I care about beauty in science: Aesthetics in scientific practice and pedagogy. By Punya Mishra, Sarah F. Keenan, Rohit Mehta & Danah Henriksen

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I CARE ABOUT THE BEAUTY IN SCIENCE: AESTHETICS IN SCIENTIFIC PRACTICE AND PEDAGOGY

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In this article, we argue that an aesthetic appreciation and motivation for understanding science is missing in the majority of discussions about learning today, which are instead focused on more instrumental perspectives. We introduce a four-pronged formative framework to aid our understanding of the value of aesthetic experiences in science, and develop this framework through an examination of three different kinds of participants in science, technology, engineering, and mathematics (STEM) fields. Looking at the experience of professionals in the field, a popular television series, and practices of teachers, we develop a more finely tuned understanding of how an aesthetic perspective is both more authentic to the field and holds great potential for understanding STEM in a way that supports transformative experiences.

STEM TRENDS

Why should we study the disciplines of science, technology, mathematics, and engineering (STEM)? The typical answers given to this question are instrumental in nature. The core of an instrumental focus suggests that STEM disciplines are essential for jobs in the future, for the growth of national economies, world progress, and so on. A recent federally funded five-year Strategic Plan for STEM Education was developed in partnership with U.S. Department of Education. This report listed the main reasons for investing in STEM education as: *"The jobs of the future are STEM jobs… Our K-12 system is 'middle of the pack' in international comparisons… Progress in STEM is critical to building a just and inclusive society"* (National Science and Technology Council, 2013, p. vi). While we do not deny the importance of these goals, we believe that these instrumental reasons do not connect with the deeper motivations and passions that sustain learners in educational contexts. We suggest that this push toward the instrumental may be partly why many people feel disconnected from science as a subject from schooling onward (Firestein, 2012), and why students often find science content to be dry or dull (Millar, 1991).

We argue that STEM teaching is missing a key element – that of an affective, aesthetic understanding of content. There can be a feeling of delight and personal pleasure that comes from participating in sciences – a perspective reiterated by mathematicians and scientists across contexts and throughout history (Root-Bernstein, 1996). Rather than taking an analytic, objective step back, practicing scientists encourage an involved and subjective step into the material. The creative success of many scientists comes from their ability to appreciate the beauty in the work they do, the world around them and the ways in which science can provide insight into that world. As one scientist explained in Root-Bernstein, Bernstein and Garnier (1995):

> The scientific world is extremely beautiful. I'm much more interested – I mean, if you ask me what I really care about – I care about the beauty in science; and this novelty of discovery is a really aesthetic pleasure. It's just comparable, I think, to

> any other of the great artistic emotions. It isn't rational. It's beyond reason. (p. 126).

However, the inherent beauty of science is often lost in schools' rigid treatment of STEM disciplines; and its fact driven, instrumental ways (Henriksen, 2014; Root-Bernstein, 1996; Root-Bernstein & Root-Bernstein, 1999). In addition, standardized, high-stakes testing has further emphasized factual, decontextualized science knowledge (Giroux & Schmidt, 2004), and steered away from a focus on the inherent beauty in scientific ideas (Firestein, 2012; Schwab, 1982). This has increased the gap between scientific practice and instruction, and removed what learners find exciting and compelling – ultimately leading to weaker scientific literacy among adults (Miller, 2014). There is also an inherent mismatch between the representation of scientific knowledge in schools and scientists and experts' impression of it (Firestein, 2012).

In this paper, we provide an argument for appreciating and including aesthetics in STEM education, contrast it with instrumental reasons, and situate our work within three research studies. In the first study, we focused on an analysis of interviews with some of the leading cosmologists in the world to identify their instrumental and aesthetic motivations in how they approach their work. In the second study, we conducted a qualitative analysis of instrumental and aesthetic approaches as exhibited in a popular science television series. Finally, we conducted an analysis of interviews with award-winning, creative STEM teachers to understand better the role that aesthetic plays in their practice. In essence, this paper presents a program of research around aesthetics, and teaching and learning in the STEM fields. Although these three studies can stand alone in design and findings, they connect within an overarching area of research, which helps us develop some important themes on the intersection of aesthetics, science, and education.

