities, which are not reflected here. We also argue that while these new types of epistemic intersections frequently occur in this work, it would be unlikely to find all of them well represented in any one STEAM activity. Rather, these examples serve to highlight and illustrate our emerging understandings.

3.1 Example 1 – STEAM-Rich Tinkering in a Weekly Afterschool Youth Program

At the Sunshine Public School (an alias) afterschool Making and Tinkering program (conducted in partnership with the Exploratorium Tinkering Studio), young people explore various physical materials as they engage in everyday versions of “engineering practices” to design and build contraptions of various types. Participants develop design goals inspired by the available materials as well as examples of prior work shared in the introduction of the activities. Negotiating form and function is at the heart of tinkering. Students’ initial aesthetic goals inevitably lead to cascading sets of unforeseen constraints forcing improvisational problem-solving and generating new possibilities and ideas. This iterative process may be more reactive and less scripted than most formalized engineering processes, but it similarly involves optimizing performance while maintaining commitments to particular (often evolving) aesthetic goals and design solutions.

An example of this back-and-forth in artistic and scientific/engineering practices of creative production can be found in the story of a young, teenage student, Stephan. We documented Stephan, during a weekly afterschool program, as he designed a marble machine: a 5-foot peg board on which one builds a series of ramps and tracks that can guide a marble’s journey from the top to bottom of the board. At the onset of this activity, Stephan developed an aesthetic goal, unique to him among his classmates, to use both sides of the peg board to make the marble’s pathway that much longer and therefore that much slower than it would be otherwise (Bevan et al. 2018). His personal solution to the challenge of slowing the descent created a unique set of challenges that other students didn’t have to negotiate: at the points where he tried to connect the tracks at the front and back of the board, the marble frequently shot off to the side, or got caught at the joints of connecting ramps. Stephan experimented with many materials and methods for rounding the edges of the board before deciding to use a Slinky as a tunnel that could curve around the board. This elegant solution addressed one problem, but it created a new one: the Slinky’s sagging coils created dips or valleys that caught the marble. Stephan needed to create a dense network of supporting dowels to prop up the Slinky at key points. Inspired by the demonstration model shared by the facilitator, he explored how different fabrics could be used to line the track and slow the marble further. Through principled iterations, he discovered that the most textured fabrics slowed the marble

the most. Finally, when he placed a metal bowl at the bottom of the ramp to catch the marble, he was surprised by the delightful ring the marble made when it dropped into the bowl. This unplanned discovery led him to go back to the top of the peg board and add metal objects throughout so that the marble's journey became a sound installation as well.

In this STEAM activity we can see epistemic practices of both art and science, as well as a hybrid form inherent in tinkering. Engineering practices included designing solutions, testing and optimizing solutions, and later communicating results (NRC 2012b). Aesthetic practices included looking closely, augmenting meaning through aesthetics (as in the case of the wrap-around track), and even evaluating the success of the project exemplified by his decision to add musical elements to the entire project (Kafai and Peppler 2011). The integrated or hybridized practices of tinkering involved iterative but not necessarily systematic experimentation. Choices were purposeful, and frequently made in response to aesthetic goals. Through these iterations, Stephan engaged with scientific concepts (such as velocity and friction) and gained intuitive feelings for the properties of materials and phenomena that could serve as the foundations for more formalized sense-making experiences. His positive experience may also inspire interest in taking up such formalized experiences in the future. In the example we provide here, sense-making is implicit. The classroom was organized so that young people could observe each other's work, and choose to adopt or adapt particular solutions (Petrich et al. 2013). Facilitators also led student share-outs on a regular basis. These processes allowed students to collaboratively engage in various forms of sense-making about the materials they were investigating or the design practices they were undertaking. The educators introduced forms of criticality by taking students on field trips to visit and speak with local artists who worked with similar materials or mechanisms (Ryoo et al. 2016). In addition to conveying a sense of standards in the field (what professional uses of the same materials or skills looked like and led to), field trips operated to expand horizons by making connections between the students' afterschool experiences and related professional pathways.

Not as evident in our example is the articulation of evidence-based reasoning. However, we posit that its use may be implicit in the evolution of the increasingly optimized as well as aesthetically embellished marble machine. Where evidence-based argumentation is seen as a key aspect of STEM practices, in the context of making, the ways in which productive strategies for getting objects to work are taken up by others could perhaps represent an implicit form of scientific argumentation. Our example of Stephan adopting the method to lining tracks with fabric might suggest that he accepted this "solution" as a better strategy than others to slow down the marble. More specifically, it suggests that Stephan accepted the implicit "argument" that rough materials could create friction that would reduce the marble's velocity. On this view, hacking the ideas of others might serve as an active, embodied form of argumentation. This implicit understanding could be made explicit through the guidance of the afterschool educator.

