The STEAM Journal

Volume 2
Issue 1 *Synapse*

Article 3

September 2015

From STEM to STEAM: Reframing What it Means to Learn

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STEAM is a bi-annual journal published by the Claremont Colleges Library | ISSN 2327-2074 | http://scholarship.claremont.edu/steam

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Abstract
Although involvement in art and design have been shown to play an essential role in catalyzing STEM research, true integration is still an area of active research. The realization of STEM education via STEAM lends itself to interactive and participatory dialogic art; this juncture provides a nonjudgmental space to cultivate the question-making aspect of inquiry, the ability to comfortably hold uncertainty, and a sensitivity to the process of discovery. Even though STEM education can (and often is) inquiry-based, assessments still tend to focus on whether knowledge or skills have been obtained, and this is no different than the current general practice in the arts. Consequently, what does it mean to learn in a STEAM context? This article presents a multifaceted view which can be used to organize meaningful assessments for STEAM learning.

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Keywords
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STEAM and the Age of Empathy

According to McGrath (2014), organizations are about to experience a major shift in their conceptual models - one that will naturally emphasize the virtues of STEAM. In the early 20th century, we experienced *organization as machine* (Taylorism), which shifted towards *organization as knowledge and knowledge flows* in the 1990's (popularized by Peter Senge, Tom Davenport, and others). Methods for defining, achieving, and improving quality flourished throughout these two eras. But the third and emerging era, she asserts, will be the age of empathy – where *organizations become mechanisms for creating complete and meaningful experiences*. Platforms for learning and creation, particularly those that allow people to find meaning for themselves and within their relationships, will become particularly important.

Heimans and Timms (2014) expressed that this impending transformation is already being embraced by new organizations, employing "New Power" models that are driven by the agency of crowds. Whereas "old power is enabled by what people or organizations [uniquely] own, know, or control," new power is fueled by our collective desire to transcend habits of passive consumption and emerge into a more meaningful social milieu. Beyond consuming and sharing what is consumed, "New Power" leverages crowdfunding to support new ideas, creating and delivering content in the context of social and organizational networks, and co-ownership of co-created ideas. As part of their conclusion, Heimans and Timms advise everyone to begin the work of "redesigning society's systems and structures to meaningfully include and empower more people." By effectively organizing and promoting rich environments for STEAM learning, we can immediately and purposefully engage in supporting that outcome.

Experiences of Art: Interactive, Participatory, and Dialogic

Our impetus for examining the nature of learning in STEAM was a capstone project that we advised during the 2014-2015 academic year in the undergraduate Honors program at James Madison University (JMU) in Harrisonburg, Virginia. Our students represented two programs: Integrated Science and Technology (ISAT), which focuses on holistic, socially responsible problem solving using technology, and Media Arts and Design (SMAD), which explores multidisciplinary creative mass media. The students prototyped a zonohedral dome (or "zome") to serve as an interactive learning space (Baer, 1970), where participants' physical motions would dynamically generate a sound and light show that was responsive to their presence and movements. The zome they designed and constructed using 3D printed components, intended as the basis for a 30’ diameter walk-in model, is shown in Figure 1.