We divide the following sections are in three key parts, describing: (a) the instrumental arguments typically made for learning in the STEM disciplines; (b) a framework for investigating aesthetic aspects of learning; and (c) outlines of our three on-going research studies on the intersection of science and aesthetics.

Framing the Instrumental

In recent years, a focus on maintaining competitive economic advantage has been fueling instrumental approaches to science education. STEM education has been associated with such competitive concerns – exacerbated by a range of forces such as the advent of international tests (e.g., TIMMS and PISA) and globalization, making standardized comparisons across nations easier to accomplish. For instance, in the United States, President Obama tied together STEM achievement with this historical sense of slipping supremacy by comparing America's industrial and technological progress with Asian countries, suggesting a new generation's "Sputnik moment" had arrived (White House Press Office, 2010).

Such concerns have manifested themselves in a number of different ways, resulting in a similarly diverse spectrum of solutions and perspectives on how and what to focus on in STEM education. Pedagogically, this has manifested itself in a variety of teaching styles that have achieved differing levels of success. From drill and memorization to more constructivist inquiry-based science teaching, the vast majority of science teaching focuses on the functional goals of learning science. Typically, these instrumental concerns surface in reference to economics, social justice (like gender and race inequalities in STEM areas), or developing scientific literacy.

In addition, nations often use science as a gauge of their ability to maintain economic and innovative supremacy. This instrumental focus thrives by honing in on the ability and number of STEM degree-holding graduates, and international rankings of standardized scores for K-12 students. Arguments for promoting an interest and real-world application of science for future workforce success fall into this category.

Finally, competency in STEM fields is increasingly seen as a necessary requirement to be an informed citizen; this kind of scientific literacy has been another area of concern for many political and economic leaders. Awareness of major scientific events such as climate change, exponential population growth, technological shifts, and food supply or health issues, like obesity, require such scientific awareness and literacy, as do everyday decisions such as vaccinations.

Framing the Aesthetic

Clearly, instrumental reasons are important for educators to consider, and we do not dispute their role in teaching and learning science. Every profession has its practical goals; and for teachers, the future success of their students is clearly important. That said, another goal of education is to advance curiosity, promote new questions, and improve literacy and the life of the mind across subjects. Therefore, we argue that giving short shrift or ignoring the aesthetic aspects of learning can be deeply detrimental to the very nature of STEM work and learning. Part of the challenge of course is how we define what we mean by the aesthetic.

Our understanding emerges from Girod's (2007) exploration of the role of aesthetics in science and the four dimensions of the aesthetic experience that he laid out. The first of the themes identified by Girod is beauty in the representation of scientific ideas. This intellectual beauty can be appreciated with varying degrees of content knowledge — it does not take a fully trained scientist to appreciate the ripples made by dropping a stone into a pond. This affective appreciation of scientific beauty can be inspired from increasingly abstract instances of science — formulas and theories — when scientists have the knowledge necessary to perceive and appreciate their explanations.

The visceral reactions of scientists in their interactions with their work are the focus of this second theme: the awe, wonder, and fright that can arise from witnessing beauty in the sublime. This feeling arises as an appreciation for the sheer scale of a subject or of the extraordinary comprehension necessary to have developed something that explains it.

The third element of this framework encompasses the beauty many scientists write about when they understand their work to have revealed a sort of divine structure in the universe; beauty as truth. This is frequently the kind of language used by cosmologists and astrophysicists, the feeling of enlightenment that comes from discovering something that seems perfectly and purposefully arranged.