3.2 Example 2 – STEAMY Science Engagement at a Music Festival

Based in London and New York, Guerilla Science offers public engagement with science events that target young adults. They do this primarily through arts events (e.g., concerts, exhibitions) that feature scientific phenomena or through science events (e.g., interactive talks, hands-on activities) held at music, arts, or street festivals. In their science communication activities, the program draws from theatrical practices of cabaret, alternative comedy, and masquerade to stimulate curiosity and immerse their audience in a kind of “figured world” where the nature of scientific questions, evidence, and knowledge is explored and made concrete. At a camping music festival targeting young adults, these immersive and interactive engagements with scientists address topics such as the science of sexual attraction, the role of celebrity in social behavior, knowing your biome, or the effects of psychedelic drugs on the brain. Both in their choices of topics and in the high production quality of their presentations, Guerilla Science signals to its audience that science is a journey, and it invites audiences to learn about and join this journey.

An example of how Guerilla Science interweaves arts and science practices in the festival format comes from the fourth day of a music festival held over a long weekend in the English countryside. A scientist, wearing a mini dress, striped stockings, and a bowler hat—i.e., looking like the other festival goers (and indeed she had spent 3 days camping out at the festival)—introduced herself to the 100 or more people draped about the lounge chairs in the performance tent.

I am a psychology researcher—a psychology lecturer—at the University of [X]. And I am also really passionate about dreaming. And I do my academic research on dreaming. So I am what they call an “oneirologist,” which comes from the Greek word *oneiros*, which means dream. And I am also an oneironaut, which means I am a dream explorer or a dream investigator or a dream traveller, something like that.

In the interactive presentation, creative production is largely the work of the scientist drawing on elements of dramatic narrative to create a sense of intimacy with the audience that invites them into the social and cultural world of science. In this presentation about the science of lucid dreaming, the dream researcher’s scientific narrative integrated personal descriptions of her own lucid dreaming, including flying to explore another planet or watching her face melt in the mirror. She described compelling reasons for why lucid dreaming might be of interest to those in the tent, including providing the opportunity to fly, to have sexual relations with people not normally available (such as celebrities), to improve one’s musical skills through practice drills in one’s sleep, or to engage in psychic and even physical healing. Thus, through interweaving personally relevant connections with the story of how lucid dreaming was being pursued as a scientific process, she engaged the audience in how questions of relevance guide processes of scientific inquiry.

Scientists who work with Guerilla Science typically stress the tentative, emerging, contested, and socially relevant nature of the scientific enterprise:

It may surprise those of you that are lucid dreamers that it wasn't until about 50 years ago that the scientific community actually agreed that it was a real phenomenon. ... [Until then it] was viewed very skeptically almost like fringe science, like pre-cognitive dreams or tarot, or these kind of what's considered New Age things. But somebody developed a really ingenious way to show, beyond doubt, that lucid dreams are a real phenomenon. ... They got [a group of lucid dreamers] to go sleep in the Lab. They were hooked up to EEG machines, which means that they're measuring their brain wave activity on the scalp. They were also hooked up to EOG, so you could measure the activity of the eyes. And EMG, which is measuring the activity of the muscles, which is usually on the chin. And the reason that's important is that because using the brain waves and the muscle activity we can tell when somebody is in rapid eye movement sleep [or deep asleep]. [Using these machines, the scientists were able to capture a] signal that [the lucid dreamers had agreed they] would show them to indicate that they were ... [both asleep and also] lucid dreaming, [by moving] their eyes in [a] deliberate way that show[ed] that they were [both asleep and aware that they were asleep because they were in a dream].

The scientist presented and described data representing eye movement of an awake and a sleeping person. She resumed her description of the experiment:

... The brain wave activity was showing beyond doubt that they were asleep. And the muscle paralysis was showing that they were asleep. [But the agreed upon eye movement signal also showed that they were conscious in their dreams: They were lucid dreaming.] So 50 years ago they were able to prove that lucid dreaming is a real phenomenon and that's when the research really started to take off.

After describing further benefits of lucid dreaming, she closed her account with the following description of the tentative and contested nature of scientific knowledge:

... Finding out the kind of outer limits of what our imaginations can do, which is what we can do with lucid dream research, is a worthy thing to do and needs to be researched... And the last thing I am going to mention is pre-cognition. There are some researchers that think that precognitive dreams are most likely to happen, if they exist, in lucid dreams. So a precognitive dream is when you can foretell the future in a dream. And a lot of people, many many people, think that they have these kind of dreams. It's very controversial in the scientific world because a lot of people have found very good evidence that they do exist and a lot of people have found evidence that they don't. So it's kind of—we're undecided.

