



STEAM: Using the Arts to Train Well-Rounded and Creative Scientists

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While the demand for a strong STEM workforce continues to grow, there are challenges that threaten our ability to recruit, train, and retain such a workforce in a way that is effective and sustainable and fosters innovation. One way in which we are meeting this challenge is through the use of the arts in the training of scientists. In this Perspectives article, we review the use of the arts in science education and its benefits in both K–12 and postsecondary education. We also review the use of STEAM (science, technology, engineering, arts, and mathematics) programs in science outreach and the development of professional scientists.

INTRODUCTION

While the demand for a strong STEM workforce is growing and is recognized by academic, non-profit, and government institutions alike, there are challenges that threaten our ability to recruit, train, and retain such a workforce in ways that are effective and sustainable and foster innovation. Educator-scientists are meeting some of these challenges by infusing creativity—by means of the arts—into the education and training of future scientists. Many are superficially aware of these efforts through familiarity with the STEAM acronym, a modification of the STEM acronym to include the Arts (Science, Technology, Engineering, Arts, and Mathematics). When we think of integrating arts and science, the most obvious art form that comes to mind is the visual arts. After all, most scientists have had to generate diagrams to communicate their science effectively. At the same time, performance arts such as dance and theater also lend themselves to integration into science education and training. In this Perspectives article, we review the use of visual and performance arts in science education and their benefits in both K–12 and post-secondary education. We

also discuss STEAM programs in science outreach and the development of professional scientists.

DISCUSSION

Visual, spatial, and graphical arts as STEAM

From our first cell diagram drawings in primary school to the advanced visualizations that illuminate our community's journals, visual literacy is an essential tool in learning and communicating biology. Historically, drawing was assumed to be part of the biology student's and professional's toolbox (1). Today's visual arts STEAM initiatives are the heirs of those learning traditions—many incorporate explicit notes of esthetics, visual literacy, and communication. These initiatives have wide-spanning benefits: broader access and inclusion in STEM, enhanced learning of scientific concepts, building technical skills that are underserved in the curriculum, and enhancing students' mastery of design and cross-disciplinary collaboration (2).

STEM disciplines, as both professions and practices, are functionally dependent on visual modes of problem solving and communication, including schematics, symbolic logic, scientific illustration, and photography (1, 3). STEAM projects recognize the value of art as not simply a vehicle for scientific content, but as a complementary contribution. For example, many STEAM projects recalibrate the typical relationship between science and illustration, resulting in images of scientific phenomena that mutually exalt STEM

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and artistic merit (4–6). Similarly, the proliferation of STEAM scientific image contests speaks to the power of art as a pathway to attract participation and interest in STEM (7–10).

Although scientific illustration is a familiar platform for STEAM, it is not the only model for productive scientific–artistic collaborations. Visual, spatial, and graphic arts have the potential to reveal science and culture in distinct ways that are complementary to our traditional ways of understanding science (2, 11). Fostered through artist residencies as well as individual initiatives, STEAM efforts are yielding visual and spatial art that turns a new lens on the structure of scientific work (2, 12, 13). For example, art can reinterpret scientific themes, providing us with new ways to look at our understanding of the natural universe—from finding new ways to visualize oceanic data that reveal the impact of climate change on marine life (14) to new points of view on the microscopic from artists shadowing scientists at the lab bench (15). Art can also make scientific thought and culture relevant to a broad audience. The arresting visual depiction of the intersection of synthetic biology with urban design and human reproduction (16) or of research life in the arctic provides a “hook,” to both scientists and nonscientists, to pause, look closer, and reflect (16, 17). For these reasons, STEAM among scientists and visual/spatial artists has been particularly fruitful in three domains: helping science become accessible and inclusive; clarifying the meaning of scientific concepts and culture; and fostering collaborative works in which scientific and esthetic components are mutually enhanced (2).

Visual art STEAM projects in education similarly support all of these purposes within learning contexts. STEAM has shown great potential for making science (and science professions) accessible and relatable to students. STEAM learning is especially effective when students are cast in the role of artist and scientist rather than in that of audience. A successful template for STEAM-for-accessibility has been to first facilitate students’ scientific participation or discovery, and then facilitate the students’ reflection on their scientific experience through the creation of visual art—often a drawing or painting (18–22). A common theme expressed across accounts of using visual arts activities to enhance scientific experiences is that students’ enjoyment of the art creation makes the entire activity, including the scientific experience, relatable and fun, which is naturally a key aim of student science outreach (2, 20, 23, 24). It is likely that the drawing component of these STEAM activities yields cognitive benefits as well as creative ones and aids in making sense of both the physical world and abstract concepts (25–27). Drawing fosters close observation, helps elicit relationships between function and form, and can serve as a model realm for problem-solving (1, 3, 27, 28). Manipulative visual arts such as sketching, photography, and origami have been proposed as effective cross-training for spatial intelligence, which is a crucial attribute of successful STEM professionals (29). In addition, there has been evidence that incorporating drawing activities into STEM learning helps students learn

