Chapter 7
Developing a Rhetoric of Aesthetics: The (Often) Forgotten Link Between Art and STEM

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Euclid alone has looked on Beauty bare.
Let all who prate of Beauty hold their peace,
And lay them prone upon the earth and cease
To ponder on themselves, the while they stare
At nothing, intricately drawn nowhere

— Ed St. Vincent Milay

The greatest scientists are artists as well

— Albert Einstein

Introduction

A child's first experience, of peeking through a telescope to see the vivid sharply etched, yet fragile, rings of Saturn is a powerful one; perhaps as powerful as standing amidst redwood trees listening to the sound of wind rustling through the leaves or experiencing a moment of clarity when an elegant geometrical proof, surprising in its simplicity, emerges from a chaos of sketches and doodles. It is in this sense of awe and wonder that our minds nibble at confronting powerful *ideas* such as infinity (whether the infinity of numbers, or the interminably large scale of the cosmos, or the immeasurably small universe of cells and atoms and quarks). The emotional turbulence that overwhelms us when we reflect on nature, truly understand a scientific idea, or solve a tricky mathematical or engineering problem often leads to powerful aesthetic experiences. These experiences, we argue, are no different or less

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than the aesthetic experience we have in engaging with powerful artistic human creations, be it music or the visual arts.

Our case for marrying the arts with STEM into a STEAM view of learning pivots on such aesthetic experiences of beauty, curiosity, wonder, awe, and the inherent pleasure of figuring things out. In this chapter, we put forward our rationale for how aesthetic experiences are the often forgotten link between the arts and STEM. Given this link, we propose developing a *rhetoric of aesthetics* in STEM as a practice-based approach to implementing STEAM-based teaching and learning. We share outcomes of our own research which led to the development of a threefold rhetoric that explains the role of the aesthetic in STEM disciplines. The three frames that emerged from this work involve intersections of arts and STEM and can, therefore, be seen as the fuel to designing STEAM pedagogies. Finally, we give examples of how we have used this rhetoric to guide teacher professional development for STEM educators, focused on building a more aesthetically driven STEAM view of learning.

Rationale for the Rhetoric

A rhetoric of aesthetics in STEM emerges from examples of how scientists, mathematicians, and engineers explain and understand their lived experiences of doing science and mathematics. They often speak in affective terms, of beauty and elegance—of frustrations at momentary failures and pleasure at the process or the culminating, momentous thrill of discovery (e.g., Hoffmann, 1990; Holton, 1988; Tauber, 1997). Through this they provide us a glimpse of an aesthetic lens that influenced their vision.

Both Hegel and Kant considered aesthetics to be a bridge between the sensuous and the intellectual (Scruton, 1983). Metallurgist, Cyril Stanley, exemplifies this connection, explaining, “The stage of discovery [is] entirely sensual and mathematics [is] only necessary to be able to communicate with other people” (as quoted by Root-Bernstein, Bernstein, & Garnier, 1995, p. 133). The deeply personal experience within scientific practice, which is often kept separate from the public face of science, is a theme repeated across the stories told by many scientists and mathematicians (as seen in autobiographical accounts, see Chandrasekhar, 1987; or for other scholars’ reflections on their processes, see Girod, 2007, Tauber, 1997). However, when presenting science to the public, this “personal” account of science is often suppressed in favor of more straightforward linear accounts (Holton, 1988).

The literature around science is full of examples of beauty and wonder-driven approaches (Chandrasekhar, 1987; Orrell, 2012). These are abundant in the stories of everyday scientists and mathematicians in their discovery of the “truth” that nature holds (Girod, 2007; Mehta, Mishra, & Henriksen, 2016; Mishra, Terry, & Henriksen, 2013). From Pythagoras to Kepler, from Newton to Einstein, most stories of real-world scientific inquiries by notable scientists are laden with experiences of wonderment with inquiry (Orrell, 2012). This pairs with an awareness of beauty or elegance, both in nature, and the theories and formulae that describe nature. For instance, in an article in *Scientific American*, Nobel laureate and physicist, Paul Dirac (1963), suggested that beauty may even be the most important thing of all:

> [I]t is more important to have beauty in one's equations than to have them fit experiment … It seems that if one is working from the point of view of getting beauty in one's equations, and if one has really a sound insight, one is on a sure line of progress. If there is not complete agreement between the results of one's work and experiment, one should not allow oneself to be too discouraged, because the discrepancy may well be due to minor features that are not properly taken into account and that will get cleared up with further developments of the theory. (p. 47)

Mathematicians of course, maybe more so than scientists, speak to beauty, elegance, and simplicity in what they value in their work. Ignoring this aspect of their work, in the words of Poincare (1910), "would be to forget the feeling of mathematical beauty, of the harmony of numbers and forms, of geometric elegance. This is a true esthetic feeling that all real mathematicians know, and surely it belongs to emotional sensibility" (p. 331).

Aesthetics is by no means constrained to the realm of science and mathematics. Engineers and computer scientists speak of their work in aesthetic terms as well. This may appear somewhat surprising given that the ultimate goal of engineering is functionality—i.e., creating a functioning, working device or program or artifact. But, as Gustave Eiffel, of the eponymous tower, said, "Can one think that because we are engineers, beauty does not preoccupy us or that we do not try to build beautiful, as well as solid and lasting structures? Aren't the genuine functions of strength always in keeping with unwritten conditions of harmony?" (as quoted by Petroski, 2011). Similarly, in looking at the aesthetic aspects of computer programmers, Good, Keenan, and Mishra (2016) wrote that:

> Professional programmers will readily share their experiences with code that they might describe as elegant, beautiful, or clean… both novices and experts describe [code] as *ugly* and *beautiful*. Both groups reported aesthetic experiences related to code they had observed, albeit with functionality being of higher importance. (p. 315)

We could provide hundreds of such examples to demonstrate the significant role the aesthetic plays in how scientists engage in the STEM disciplines. But the overall point we seek to convey in this chapter is clear: *if we want students to have authentic experiences with learning in the STEM disciplines, to cultivate a true STEAM view of learning, we cannot ignore the role of the aesthetic*. Doing so does a disservice to the very reasons that *practitioners* view as key to their own motivations and passions for doing science, mathematics, and engineering. Ignoring the aesthetic, moreover, devalues the humanistic and artful aspects of the STEM disciplines, the tissues and sinew of the body of science, leaving behind just the functional and the practical, the bare bones, as it were.

Instrumental and Aesthetic: The Yin and Yang of Motivations for Science

There are a multitude of reasons that much conventional teaching and learning has often ignored the value of the aesthetic in how science and technology are represented in our curricula and presented to students in our classrooms. We suggest that in attempting to find efficient ways of teaching STEM in schools, over the years, our teaching and curricula have increasingly adopted purely functional, *instrumental* reasons for studying science, mathematics, engineering, and technology. Such instrumental reasoning positions science as a tool rather than a personally motivating, enjoyable, or beautiful subject. This happens when we push participation in STEM fields, because they may offer a high-paying profession or stable job, or because it feeds into a patriotic rhetoric wherein STEM helps nations best others in international competitions. This logic was reified in the US-USSR space race in the 1960s, where STEM was used as a tool to win at an international competition—space exploration being its by-product. This sense of war and competition as the true value of education can be seen in influential reports, such as 1983's *A Nation at Risk*, where the authors begin by stating, "If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war" (National Commission on Excellence in Education, 1983, p. 5).

Though we do not deny the value of instrumental approaches (no doubt STEM fields play a significant role in the economic growth and innovation of society), we do believe that a singular focus on such approaches misses what is engaging and motivating about science and engineering—and ironically misses the key driver that has motivated the most innovative STEM thinkers through history. We argue that, at its core, the sensation of wonderment, the sublime feeling of awe, the natural sense of curiosity, and the intrinsic joy of discovery—the *affective and emotional components* of the experience of doing science—are the key to learning in the STEM disciplines. As educators, we often ignore them at the risk of alienating the very students we want to reach. We argue that doing science is an inherently emotional, and thereby humanistic, aspect of our lives. It is fueled by curiosity, steered by wonder, soothed by beauty, and replenished by the joy of discovery. This is why we love to solve problems, explore new lands and seas, and build enormous bridges and miniscule nanobots. It is who we are as humans—curious, complex, and forward-looking. This is the aesthetic and affect-based reason for doing science. Certainly, an instrumental reason complements it by grounding us in pragmatism, but it is not the primary motivator and therefore cannot be the single, sole lens through which we view STEM pedagogy.