The final theme in this framework *is beauty in the experience* of research itself. This Deweyan perspective speaks to the pleasure or excitement of "inquiry," and unites the subject of science back to its experience with participants. This aesthetic experience is a dynamic one, in which an understanding and interaction with the subject changes both the participant's perception of the world and the subject itself.

While Girod (2001) worked to examine the use of this framework in practice, a great number of other science education studies examined the role of aesthetics in other, more nuanced forms (for example, Jakobson & Wickman, 2008). Our aim here is to extend the discussion

aesthetic plays in motivation and sustained engagement in STEM fields, and to support efforts that focus on participation in this way.

In the next part of the paper, we focus on three research studies that seek to apply Girod's four-fold framework. The first research study consists of qualitative analysis of 27 in-depth interviews with top ranked cosmologists to understand better the role of instrumental vs. aesthetic motivations in their own work. The second study does a similar analysis but this time of popular representation of science and scientists on TV. Finally, we look at how award-winning teachers in the STEM disciplines describe their own work in instrumental and aesthetic terms. These three studies connect in a program of research that seeks to understand the role of aesthetics in the teaching of STEM disciplines.

THREE STUDIES: WHERE AESTHETIC MEETS SCIENCE

Aesthetics and Cosmologists

The complete interview transcripts from the twenty-seven cosmologists whose content provides the bulk of Origins: The Lives and Worlds of Modern Cosmologists by Alan Lightman and Roberta Brawer (1990) also provide the data for our first exploration of instrumental and aesthetic values held by practitioners in the field. Using the four-dimensional framework for aesthetic understanding developed from Girod's work and our categories for understanding instrumental motivations, we completed a preliminary coding of these transcripts in the qualitative software, NVivo. We developed codes to reflect intellectual beauty, beauty in the sublime, beauty as truth and as experience. Within each of these, subcategories have emerged that we are analyzing to incorporate into the framework.

The interviews cover a range of technical and personal detail, offering insight into the motivations these scientists held as they entered the field, and the affective nature of their continued participation. Books that piqued interest and inspired further investigation offer one common thread amongst the interviews. The interviewees discussed these books in aesthetic terms (e.g., being "turned on" to science, developing "serious interest"), which is a theme that developed throughout the interview, even if initially accompanied by an instrumental or practical reason for pursuing science or math. Such sustained aesthetic references speak to the compelling nature of aesthetic appreciation that Girod and Wong (2002) identify as being a key characteristic differentiating aesthetic understanding from conceptual understanding.

One of codes that appears most frequently is that of beauty as experience. The scientists often discuss their research experience in affective terms, talking about their work and their reactions to others' in terms of being "worried," finding things "fun" and "exciting" or being "bothered" by certain ideas. This is one kind of aesthetic connection to the material, which drives continued engagement with problems and a passion extending that engagement. When discussing the message, Robert Wagoner, astrophysicist at Stanford, tried to communicate to the public about the importance of his work and explained, "I really got worried about people being too concerned with their everyday life and not looking out to be aware of their cosmic environment, to put things in perspective."

This attempt to evoke emotional reactions to the vastness of the cosmos is an almost exact definition of our third category: sublime beauty – beauty in awe and wonder. This reiterates the importance that an aesthetic understanding of science can hold a means of communicating value and providing accessible points of contact with the public.

Overall, what we see when we look at this is that successful STEM practitioners do not focus on the instrumental aspects of their field when speaking about what is exciting or motivating

or what drives curiosity in science. This resonates with messages of interest and sustained motivation, and is a recurring theme throughout our other studies.

The Aesthetics of *Cosmos*

In a qualitative study on aesthetic representation of science in popular culture, we analyzed the transcripts of an immensely popular and critically acclaimed television documentary series, *Cosmos: A Spacetime Odyssey*. This is an updated version, or sequel, of the original series, *Cosmos: A Personal Voyage*, hosted, written and co-created by renowned astrobiologist, Carl Sagan. Such popularity comes seldom to science documentary shows, which became our rationale to analyzing the elements in the show that could have helped gain this popularity among public at large.