In her 15-min narrative, she thus invited the audience to hear about and care about how scientists employ the epistemic practices of science, including developing a question, designing a valid experiment, engaging in evidence-based reasoning. She then engaged them in an activity to induce hypnagogic sleep—a state of dreaming while still awake—essentially turning the audience's own bodies into experimental apparatus to explore some of the ideas she had presented. Afterward, the audience engaged in a sense-making process, where they informally shared the results of their attempts to hypnagogically dream, and asked additional questions relevant to dreaming and lucid dreaming.

This art-and-science event—leveraging the fantastical and transgressive aspects of a cabaret ethos at a music festival, while engaging the audience with current science—integrated hybridized STEAM practices in several ways. Science is both wondrous (e.g., enabling flying through lucid dreaming) and evidence-based, as illustrated through the laboratory experiment described by the scientist. This juxtaposition operates to trigger an emotional openness that can enhance audience

engagement with scientific explanations. Her presentation used multiple modalities: a “lecture” provided by a scientific authority, followed by an invitation to each audience member to engage in an embodied experimentation around hypnagogic sleep. Critique was supported through audience members sharing their hypnagogic experiences, or lack thereof. Moreover, the performative presence of the scientist—who seamlessly connected her familiar everyday interests in one’s dreams with a larger enterprise of scientific investigations of dreaming, i.e., who clearly communicated the relevance and social nature of science—created the invitation to consider how scientists use evidence to advance understanding, as well as the contested and emerging nature of knowledge in science, i.e., the centrality of a critical stance.

4 Conclusions

As our two examples show, epistemic practices are interwoven, rather than sequential. In *Making*, designing solutions occur as materials are explored, and the materials themselves prompt aesthetic goals which create new engineering constraints. In the *Guerilla Science* case, audiences are invited to see the use and value of experimental design, drawn in by the personal passions of the scientist for a subject (dreaming) that is available and meaningful to everybody in the tent.

We are only beginning to explore these connections and expect to elaborate the conjectures shown in Table 1, to add new conjectured practices, and possibly to find that some are either rare or difficult to enact in authentic ways. For example, while critique is a regular part of arts education programs, engaging in scientific argumentation is rare in many science education programs. Yet, bringing critique to science learning promises to open a door not only onto “what constitutes the best evidence” as described by the NRC (2012b), but also to the possibilities for developing a critical stance toward the culture of science and its history of power, especially with marginalized communities, thus addressing a gap some scholars have noted in current science reform efforts (see Philip and Azevedo 2017). Our *Making* example provided above suggests that perhaps in a STEAM context there is a kind of embodied critique—the evaluation and adoption, adaptation, or hacking of techniques or ideas from others as representing a consideration of alternatives and the utility or vibrancy of one approach over another. In this sense, critique may be embodied through choices that build on convincing approaches, rather than explicit production and consideration of evidence. In the context of the *Guerilla Science* presentation, the cabaret-like setting and mode of presentation is designed to upend normative power structures and expectations. The resulting dissonance, or suspension of quotidian patterns of interaction, opens up the contested nature of science in ways rarely available in most mainstream media accounts or school classrooms.

Adopting a critical stance in science is a significant step forward for efforts to address broadening participation in STEM. But to fully realize the potential of STEAM to advance participation in STEM or the arts, it will be important for STEAM educators to explicitly relate program activities and practices to relevant

careers, academic pursuits, and other community-learning opportunities where such practices are valued. Brokering opportunities for young people to recognize and take up these opportunities is as important as providing them the initial chance to develop them.

Finally, a focus on epistemic practices may support critical reflection on the part of STEAM educators, which is key to advancing the field of STEAM education. In designing, implementing, and assessing programs, educators can probe the extent to which their programs engage learners in ways of knowing. Drawing on student work examples, video or written vignettes, or other forms of data, educators can reflect on whether or not “art” has operated as a token part of their science program, or vice versa. If deeper learning emerges through engaging in epistemic practices, reflection guided by clarity about what those practices look like can elucidate whether their programs are truly hybridized forms of STEAM, or rather token forms of integration. Educators can be challenged to design for and demonstrate how student experiences in producing knowledge or representations of ideas and insights result through the integrated nature of STEAM practices.

Thus, theorizing the epistemic practices of STEAM may provide educators with a tool for articulating as well as improving practice, leading to a fuller realization of what STEAM can mean for creating purposeful and agentic learning.

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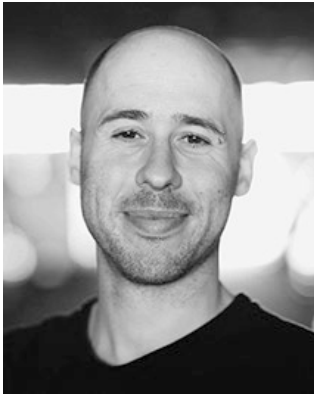
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