To be more specific, the instrumental arguments for the most part are somewhat removed from the humanizing, rich, personal, subjective, here-and-now experiences of learners. Instrumental arguments are grounded in meeting an abstract, and essentially unknowable, possible future need, rather than a tangible, concrete present. It suggests that learning the STEM disciplines would ultimately, in the future tense, be extrinsically beneficial to both the individual (e.g., successful career options, financial stability) and society (e.g., technological progress, economic growth, global competitiveness). Learners who start hearing these arguments at a young age are expected to accept these at face value. But it is not surprising that these distant goals cannot sustain motivation in STEM, if they motivate at all. We need more proximate goals that are inherently motivating and which can be infused within a STEAM curriculum.

Why the Aesthetic Is Sexy: One Possible Answer

Our previous discussion suggests that if we are to go with what motivates practicing scientists, mathematicians, and engineers, we need to consider the role of aesthetics in our curriculum. But this also begs the question of why fields focused on understanding the world or constructing things are so motivating. Why *do* we get a frisson of pleasure when we solve a problem or understand something new?

One possible answer emerges from a classic paper written by psychologist Alison Gopnik titled, "Explanation as orgasm and the drive for causal knowledge: The function, evolution and phenomenology of the theory-formation system" (Gopnik, 2000). In this paper, she argues for an evolutionary argument to explain why, for humans, the process of understanding something can be inherently pleasurable.

In constructing her argument, she suggests that a parallel can be found in the argument that evolutionary biologists and psychologists have made for the qualitative experience of pleasure, particularly in the evolution of sex. The practical (instrumental/functional) reason for sex is to reproduce in order to ensure the survival of the species. However, individual organisms, within a species, do not have any sense of these evolutionary plans. The essential function of the gene is to reproduce, as the survival of the species depends on it. So evolution, in its blind yet creative manner, has come up with a perfect solution—providing a local incentive that will lead to meeting the global goal. It has done so by making sex inherently fun, i.e., individuals within a species indulge in sex not to propagate the species but because they enjoy it.

Building on this, Gopnik argues that for a species that depends on higher-order thinking to make sense of the world, namely, humans, it makes a lot of sense for evolution to make the process of higher-order thinking itself fun, pleasurable, or fulfilling. Completing the analogy, Gopnik writes:

> … explanation is to theory-formation as orgasm is to reproduction. It is the phenomenological mark of the fulfilment of an evolutionarily determined drive. From our phenomenological point of view, it may seem to us that we construct and use theories in order to achieve explanation or have sex in order to achieve orgasm. From an evolutionary point of view, however, the relation is reversed, we experience orgasms and explanations to ensure that we make babies and theories. (p. 300)

Pleasure is the incentive that evolution has provided to make us continue to think and understand. The physicist and educator Frank Oppenheimer made a similar argument when he suggested that "Understanding is a lot like sex; it's got a practical purpose, but that's not why people do it normally." Or as Gopnik (2000) suggests, "finding an explanation for something is accompanied by a satisfaction that goes beyond the merely cognitive" (p. 311).

We suggest that we should learn from the blind intelligence of evolution and focus also on the proximal motivators for learning in the STEM disciplines, i.e., the aesthetic. The aesthetic exists in the pleasure of understanding and figuring things out. It lives in the thrill of the chase and discovery. It appeals in the sense of awe we feel when we confront at the beauty of nature and the immensities of the universe. It endures in the elegance of a proof or in a subtle line of code.

Where the aesthetic does *not* exist is in the approach of most traditional subject curricula and lessons we have in schools and standards-based learning today. There are encouraging signs in some of the work being done in the STEM disciplines, such as the maker movement and discovery science projects, but those are often exceptions rather than the rule. And more importantly, even in learning contexts where the aesthetic is seen, it is ad hoc, with little or no systematicity to how it is introduced and lacking a framework to articulate its inclusion. The aesthetic emerges, more often than not, as a side effect of some other intervention, rather than a goal in and of itself.