Although the beauty of science is often lost in its presentation as a school subject matter, programs like *Cosmo*s manifest a different pedagogical approach, in which the public at large finds science both compelling and exciting. When presented as such, it serves to strengthen a better interest and understanding of science. Therefore, our particular interest in this study was to examine how this aesthetic framing could have affected public engagement with science, and whether it shows promise as an approach to foster scientific literacy.

This study, specifically, involved a qualitative textual analysis of the transcripts of all 13 episodes of the documentary series. We obtained the transcripts from an online TV and movie transcript database, *Springfield! Springfield!* First, we examined the videos to verify the accuracy of the transcripts and identify the overall structural and multimodal elements in the series. We also used this viewing to highlight appropriate positions for further detailed analysis in the transcripts. Second, we coded the transcripts using a qualitative coding software HyperResearch, noting every instance of a theme.

When coding, we started with a top-to-bottom approach, using Girod's (2007) framework of aesthetic in science. While we used these four themes as the starting point for our coding scheme, we were open to other examples and themes that speak to the aesthetic framing and present an appealing pedagogical approach to science. We repeated this process for all the episodes. Multiple iterations of coding helped ensure that all the instances and examples of themes/codes in the text were thoroughly identified (Anfara, Brown & Mangione, 2002).

Our analysis of the transcripts identified five emergent themes, which included versions of Girod's four themes. Out of Girod's four, we found the concept of beauty in sublime to be a prominent theme. Here is an example where Cosmos portrayed science as sublime, capable of inspiring awe and wonder, and even fear:

> In order to imagine all of cosmic time, let's compress it into a single calendar year…On this scale…we humans only evolved within the last hour of the last day of the cosmic year. (Episode 1).

The fifth new theme that we found – which was consistent throughout the show – highlighted the representation of scientists as adventurers, detectives, and explorers. For example, "Halley set out to solve this mystery as a detective would, by gathering all credible eyewitness testimony" (Episode 3).

The emphasis of the show on beauty and aesthetics in science, and the excitement that the profession beholds, at one level, captures the essence of Carl Sagan's "*Cosmos* perspective," but also aligns well with the aesthetic framework described in this paper.

We believe that this line of work has the possibility of informing current discourse on scientific literacy and STEM learning — by shifting the focus from instrumental reasons for

learning science to ones that connect with deeper themes of aesthetic experience that can make science a more compelling and engaging experience.

The Instrumental and the Aesthetic in Teaching Science

Henriksen (2011) interviewed eight teachers who won (or were finalists for) the national "Teacher of the Year" award in the United States. As teachers who have been noted as "exemplary" through this award, she analyzed their understanding of creativity, the ways in which they demonstrate this in their classrooms, and the ways in which their outside activities and personal creativity influences their teaching practice. The presence of both aesthetic and instrumental references in these interviews provides an interesting insight into the many factors that contribute to teaching, learning and classroom practices in the STEM disciplines.

Of the original eight interviews, we selected three for preliminary analysis for aesthetics and instrumental themes, based on their teaching of STEM subjects. Mr. K is a middle school math teacher, while Mrs. T and Mr. G teach science at the middle school level. One of the authors conducted the preliminary coding in NVivo using the same basic framework for identifying references of aesthetic understanding that fall along Girod's four dimensions, and our previously referenced three-category instrumental framework.

These award-winning teachers put much emphasis on creative teaching and used compelling examples of teaching/learning in the classroom. Given this, it was not surprising that many of the lessons they described as "creative" also had strong characteristics of aesthetic learning. For example, Mr. K had his students participate in a "number line dance" where students make positive and negative signs with their arms in front of their bodies and then point to the left or the right to indicate going "up" and "down" the number line. Mr. K, on the other hand, writes, sings and creates rap music videos related to mathematics. Mr. G had his students learn science concepts using theatre, such as playing different organisms in an ecosystem or particles in an atom, in order to understand concepts being covered. This sense of being in and part of an abstract concept, and deep and experiential learning of a concept, is part of the engaged and transformative experience of aesthetic learning.

