A Place for **ART** and **DESIGN** Education in the STEM Conversation

The recent push for STEM (Science, Technology, Engineering, and Mathematics) education introduces (through the emphasis on engineering) a design process to science classrooms; some educators have also pushed for the artistic or creative process becoming a part of STEM education. In certain cases, this might be an opportunity for greater prominence for art education, better art and STEM learning, and heightened student engagement; in others it might weaken each discipline and confuse the boundaries between different approaches. In what follows we describe the possibilities and pitfalls of an approach that infuses both the creative process and design thinking into a new iteration of STEM education that adds arts (with a capital "A") to the acronym to make STEAM.

The authors of this article are respectively a university-based art teacher educator/researcher and a museum-based informal education researcher/STEM educator. Our response to crossing boundaries between arts and science is predicated on the perception that these areas can meld fluidly together, and that a synergistic relationship may result. That said, we examine possibilities inherent in such an approach, and also unpack some important caveats. This work should interest teacher educators and researchers in both science and arts disciplines and, we hope, recruit new educators to involve themselves with STEAM or incorporate STEAM philosophies into their practice. We argue the "cultural, pedagogical, and economic aims" of art education (Vande Zande, 2010, p. 248) will be best served when art educators communicate both within their field, and to a broader audience of educators working in the STEM disciplines, that design education as taught in art classrooms can be far more than compositional (i.e., the formalist arrangement of design principles and art elements). When visual arts teachers also approach functional design as part of the curriculum, the aesthetic nature of the design process is revealed in the products, environments, graphic design, information architecture, and interactive situations contemporary designers create. Teaching design in art classrooms is as much the business of art education as teaching the artistic/creative process. Both should be included in art curricula, and communicating this inclusion to non-art educators can open up enormous possibilities for cross-curricular collaboration, and student involvement and engagement with art.

"Design education is the study of aesthetics and utility of items in our daily lives (Vande Zande, 2010, p. 249). Both the design process and the creative process engender a certain kind of thinking and intended outcomes. "Artists represent an idea, concept or object through a medium.... The outcome may be sculpted, painted, photographed, and so on" (Vande Zande, 2011, p. 17). Designers use steps in the design process to solve problems, and “[a] level of skill is needed to design an outcome, such as products, software, events, advertisements, and so on” (p. 17). Design industry leaders describe what designers do as design thinking. Visual arts educators describe the way artists’ think and work as artist habits of mind (President & Fellows Harvard College, 2003).

Savvy art educators, who are tuned in to the national conversation about the connectedness of the arts and American economic competitiveness, understand the importance of promoting art as a way of knowing in today’s educational climate. Savvy art educators can also alert STEM colleagues, school administrators, parents, and other stakeholders that teaching an engineering design process that ignores the aesthetic thinking inherent in almost every form
Figure 1. Nathalie Miebach, "Antarctic Explorer." 2007. Reed, wood, plastic, data, 4.5’x 3’x 2’. This portable data device, worn by the artist/researcher, explores the transition from complete Antarctic darkness in June to 24-hour sunlight in October. Data translated include weather patterns, temperature variations, barometric pressure, wind velocity, azimuth of the sun, tides, moon phases, moonrise, sunrise, and more.
Arts teachers (and others) in STEM-focused schools have scrambled to make their disciplines relevant with little assistance from packaged curriculum that tout STEAM learning.

1. Identify the need or problem
2. Research the need or problem
   • Examine the current state of the issue and current solutions
   • Explore other options via the Internet, library, interviews, etc.
3. Develop possible solution(s)
   • Brainstorm possible solution(s)
   • Draw on mathematics and science
   • Articulate the possible solution(s) in two and three dimensions
   • Refine the possible solution(s)
4. Select the best possible solution(s)
   • Determine which solution(s) best meet(s) the original need or solve(s) the original problem
5. Construct a prototype
   • Model the selected solution(s) in two and three dimensions
6. Test and evaluate the solution(s)
   • Does it work?
   • Does it meet the original design constraints?
7. Communicate the solution(s)
   • Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the initial need or the problem
   • Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
   • Overhaul the solution(s) based on information gathered during the tests and presentation
of functional design might shortchange students and compromise the theoretical arguments that underpin current national academic standards espousing the interdisciplinary nature of STEM learning (NRC, 2011; AAAS, 1993; ITEA, 2000).