In contrast, we suggest, paraphrasing Frank Oppenheimer, that STEM has an *instrumental* purpose, but that is not generally why people would want to do it. We argue that the basis of aesthetics is in the personal and the subjective, in the powerful human impulses of inquiry, communication, construction, and expression (Dewey, 1943).

The question then becomes, what would a rhetoric of aesthetics for STEAM pedagogy look like? How do we find a pedagogical balance to capture both the aesthetic and the instrumental aspects of doing science? In this chapter, we attempt to use our explorations of aesthetics in science, math, and engineering to push beyond an instrumental STEM to a more inspiring STEAM, with practical methods to integrate an aesthetic and affective rhetoric in a science classroom.

Framing a Rhetoric of Aesthetics: Theory and Research

Thomas Conley (1990) defined *rhetoric* as the art of conducting a discourse of persuasion and motivation, depending on context. In our context of STEM teaching and learning, a discourse of persuasion and motivation to encourage science, mathematics, and engineering would require carefully designed pedagogical moves that draw upon the human impulses toward exploration and understanding. It would require us to create opportunities to inspire affective and emotional elements of beauty, curiosity, wonder, and awe. In addition, the design of a rhetoric requires us to understand the frames that would constitute the discourse. Frames, according to Davis and Russ (2015), are "a set of simple elements that organize the perception of a given situation. Framing is how those elements tune the interpretation of a phenomenon" (p. 223).

To develop a rhetoric of aesthetics, and in order to frame it properly, we build on the work of previous scholars and researchers. For instance, Dewey in his book, *Art as Experience*, makes a case for a transactional framing of the aesthetic experience. He wrote:

> In order to understand the esthetic in its ultimate and approved forms, one must begin with it in the raw; in the events and scenes that hold the attentive eye and ear of man, arousing his interests and affording him enjoyment as he looks and listens… [One] should be carried forward, not merely or chiefly by the mechanical impulse of curiosity, not by a restless desire to arrive at the final solution, but by the pleasurable activity of the journey itself. [sic] (Dewey, 1934/2005, pp. 2–3)

Dewey suggests here that understanding should be seen as a "pleasurable" *experience* of doing science and math, where the idea of aesthetic experience is one of unfolding over time. He makes an argument for the value and pleasure of engaging with the process of science, not just the spark of curiosity or satisfaction of the solution. Instead he speaks to *the trajectory of engaging* with process—with a journey that is more than just the destination, with not only the question or the answer but everything that lies in between them.

This is a transactional framing of the aesthetic experience, where people and their worlds mutually interact and co-create meaning (Dewey, 1934). So, Dewey argued that a learning experience is somewhat unique to the individual learner and must be seen as a form of unfolding interaction over time, which can also be collectively shared and understood. In this view, the aesthetic experience is characterized by a sense of heightened engagement, as well as a feeling of anticipation, akin to watching a thoughtfully created book or movie. The pieces work together holistically, and it is through this process of engagement that we create experiences that can be truly transformational. Clearly, this idea of experience is not a static one but rather speaks to a dynamic, dialogic process of interaction between the learner and their world (a world where most STEM experiences happen in contexts mediated by teachers, textbooks, schools, and curricula). Through this process learners shape and construct their understandings and meanings, over time. Disciplinary frames play a crucial role in this process as do certain broad aesthetic themes and ideas.

In developing our approach, we were also guided and inspired by theoretical and empirical work of Girod and Wong (2002), Girod (2007), Pugh and Girod (2007), and Jakobson and Wickman (2008). In their work, these authors offer a definition of aesthetics as a mélange of emotional responses elicited from a variety of experiences (Dewey, 1934/2005). Jakobson and Wickman (2008) connected the positive rhetoric of aesthetic connections in science to what students pay attention to or ignore. Studying student and teacher's scientific discourse, they identified that aesthetic connections shaped students' lived experiences and transformed science content for them.