However, we also noted that these teachers also included an instrumental focus at times, particularly in sharing the rationale, goals, and rewards of the profession. Several of these teachers practice in schools with students coming from low-socioeconomic backgrounds and limited resources, intensifying their desire to present subjects as practically useful and relatable to students' everyday lives. When asked about the rewarding aspect of teaching, Mr. K considers the student beyond the subject, saying, "[W]hen a former student comes back years later and is all grown up and being a productive member of society I really think of myself, 'Yeah, yeah, I think I helped play a part in that.'" Mrs. T's explanation revolved around seeing "a future that might be brighter than what [the students] originally anticipated." Although, again, this instrumental articulation of pride is couched in her larger narrative of constant experience and "science being everywhere."

What we see among some of the best teachers in the field is that instrumental reasons do naturally pop up (all professions have their practical goals, and teaching is no exception), in that they consider their students' job security and academic accomplishment. However, these award-winning teachers manage to connect with and navigate these instrumental aspects, while also going beyond them, to speak about their personal interest in the subject and pursuits outside of teaching more aesthetically. Instrumental aspects of teaching and learning will always be present in the profession – and we do not quibble with the importance of teachers working toward instrumental goals to help their students relate to the content in

practical ways, and find success and security in their fields. However, we do emphasize that among highly effective teachers, the story does not end there – they also place a strong focus on aesthetic interests in terms of curiosity, and unique and engaging approaches to content. They focus on ways to highlight both curiosity and excitement for ideas, along with relevant and practical demands of the profession. This requires navigating a tension between the aesthetic and the instrumental, as clearly both are valuable in the effective and impactful teaching of STEM content.

CONCLUSIONS AND CONTINUATIONS

This paper describes a preliminary framework for thinking about aesthetics in STEM education, through the discussion of three different research studies that deal with aspects and approaches to this. These three studies are part of a program of research on aesthetics and STEM teaching, and provide us with a look at aesthetic vs. instrumental reasons for learning STEM content, compared from different perspectives. We assert that aesthetic reasons for learning in STEM subjects – and thus aesthetic or creative approaches to teaching them – are often overlooked and de-emphasized in most education policy and curriculum (though to be fair our work is situated within the context of education in the USA). Much of the high-stakes and standards-based approach to learning that has characterized recent educational policy eschews aesthetic reasoning, curiosity, and wonder, in favor of more straightforward, decontextualized and facts-only based learning. Much of this is driven by instrumental reasons such as job growth in these fields, global economics, and the need for countries to be more competitive in tested STEM competencies.

While we do not deny that instrumental reasons are important, we assert that they have received disproportionate attention in the teaching of school STEM curriculum, which may adversely affect interest, motivation, curiosity, and thus competency in these fields. This also does not align with the reasons that inspire people who pursue these fields professionally. We therefore suggest that an aesthetic perspective is valuable in its own right and as a means by which these instrumental motivations can be strengthened.

While instrumental reasons must naturally show up in the teaching of STEM content – for the most successful of classroom teachers, the aesthetic reasoning or connection to content also is important. At least within the context of the USA, educational policy has de-emphasized the aesthetic in the standardized teaching of science – the most exceptional, award-winning teachers still find ways to bring it in. In this paper, we have suggested, and shown through several pieces of research, the way that aesthetic approaches and reasons in STEM teaching and learning are important. In addition, we have tested the framework proposed by Girod. While the instrumental will still necessarily play a role in classroom teaching, the story does not end there, and we must find a way to incorporate the aesthetic – giving service to both. This work suggests that there is promise and need for additional research in this area.

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