There are of course other compelling models for engaging the arts to strengthen STEM skills in interdisciplinary contexts. One is to look at artists who include science in their artworks; we offer three examples of contemporary media and performance artists/designers who have come to treat science (and other STEM disciplines) as topics in their practice. Introducing students to hybrid works of art can help young people understand more about the artistic/creative process, design thinking, and the value of aesthetic inquiry. Examining how artists mix art, science, technology, and math in imaginative artworks that blur boundaries between art, design, and STEM disciplines can develop "thinking dispositions that are valued both within and beyond the arts" (Hetland, Winner, Veenema, & Sheridan, 2007).

In the sections that follow we trace the advent of STEM and why moving toward STEAM (Science, Technology, Engineering, Arts, Math) education is gaining converts. The design process, creative process, and the arts-based nature of design thinking are also discussed. The article closes with a call for embracing teaching that explores both functional design and interdisciplinary artists. We urge art educators to join the conversation about how the arts connect to STEM because art and design are core constituents of 21st-century art education.

From STEM to STEAM?

Since the end of the 20th century the National Science Foundation (NSF) and others have advocated for adding an engineering component to a new breed of comprehensive science education that interfaces with technology and math. Identifying what's central about Science and how that overlaps with Technology, Engineering, and Math led to the acronym STEM. Advancing the STEM brand has become a well-supported campaign to better link K-12 science teaching to 21st-century American workforce. Numerous federal (i.e., NSF, USDE) and corporate (i.e., Exxon-Mobil, Boeing, IBM) funded initiatives also support efforts at the district and school level, where integrating engineering into existing science and mathematics coursework is very much en vogue. And for schools looking for a quick fix, new prepackaged curricula with names like Project Lead the Way (www.pltw.org) and Engineering is Elementary (www.mos.org/eie) were quickly developed. Arts teachers (and others) in STEM-focused schools have scrambled to make their disciplines relevant with little assistance from packaged curriculum that tout STEAM learning.

It seems "acronyms [like STEM] encourage rampant me-tooism," (Angier, 2010), as other fields now lobby for inclusion under the STEM umbrella—adding a second "M" for "Medicine" to make STEM or an "A" for "Arts" to make "STEAM," for example. This article explores the latter notion of STEM becoming STEAM, and how the arts might bring a relevant disciplinary focus for STEM education. We argue that interdisciplinary work in the arts and sciences can lead to curricular components that combine aesthetic and analytical modes of thinking (Fitzsimmons, 2011) to the betterment of both science and art.

As terms go, STEAM, like STEM, may seem didactic and jargony (Angier, 2010), yet clearly there is national interest in integrating the arts into science learning (Piro, 2010; White, 2011; www.exploratorium.edu; www.moundsview.schools.org). "Hands-on, imaginative approaches to science education, using many of the methods used in the creative arts, have been shown to attract and retain young people in the fields of Science, Technology, Engineering and Mathematics," opined organizers of an NSF-sponsored conference of scientists, artists, educators, business leaders, researchers, and policymakers in 2011 (www.artofsciencelearning.org). Attendees explored how the arts can be engaged to strengthen STEM skills and spark creativity in the 21st-century American workforce.

Some STEAM efforts (e.g., Piro, 2010) present the arts as the entryway to STEM learning. However, Eisner (2002), Hetland, and colleagues (2007), and other art education researchers reject instrumental justification for study in the arts as a way to improve student performance in other disciplines. "The two fields can be of assistance to one another. [A]rt education need not be teleological in order to be of value…. Creativity, aesthetic sensibilities and appreciation, higher spatial reasoning skills, sensory awareness, and many other benefits of art have cultural value that are not easily measured" (Bruce, 2010). Understanding how the thinking strategies teachers help students develop in visual arts classes inculcate Studio Habits of Mind—dispositions used in many academic arenas and in daily life (Hetland et al., 2007)—is a more appropriate rationale for art education advocacy. In other words, when the arts are seen as an end goal, not just an entryway to presumably more important STEM topics, thoughtfully developed STEAM curricula can truly engage sustained cross-disciplinary student learning in PK-12 settings and informal education.
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**Similar Design Processes and Dispositions, Varying Aesthetic Intentions**

An important strand of engineering education is the design process or cycle—the steps designers go through in the process of engineering. Although defined somewhat differently by design educators (e.g., Stanford’s School of Education and Hasso Plattner Institute of Design; David Edwards’ ArtScience lab at Harvard; Todd Siler’s Metaphorming design process), the design cycle generally includes steps like considering the problem and challenges that need to be solved, the benefits and drawbacks of different ideas and material choices, coming up with one or several design options, conveying raw ideas as prototypes, and then testing and evaluating their usefulness. Not surprisingly, this process shares many features with functional design as taught in art classrooms: “defining a problem, researching, brainstorming, creating prototypes, presenting to an audience... and refining to the final solution” (Vande Zande, 2011, p. 17).