In particular, our work is deeply connected to and builds on Girod's (2001) study of teaching in a science classroom. In his study, Girod compared two fifth-grade classrooms, one interlaced with a rhetoric of aesthetic connections in science and the other focused on conceptual understanding. Using the quantitative comparisons of students' feelings toward science and conceptual understanding (measured across several different points in time), Girod's analysis demonstrated that, when presented with science in aesthetic terms, students learned more, had deeper understanding of the concepts, and forgot less than students in the control classroom. As he wrote:

> Teaching for aesthetic understanding brings students to high levels of conceptual understanding while simultaneously bolstering more positive feelings toward science and fostering changed action and renewed interest in exploring and engaging with the world. (p. 229)

These studies, though few in number, suggest that a curriculum that includes the aesthetic (or one that places it at the center of the learning experience) can have significant positive impact on student engagement and learning.

In addition, our work builds on theoretical work by Girod (2007) where he offers four themes for considering the aesthetic in science curriculum design. These four themes are listed and briefly described below:

1. *Beauty in experience*: The idea that beauty in science lies in the nature of the experience of doing science as scientists engage in scientific research and creativity
2. *Intellectual beauty*: Beauty in the representation of scientific ideas, in the simplicity and elegance of ideas that explain the most complex of phenomena with ease and grace
3. *Sublime*: The feeling of reverence, wonder, and awe toward the power and grandeur of nature
4. *Beauty as truth*: The beauty in recognizing the truth and the fundamental structures that govern the universe, including a sense that science reveals the grand design of the world

Girod's four themes for considering the aesthetic resonate deeply in our work. It is these themes that we utilized in three different studies, described below. Along the way, however, we also came to develop a new threefold approach toward the aesthetic in STEM that, perhaps unsurprisingly, has a strong affinity with Girod's work while extending it further.

The three studies we describe were meant to help us understand the aesthetic framing of science in three different discursive contexts. Briefly, the first study focuses on the rhetoric of science popularization, the second on the personal experiences of some of the world's top astrophysicists, and the third on comparing the results on memory and experience of aesthetic and instrumental framing of scientific texts. Each of these studies allows us to both build on Girod's themes and to extend their reach, allowing us to revisit his work to refine and develop it further. We offer our new framework at the end of the three studies noted below and touch upon how this new rhetoric of aesthetics has been instantiated in a STEM-related teacher professional development curriculum.

Study 1: A Rhetoric of Aesthetics in Popular Science: The Case of Cosmos In a qualitative analysis of representation of science in popular culture, we thematically analyzed the scientific discourse in a popular and critically acclaimed television documentary series, *Cosmos: A Spacetime Odyssey*. Essentially, we analyzed the transcripts of all 13 episodes of the series, beginning by examining all the videos to verify accuracy of the transcripts and to familiarize ourselves with the data (Bazeley, 2013). We also used this viewing to highlight appropriate positions for further detailed analysis in the transcripts.

Then, we coded the transcripts using a qualitative coding software HyperRESEARCH, using Girod's (2007) themes as a frame of reference for identifying initial codes, which could then be challenged, teased apart, or revised as and when new themes emerged. We employed a bottom-up approach that allowed the coding of emergent themes (DeCuir-Gunby, Marshall, & Muculloch, 2011) focused on a rhetoric of aesthetics—to present an appealing pedagogical approach to science. 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 frames, four of which mapped on to Girod's themes, with one additional emergent frame. Out of Girod's four themes, we found the concept of *beauty in sublime* to be a prominent frame. Here is an example where Cosmos portrayed science as sublime, capable of inspiring awe and wonder and even fear:

> How can we humans, who rarely live more than a century, hope to grasp the vast expanse of time that is the history of the cosmos?… In order to imagine all of cosmic time, let's compress it into a single calendar year. The cosmic calendar begins on January 1st with the birth of our universe. It contains everything that's happened since then, up to now, which on this calendar is midnight December 31st. On this scale, every month represents about a billion years… In the vast ocean of time that this calendar represents, we humans only evolved within the last hour of the last day of the cosmic year. 11:59 and 46 seconds. All of recorded history occupies only the last 14 seconds, and every person you've ever heard of lived somewhere in there. (Cosmos, Episode 1: Standing Up in the Milky Way)

The second most prominent frame in the show was of *beauty in the representation of scientific ideas* specifically the simplicity and elegance of ideas that explain the most complex of phenomenon with ease and grace. These representations of intellectual beauty were prominent throughout the series.