more quickly and deeply, in both K–12 and higher education settings (30, 24). STEAM as a scaffold for student meaning-making is generally a stated or implied goal of activities that introduce visual arts into science learning. However, this outcome is somewhat underserved by the typical analysis of scholarship within STEAM literature. Assessing these cognitive benefits of STEAM has the potential to be a significant growth area for our educational community.

Just as STEAM collaborations among scientists and artists combine art and science with a goal of mutual enhancement, STEAM education provides both STEM and arts students with enrichment that is often not available within their set course of study. This enrichment usually starts by simply scaffolding interdisciplinary collaborations and promoting a culture where science and art are given equal consideration (31). For example, in higher education, STEAM classes can be cross-listed for STEM and arts students. Projects might also involve artistic and functional criteria, ensuring epistemological cross-pollination toward a shared visual or sculptural project or prototype (32).

In such courses, it is often observed that STEM students relish the opportunity to expand into creative roles, undermining stereotypes of the quantitative scientist with no patience for esthetic considerations (32, 20). It has been argued that this points to an unmet need to include esthetics more explicitly in STEM education—certainly for students’ own enrichment, and also to prepare them to succeed in professional pursuits wherein an attractive design is as valuable as technical proficiency (2, 33, 34).

Performing arts as STEAM

While the relationship between performing arts and STEM is less obvious than that of STEM and visual communication, we easily recognize the importance of performance skills in teaching, presenting, collaborating, and even learning itself, all key components of a scientific career. Initiatives that integrate STEM and performing arts sharpen communication skills that complement an individual’s scientific training, and the interactive nature of performance makes for highly dynamic, social, and entertaining projects for science students, professionals, interdisciplinary teams, and nonscientists alike.

Theater. Using theater as a tool in the science classroom can encourage students to find novel ways to integrate knowledge and articulate their understanding of natural phenomena that are abstract and hard to understand (35). Theater is particularly effective at engaging students of different levels as it requires doing, talking, knowing, and creating (36). Thus, theater can be used to promote a student-centered classroom (35).

One way in which theater can be used in the classroom is known as “Reader’s Theater.” In this technique, students strive to tell an interesting story while reading a script provided by teachers (37, 38). The script highlights the content

of interest. While this technique is usually used to facilitate students becoming fluent and expressive readers, when students are asked to generate the script, Reader's Theater becomes a way to catalyze scientific storytelling and to get students to summarize, analyze, and visualize content (37). Improvisational and applied theater have also proven to be useful tools in the classroom, allowing students to become better at thinking on their feet and articulating and integrating scientific ideas (39–42).

Dance. Dance and choreographed movement can be used to convey the complexity behind human discoveries and knowledge in science. Dance Exchange is one example of a company successfully catalyzing collaboration between artists and scientists. The pieces generated evoke thought and dialogue around science as a human enterprise (Table 1). In the choreographed piece *Ferocious Beauty: Genome*, the dancers explore the history and revelation of human genetic research, while their classroom curriculum invites students to model biological concepts (Table 1). Other dance efforts focused around academics include Dance your Thesis (Table 1) and STEM Danceology (Table 1). For example, David Odde and the Black Label dance company collaborated to create a TED Talk about symmetry breaking and cell migration (Table 1).

Music. Music has also been used as a tool in science. An example of this is work done by Gene 2 Music (43). As part of these efforts, Miller and colleagues convert genome-encoded protein sequences into musical notes in order to hear auditory protein patterns.

The inclusion of performance and performing arts across STEM education and research became more visible to the authors through the developing community seeded by the conference series *Cultivating Ensembles in STEM Education and Research* (CESTEMER; Table 1).

The significance of STEAM as outreach

STEAM has been capitalized on as an inspirational, motivational, and accessible means to support scientific outreach. It is important to note that STEAM is not solely intended for outreach. However, in practice, STEAM appeals to audiences who may not immediately identify with or relate to STEM.