What differs in art classes? “Functional design is a practical and visual art that includes four broad areas: objects, environments, communication, and experience” (Vande Zande, 2007, p. 1). The design of products, buildings, computer graphics, interactive video games, and the like is thus more aesthetically grounded and artistically motivated than is apparent in an engineering design cycle (See Figure 2, MA Dept. of Education, 2006).

By definition, to design is to plan, and in the arts to design is to fashion artistically or skillfully within a medium (Eisner, 2002). “People in all occupations plan, but the artist or designer is someone who plans the arrangement of elements to form [something] visual. Depending on the field these ‘elements’ will vary—all the way from painted symbols to written words to scenic flats to bowls to furniture to windows and doors” (Lauer & Pentak, 1990, p. 2). Art, like engineering, is concerned with finding answers to problems and seeking visual solutions using the design process. Art, like engineering, subscribes to the idea that design thinking is a complex cognitive process and that successful designers possess certain dispositions.

In engineering, key dispositions of design thinking can be characterized as the ability to: “tolerate ambiguity...in viewing design as inquiry...maintain sight of the big picture...handle uncertainty...make decisions...think as part of a team in a social process; and think and communicate in the several languages of design” (Dym et al., 2005, p. 104). Interestingly, one of the several languages used to communicate in engineering is graphical, “representations [are] used to provide pictorial descriptions of designed artifacts such as sketches, renderings, and engineering drawings” (p. 108) from which 3-D models are created.

In visual arts education, when the curriculum extends beyond techniques, tool use, and mimetic production, teaching about art as a way of knowing affords opportunities for subtler learning that includes development of serious thinking dispositions not unlike those engendered in engineering education. Hetland and colleagues’ (2007) embrace of Harvard Project Zero’s Studio Thinking Framework from which their Studio Habits of Mind are derived, identify dispositions like the ability to attend to relationships, engage and persist, remain flexible, shift direction, imagine possibilities, and express ideas, feelings, or personal meaning. Design is commonly considered to be the distinguishing activity of engineering (Dym, et al., 2005), and engineers are said to embrace the design process by “highlighting the creation... assessment... selection... and the making or bringing to life... of ideas (Sheppard, 2003).

Pedagogically, both art and engineering education lend themselves to problem-based learning (PBL), a way to motivate and integrate authentic learning in a discipline. PBL “develops students’ higher order thinking skills as they investigate ill-defined problems drawn from real life situations,” including aesthetic inquiry that is explicitly included in art curriculum (Costantino, 2002, p. 219). In STEM classrooms, learning the basic elements of the design process often correlates with doing real design projects. And although such projects are enjoyable in and of themselves, students can also be exposed to “some flavor of what engineers actually do” (Dym, et al., 2005). In visual arts classrooms, PBL often is the crux of art and design education.

Understanding that art is and has always been a form of mass communication, and that designers, architects, city planners, illustrators, sculptors, and the like tackle problems with very specific options and real limitations, affords a similar flavor of what artists actually do. Students learn that manipulation of “how things work and/or how things look” often leads to the creation of purposeful items of a commercial nature that “have a balance of function and aesthetics and reflect the prevailing attitudes, customs, and/or beliefs of a group of people at a particular time in history” (Findeli as cited in Vande Zande, 2010, p. 249). PBL thus provides entry points for considering the aesthetic qualities of product design and the boundary-free nature of the design process.

Highlighting the differences with students between an unesthetic engineering approach to design and one that is more artistically grounded can help them understand unique disciplinary goals, but should not create artificial distinctions that don’t reflect the considerations of real world endeavors. Perhaps because professionals in science museums blur the boundaries between STEM and the arts regularly in their own work (for instance, graphic designers and science educators work together to design exhibits that best communicate complex ideas to the public), STEM and the arts are often integrated in these settings. Middle and high school youth who work at one museum, supporting the museum’s programming and outreach to the community, regularly use design (seamlessly integrating an engineering and an aesthetic focus) to address local issues (www.smm.org/kaysc). These youth, who generally identify with groups underrepresented in the sciences (girls, youth of color, immigrants, and/or low income families) develop projects that use art and design not only as a way to engage students, but also as content and as essential to the process of conveying information.
Artmaking in Interdisciplinary Contexts

Next we consider three examples of contemporary artists and designers who treat science (and other STEM disciplines) as topics in their practice, and how those works of art can help students understand more about the role of aesthetic thinking in our society. These are individuals who explore concepts of contemporary art like hybridity, appropriation, and time (http://schools.walkerart.org/arttoday/), while blurring boundaries between art, science, technology, math, and other disciplines. Investigating imaginative artworks created by Nathalie Miebach (http://nathaliemiebach.com), Cory Arcangel (www.coryarcangel.com), and Mark Dion (www.pbs.org/art21/artists/dion/) can engage students through the processes of looking, reflecting on what these artists' are communicating, and linking those ideas to their own lives. Students in turn understand more about the artistic /creative process, design thinking, and the value of aesthetic inquiry in interdisciplinary contexts, while refining higher spatial reasoning skills, aesthetic sensibilities, and analytical acumen.