The third frame, which Girod found to be key to creating a rhetoric of aesthetics in science, was of *beauty in grand design.* Cosmos portrayed the beauty in the grand design and the structure of the cosmos by explaining the patterns that constitute it and dissecting any misconceptions that build to further misconceptions. In this process, the series revealed the beauty inherent in nature and discovery of truth. The use of aesthetic examples ranged widely—from the intricate double helix structure of DNA to evolution and natural selection, to a single theory of gravity that makes heavenly objects dance in elliptical orbits, to the intricate marriage of structure and function of a mere dandelion. Across examples, the series depicted the notion that beauty lies in recognizing the truth and the fundamental structures governing the universe.

The fourth frame of *beauty in experience* itself, as Girod (2007) also found, lies in the nature of the experiences themselves as scientists engage in scientific research and creativity (p. 41). Not only did the show reflect the idea of beauty in discovery and invention, it also reflected the sheer joy in research that most scientists feel.

Examples of beauty in experimenting, thinking about science, and experiencing science were prominent throughout the series.

But, we found that Girod's example offered just one aspect under aesthetic experience. Another aspect of aesthetic experience occurred at a somewhat meta-level where the design of the show itself attempted to create an aesthetic experience for the viewer. Cosmos used visuals and verbal cues to not only hook its viewers but to create an aesthetically satisfying experience. The choice of music (typically from the western classical canon) used in the show attempted to construct an experience for the viewer of going on an adventurous, beautiful, exciting, or uplifting pleasing journey. For instance, the evolution of life on earth was orchestrated by the host of the show with Maurice Ravel's Bolero playing in the background. The show used the Ship of the Imagination as a tool to help viewers experience things that would otherwise be impossible, such as traveling inside the body. It asked questions as baits, to compel viewers to think about a recently introduced scientific concept.

The fifth, and emergent, frame that we found highlighted the representation of the role of scientists as being adventurers, detectives, and explorers. Consider the two examples below in this frame:

> But for one man, Copernicus didn't go far enough. His name was Giordano Bruno, and he was a natural-born rebel. He longed to bust out of that cramped little universe. Even as a young Dominican monk in Naples, he was a misfit. This was a time when there was no freedom of thought in Italy. But Bruno hungered to know everything about God's creation. (Cosmos, Episode 1: Standing Up in the Milky Way)
>
> Science works on the frontier between knowledge and ignorance. We're not afraid to admit what we don't know. There's no shame in that. The only shame is to pretend that we have all the answers. Maybe someone watching this will be the first to solve the mystery of how life on Earth began. (Cosmos, Episode 2: Some of the Things That Molecules Do)

The emphasis of the show on the beauty in science and the excitement of the profession captures the essence of Carl Sagan's "Cosmos perspective" and aligns well with the aesthetic framework described in this paper. It suggests a shifting of focus from instrumental reasons for learning science to ones that connect with deeper themes of aesthetic experience—making a stronger case for STEAM in seeing it as the inclusion of a rhetoric of the aesthetic in the teaching and learning of STEM disciplines.

Study 2: A Rhetoric of Aesthetics in Personal Scientific Narratives: Listening to Cosmologists The second study was a qualitative analysis we conducted of 27 in-depth existing interviews with top-ranked cosmologists to better understand their personal rhetoric of science. The idea behind understanding their personal lens for science was to look for differences in the types of instrumental and aesthetic rationales they considered for and within their personal work. The completed interview transcripts from the 27 cosmologists done by Alan Lightman provide the content of Lightman and Brawer's (1990) book *Origins: The Lives and Worlds of Modern Cosmologists* the data for our exploration. We again started with Girod's themes for aesthetic understanding and our categories for instrumental motivations. We completed a preliminary coding of these transcripts in the qualitative software, NVivo. We then developed codes to reflect beauty in the sublime, intellectual beauty,

beauty in grand design, and beauty in experience. Within each of these, we identified and analyzed emergent subcategories to incorporate into the framework.