There are numerous examples of initiatives integrating STEAM into outreach. Many of these programs are designed as hands-on experiential learning opportunities that promote and cultivate the value of interdisciplinary collaboration. In addition, these transformative outreach activities developed with STEAM concepts are often coupled with goals to help young students bridge their interests with career aspirations (44, 25). STEAM programs can benefit society by increasing public awareness of STEM and providing resources, guidance, and mentorship (45, 46). However, the purpose of STEAM outreach is not to funnel every possible student into a science career by repackaging science as indistinguishable from creative arts. STEAM outreach does indeed provide a means for students who readily identify with creative arts to explore an expansion of their interests into STEM; yet STEAM also provides a more general means for nonscientist citizens to engage with scientific concepts, questions, and narratives with a view to increased scientific literacy, awareness, potential action, and a more positive perception of STEM, which are worthy goals in themselves for the scientific community. It is of particular relevance that the National Academies of Sciences, Engineering, and Medicine is exploring the implications of integrating learning experiences in the humanities and arts with STEM (Table 2). Furthermore, the Cultural Programs of the National Academies of Sciences (CPNAS) hosts the D.C. Art Science Evening Rendezvous (DASER), a monthly discussion forum on art and science projects (Table 2).

The diversity of these STEAM-themed outreach programs could serve as a benchmark for innovation. Perhaps even more noteworthy is that many of these STEAM programs are grassroots efforts. For example, the Art of Science, based in Memphis, Tennessee, looks to unite the vibrant communities of scientists and artists to communicate the beauty of science through the power of art. In a similar vein, Descience explores how scientific discovery can provide inspiration for fashion designers (Table 2). Other opportunities to bring together scientists and artists are provided by the Ligo Project (Table 2). Specifically, Ligo Project's Art of Science is a six-month artist-in-residence program that pairs an artist with scientists, with the goal of creating a piece of science-inspired art. Art of Science Gallery Night is an opportunity to showcase these projects for the community and allow for learning and exploring through

TABLE 1.
STEAM programs in the performing arts.

ID	Program Name	URL
1	Science Choreography	http://sciencechoreography.wesleyan.edu/toolbox/
2	Dance Your PhD Contest	http://gonzolabs.org/dance/
3	STEM Danceology	http://stemdanceology.strikingly.com/
4	Dance Exchange	http://danceexchange.org/about/mission-vision/
5	TedMed Talks: David Odde & Black Label Movement	www.tedmed.com/talks/show?id=47014&videoid=224254&ref=about-this-talk
6	CESTEMER	www.cestemer.org/

TABLE 2.
STEAM programs among professional scientists.

ID	Program Name	Link
1	Integrating Higher Education in the Arts, Humanities, Sciences, Engineering, and Medicine	http://sites.nationalacademies.org/pga/bhew/humanitiesandstem/index.htm
2	D.C. Art Science Evening Rendezvous (DASER)	www.cpnas.org/events/experience-future-events-daser.html
3	Descience	www.fashiondescience.com
4	Ligo Project	http://ligoproject.org
5	Committee for Postdocs and Students (COMPASS) Outreach Grants	www.ascb.org/2014/blog/compass-outreach-grants/
6	TEDMed Talks: David Odde & Black Label Movement	www.tedmed.com/talks/show?id=47014
7	Dance Exchange	http://danceexchange.org/projects/ferocious-beauty-genome/
8	Obama White House—Grand Challenges	https://obamawhitehouse.archives.gov/administration/eop/ostp/grand-challenges
9	TED Talk: Uri Alon, Why truly innovative science demands a leap into the unknown	www.ted.com/talks/uri_alon_why_truly_innovative_science_demands_a_leap_into_the_unknown/transcript?language=en#t-147144
10	Sloan Foundation Programs in Exemplary Mentoring, Mathematical Theoretical Biology Institute, ASU	https://mtbi.asu.edu/PEM

art. Professional societies, such as the American Society for Cell Biology (ASCB), have also embraced STEAM as an effective method to interface with the community and to support projects through the Committee for Postdocs and Students (COMPASS) Outreach Grants (Table 2). One such example is the Emerging Undergraduate Research-Inspired Cell Art (EURICA) program, an interdisciplinary science outreach program designed to inspire students to take science and apply it to their interests (47). These students participated in science experiments and were then asked to create a work of art based on their experience. Another such example was presented at CESTEMER 2014 by Margaret Corbit, who spoke on how 3D virtual worlds can be used as convergent spaces that inspire creativity and engage kids in challenging projects (48). Taken together, these STEAM outreach projects are fostering trainees to consider future careers in science while bridging the gap between scientists and community.

The case for STEAM learning among professional scientists

The contributions of art to science range from effective unidirectional communication to a better exchange of ideas and the generation of new scientific knowledge. Such collaborations can be beneficial to both fields, as well as to society as a whole.