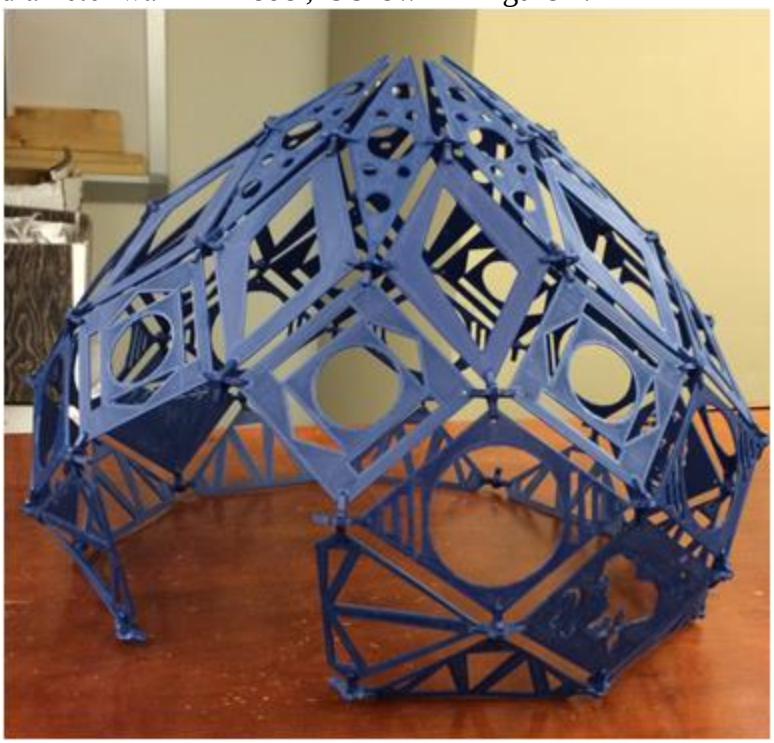

Figure 1: The prototype zonohedral dome (or “zome”) constructed for a senior capstone.

To design the zome for optimal impact in a learning environment, we had to understand the difference between interactive, participatory, and dialogic art. Using this distinction to create an effective pedagogical *platform for engagement* was the main contribution of the capstone project.

Interactive art is the simplest form along this spectrum. Designing interactive art specifically to engage participants in science and technology is not a new concept. As one example, chemist David Glowacki created *danceroom Spectroscopy*, an interactive chemistry video game which allows players to see their energy fields and use that awareness to control the motion of atoms and molecules. A fully participatory art piece, the installation not only responds dynamically to the presence of the participants, but also allows them to engage with the material directly, purposefully modifying the art in the process of experiencing it. (Glowacki, 2014)

Interactive art has been explored as a subject of research because the medium of interactivity can promote the discovery and development of meaning (Muller and Edmonds, 2006). The artist, audience, and artifacts are positioned as essential elements of a dynamic and evolving system where "meaning occurs through the process of exchange, and interactivity itself is the very medium of the work" (p. 147). That is, a participant can learn more about him or herself by reflecting on an experience with art, particularly when that experience requires action on behalf of the observer.

Whereas interactive art provides a means for its creator to engage with his or her audience in the construction of a *story*, participatory art, in contrast, plays the role of *narrative*. By leaving the nature of the participation more open-ended than in interactive designs, the creator acknowledges that the participant is actively engaged in discovering and developing meaning by reflecting on their own ability to transform the art itself. Participatory art, like interactive art, "influences us and affects our perception of, and our actions in, the world" (Novitz, 2001, p. 153).

Dialogic art is inherently participatory, but it addition, it "gains meaning through dialogue, collaboration, and interaction in dynamic responsive processes" (Alexenberg, 2004, p. 153). The art itself *comes into being* through the mechanism of the dialogue, and thus becomes polymorphic: the zome participant engages with the work by moving his or her body, and then explores a narrative in which understanding is sought about *how* he or she has been able to create tangible outcomes in the sound and light show within the zome.

What is Learning?

According to Gigliotti (1998), whose perspective is shaped by a career as a professor of art and design, education means "providing an environment in which students feel absolutely compelled to become involved in the creation of their future by understanding how important they are to the present" (p. 92). It requires teachers who "expect [students] to contribute something essential and unique to a wider communal project of well-being" (p. 92). Cunningham (2014) explores this compulsion in terms of how participatory art can encourage civic engagement and expand the capacity for imagination: "We need citizens who can imagine a different world. Otherwise, the STEM tools needed to get there become quite meaningless."