Nathalie Miebach (see Figure 1, page 41), a sculptor by trade, creates basket sculptures that plot astronomical data (Wallace, 2011). Her "work focuses on the intersection of art and science and the visual articulation of scientific observations... [u]sing the methodologies and processes of both disciplines" (Miebach, 2011). Named one of 20 fellows who presented their work at the 2011 TEDGlobal conference that advances the convergence of design, entertainment, and technology, Miebach says her piece "addresses broader questions than the [data] I'm translating. It forces the viewer to think about the visual vocabulary they associate with science versus art" (Wallace, 2011).

Mark Dion’s art (see Figure 3) "examines the ways in which dominant ideologies and public institutions shape our understanding of history, knowledge, and the natural world.... Appropriating archeological and other scientific methods of collecting, ordering, and exhibiting objects, Dion creates artworks that question the distinctions between objective (rational) scientific methods and subjective (irrational) influences" (Art:21, 2007). And lastly Cory Arcangel (see Figure 4) creates art that "imports a sense of humanity into the technological realm" (Spears, 2011). Arcangel’s art appropriates old computer games, turntables, and obsolete electronic gadgets and "through a bit of ingenious meddling... reboots this detritus to produce witty, and touchingly homemade, video and art installations" (Spears, 2011).
Pitfalls, Advice for Art Teachers, and a Call for Research

Teaching about functional design in art classrooms forefronts outcomes of the creative process and design thinking as "transmission of a personal vision in art and in design, [and why] a designer needs to consider the users' and/or clients' needs" (Vande Zande, 2011, p. 17). Educators should not allow similar surface features of the design cycle to mask deeper differences between the disciplines when implementing STEAM activities to improve student learning. Any time subject areas are integrated, there is a serious risk that one area will be paid lip service, counted as being covered, but in fact not honored. Teachers need to actually discuss and examine the aesthetic decisions or scientific evidence or whatever is being considered. But the risk is that students might just be asked to color the bridge they build in a STEM lesson without talking about the choices they made, or might talk about Leonardo da Vinci in an art lesson without actually considering his scientific work. (Both are teaching episodes we witnessed in schools.) Neither would count as actual STEAM education. And in the worst-case scenario, each of those examples might make a teacher with limited time decide not to pursue additional art or science integration.

We advise art teachers to investigate the STEM approach in their schools. Is it focused on career preparation, setting the disciplines in a more real-world context, or some other format? Understanding where your fellow teachers are positioning themselves will help determine where the arts fit into the picture. When reaching out to STEM teachers, use the language of functional design, offer examples of problem-based lessons, and extend an invitation to collaborate around engineering topics. In a job-prep setting, frame the creative work of artists and designers around 21st century skills and recent calls for innovation in the workplace. Deploy pedagogy that encourages students to be curious, experiment, and take risks—key dispositions artist habits of mind engender. People like the idea of STEAM but are easily put off when it comes down to doing it because of the lack of specificity.

Understanding where your fellow teachers are positioning themselves will help determine where the arts fit into the picture. When reaching out to STEM teachers, use the language of functional design, offer examples of problem-based lessons, and extend an invitation to collaborate around engineering topics.
Whether it's labeled as STEAM or something else, we argue that the business of art education must include advocating for elevating the prominence of the arts in STEM learning. By highlighting the essential aims of art as a discipline and how the principles that inform art and design can be adopted to present science to the public in an engaging manner, educators can stress why quality art programs warrant ongoing local and national support. But the artistic process is not one that science, math, or technology teachers have been prepared to address. Art educators need to be at the table and advocating for their expertise in any discussion of STEM curriculum.

Further research that questions the merits of STEAM and whether this approach improves education or serves the public good is needed. Research should explore when disciplinary differences and similarities are highlighted and when they are ignored, and how students engage these ideas. Can we conceptualize key components of design thinking in both art and engineering disciplines and isolate overlapping cognitive and procedural dispositions? How does design pedagogy and problem-based learning intersect in both engineering and art education, and how can student engagement, learning, and interest be fostered by more integrated art and engineering teaching? And lastly, can STEM be engaged to strengthen the arts?

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