The impact of a well-thought out professional illustration applied to science is well demonstrated by the *Biophysical Journal* cover art for volume 104, issue 6: the artwork by Patrick Lane references Robert Crumb's poster Keep On Truckin' in order to quickly summarize and communicate the experiment that the authors developed to show the translocation steps of Myosin V (49). Scientists

should consider hiring illustrators as they strive to fulfill journal requirements, publish graphical abstracts, better communicate their findings, and save time spent on generating effective figures/diagrams. As a bonus, the interaction with artists may also reveal a gap in the knowledge of the problem of interest (50).

In fact, Dr. D. Odde (University of Minnesota) and the performance group Black Label Movement (Minneapolis/St Paul, MN) seem to be making the most of such interactions. In the TEDMed talk "If truth is beauty, can art be science?" (Table 2), the collaborators illustrate how performers not only help with outreach, but contribute to brainstorming hypotheses. In a lab where "scientists and dancers collide," performers move according to prescribed rules that represent the different hypotheses generating the rapid prototyping "body storming." Such simulations are complementary to the *in silico* ones that may take weeks or months to generate.

The choreographer Liz Lerman (Dance Exchange) collaborated with more than 30 scientists from almost as many institutions to create the multimedia play *Ferocious Beauty: Genome* (Table 2). Art and science are not only symbiotic but also have similarities, according to Dr. E. Jakobsson (University of Illinois, IL): "Both better be true—otherwise they are no good. Both require a lot of discipline to get at truth. And for me, seeing a subject through both the scientific and the artistic lens deepens the intensity of the pleasure and the depth of the meaning" (<http://danceexchange.org/projects/ferocious-beauty-genome/>). The play premiered at one of the collaborating institutions, Wesleyan University (CT), and it changed its culture. According to Pamela Tatge, it was a "terrific catalyst for interdisciplinary collaboration." (<http://danceexchange.org/projects/ferocious-beauty-genome/>). The series of community-centered activities that followed engaged diverse audiences, who participated in discussions

on timely and sensitive topics such as stem cell research. Such discussions may have great impact on public understanding of science, with consequences on regulations and public funding.

Scientists can benefit from the transferable skills required in the performing arts in their research practice before their project is shared and discussed with the general public. The 21st Century Grand Challenges (Table 2) are extremely multidisciplinary and demand effective interactions among professionals with diverse training and background knowledge. Alonzo and Gaff designed and hosted workshops to promote better communications among students and faculty pursuing joint math-biology research. The activities used are derived from theater pedagogy. According to Alonzo, the benefit of transferring rehearsal and rapport skills from the theater to research collaborations is that theater has structures to do these things playfully and efficiently (51). Participants developed skills to focus on the group. They also became aware of different backgrounds, perspectives and values that are specific to each field. This performance-based skillset is invaluable for effective collaboration and handling conflict (51). Similarly, through improvisational theater, scientists become cognizant of ways of speaking and working that support reflective practice and academic, professional growth (52; Hug & Holmes, 2012, Paper presented at the American Educational Research Association, Vancouver, BC).

Even within a single field of study, educators can take advantage of theater and improv pedagogy to facilitate the introduction of active learning activities in the classroom (53), and research mentors can help members of the lab be better prepared and supported when facing the unknown. In the TEDGlobal 2013 talk, “Why truly innovative science demands a leap into the unknown,” Dr. U. Alon (Weizmann Institute, Israel) explains how risk-taking and failure are encouraged in improvisational theater, while in academia, we focus on results and share little on how we experience the process (Table 2). He observed that this can lead to frustration, depression, and stress in researchers. He explains how he actively and consciously transfers the skills he learned from theater to develop a creative, supportive, and productive environment in his research lab. He closes his talk by sharing his vision that “every scientist would know words like ‘the cloud,’ saying ‘Yes, and,’ and science will become much more creative, make many more unexpected discoveries, and be more playful.” The mentoring skills associated with his vision are improvisational. Accordingly, the Sloan Foundation Programs in Exemplary Mentoring funded improv-based trainings for faculty to develop mentoring skills as practiced at the Mathematical Theoretical Biology Institute (Table 2) Through improvisational theater training, scientists see the possibility of generating new interactions in the workplace that support collaborative communication practices and creative research (52; Hug & Holmes, 2012, Paper presented at the American Educational Research Association, Vancouver, BC).

CONCLUSIONS

While often lacking in academia, STEAM strategies are a good complement to conventional pedagogy and training approaches in the sciences—allowing trainees to exercise creativity and innovative thinking. As we look to innovate in the sciences, we should strive to use STEAM approaches to foster the creativity of scientists and scientists-in-training.

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