How can STEAM make STEM tools meaningful and applicable? With this in mind, our model for learning is aligned with the vision of a "New Power" organization as a vehicle for creating complete and meaningful experiences. It accommodates what learning looks like when it happens in the context of networks rather than an instructor-to-student chain of command. It takes into account the sociocultural perspective on learning (Moss, 2003, p. 14):

> *From a sociocultural perspective, learning is perceived through changing relationships among the learner, the other human participants, and the tools (material and symbolic) available in a given context. Thus learning involves not only acquiring new knowledge and skill, but taking on a new identity and social position within a particular discourse or community of practice. As Wenger puts*

> *it, learning "changes who we are by changing our ability to participate, to belong, and to experience our life and the world as meaningful."*

Consequently, we present a model for STEAM learning:

- Learning happens on four different levels: 1) the accumulation of *stocks* of knowledge, 2) the creation of *flows* of knowledge between people and organizations, 3) the *changing perception of self* as new knowledge, skills, and one's ability to participate in a community of practice are assimilated, and 4) *other people's changing perceptions of the learner* as those new capabilities are leveraged within the context of a network.
- It presumes a creative ecosystem that necessarily crosses organizational boundaries. The organization becomes a *custodian of talent*, not a creator or originator of artifacts. Consequently the organization has a responsibility to leverage its resources to maximize the benefits of the STEAM practitioner's talent to society.
- Learning occurs over an irregular time horizon: not semesters, academic years, quarters or fiscal years (which are necessarily arbitrary), but moments and decades and lifetimes.
- Financial/career benefits may not be immediate (e.g. obtaining a lucrative job), or may occur exogenously--i.e. outside the boundaries of traditional financial/career trajectories.
- Learning is emergent and not prescriptive. It requires that you ask questions which will enable you to develop your own direct and indirect measures for whether the experience was worthwhile.

Participatory and dialogic art seem particularly well suited as catalysts for stimulating the creation of these types of learning environments, as our capstone experience illustrated.

The STEAM Learning Experience

Throughout the course of the capstone, we reflected on the elements of the learning model above, as well as the similarities and differences that this learning experience provided both for us (the faculty advisors) and the student team in comparison to prior STEM-only projects. We recognized that a project centered around STEAM could "foster creativity and new ways of thinking" rather than ensure convergence upon an optimal or acceptable solution (Robelen, 2011). However, our students are accustomed to working on projects that conform to society's much more conventional definition of "science"--from the students' perspective, convincing the science and technology faculty to approve their work on an "art" project was a daunting, and intimidating feat. They felt the need to justify their project more strongly to faculty and administrators, and there was an unspoken pressure to convince other *students* that their work wasn't trivial and was just as rigorous as other science or engineering projects.

These pressures prompted us to reflect on the nature of learning at the interface of art and technology. For example, the character of the inquiry was vastly different than what we had experienced advising our other science and technology driven capstone projects over the past decade. Our STEAM students more aggressively asked:

- Why are we really doing this project? Does it matter? Should it matter?

- What does our work mean? What will it mean to others? What *can* it mean to others?
- What *feelings* will our work inspire in others? What feelings do we *want* to inspire?
- What will our work help other people *discover* about the world? About themselves? About their relationships with others in their day-to-day environment?
- Is there something wrong with this project? It feels like it is *way too much fun* to "count" as a science and technology capstone project.

We discovered that there is a large class of people who are actively thinking about precisely these kinds of questions: museum exhibit designers and administrators. After reviewing Simon's (2010) book *The Participatory Museum*, we now recognize that there is a substantial body of work that can help us more accurately reflect on the implication of learning platforms in STEAM.

Implications for Assessment

The National Center for Education Statistics (NCES) proudly submits that it provides "the largest nationally representative and continuing assessment of what America's students *know* and *can do* in various subject areas." (U.S. DOE, n.d.) According to the National Endowment for the Arts (n.d.), the situation is not much different in that domain. Assessment in the arts still focuses on determining whether people have *acquired knowledge* or *developed skills*, not the relational skills or personal transformations that have occurred. Assessment for STEAM learning must be designed with the four levels of learning in mind, and when participatory and dialogic art is used as a pedagogical tool or platform, the question of *where and how meaning has been made* (for the project participants as well as those who will experience the art) are paramount.

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