The interviews covered a range of technical and personal detail, offering insight into the motivations these scientists had for entering the field and the affective nature of their continued participation and motivation toward STEM fields. The interviewees discussed books that piqued their interest and inspired further investigation by using aesthetic terms (e.g., being "turned on" to science, developing "serious interest"). This theme of emotional arousal consistently grew as the astrophysicists described their career trajectory, even if their involvement in science had included instrumental or practical reasons. Such sustained aesthetic references spoke 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 the codes that appeared most frequently is that of *beauty in experience*. The scientists often discussed their research experience in affective terms, talking about their work and their reactions to others in terms of *feeling* "worried," finding things "fun" or "exciting," or being "bothered" by certain ideas. This resonates with Dewey's idea of the heightened emotional or affective dimensions of any aesthetic educative experience (Dewey, 1934). It is one kind of strong aesthetic connection to the material, which drives continued engagement with problems and a passion extending that engagement. For instance, Robert Wagoner, astrophysicist at Stanford, in attempting to communicate the importance of his work 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: *beauty in sublime*–or beauty in awe and wonder. This reiterates the importance that an aesthetic understanding of science can hold as a means of communicating value and providing accessible points of contact with the public.

Overall, what we see when we look at the personal rhetoric of these astrophysicists 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. Instead, they focus on the highly aesthetic and affective dimensions of participating in STEM fields. And this incorporation of the aesthetic drives a more STEAM-based sensibility toward STEM.

Study 3: The Rhetoric of Aesthetics (and the Instrumental) in Science Texts—An Experimental Test The third study we conducted focused on disentangling the influence of aesthetic and instrumental perspectives on how undergraduate students read and interpret scientific texts. This experimental study was designed along the lines of past cognitive interventions that have investigated the effect of "framing" on memory, recall, engagement, and understanding (e.g., Anderson & Pichert, 1978). In this context, participants were given either an instrumental frame or an aesthetic frame prior to reading a scientific text. Participants in the aesthetic condition were given a framing passage that suggested aesthetic reasons like curiosity, transformative experiences, and intellectual beauty as reasons to study science. Participants in the instrumental frame received a frame that emphasized the value of doing science in terms of economic mobility, enhancing representation, and scientific literacy.

After reading their frames, participants "wrote back" what they could remember about the frames to help them internalize the ideas about what some core reasons were for doing science. Each group then reads their first scientific text passage (about virus reproduction), completed a distractor activity, and wrote back all they could recall about the passage. Following this they were given a prompt to write about the reasons they were given for studying science (the frame), then read the second scientific text passage (about the structure of atoms), completed another distractor activity, and then wrote their final recall.

To determine whether the framing passage affected participants' recall of scientific texts, identifiably unique statements made in each scientific passage were given a code and compared to participants' responses. The results of the study were inconclusive. It is true that participants in the aesthetic framing group did recall a higher number of ideas from both scientific text passages than their instrumental counterparts, yet (possibly due to a small sample size) it was not at a statistically significant level.

The next step of the analysis focused on whether there was a difference in *which* statements participants recalled. To determine whether the frame affected *the way* participants constructed their recalls, all recall responses were run through the Linguistic Inquiry and Word Count (LIWC) database and analyzed along 28 dimensions. There was only one significant difference between the groups, but again looking at effect size revealed additional differences between the constructions of the recalls that suggest different approaches and interpretations of the scientific texts.

One of the complications in the study was a possible interaction with the content of the scientific passages. Participants, in reporting their enjoyment of reading the passages, revealed a statistically significant preference within the aesthetic group for the virus passage over the atom's passage along four dimensions. In contrast, the instrumental group preferred the same passage but only along two dimensions. This offers tentative support to the hypothesis that participants who received an aesthetic framing passage not only had stronger emotional reactions when considering the passages (in their more clearly defined preference for the virus scientific passage) but also enjoyed the process more than their counterparts in the instrumental framing group.

The results of this experiment offer preliminary support for our hypothesis that the framing of the participants' perspectives (along aesthetic or instrumental dimensions) influenced their recall of scientific text and the affective quality of their experience with it. This study offers an exploratory first step toward our understanding of how those perspectives may influence what students pay attention to and their enjoyment of the process. Additionally, these findings demonstrate that highlighting aesthetic reasons for pursuing STEM knowledge at the very least did not hamper participants' performance and arguably increased their enjoyment of the process as compared to their peers who had been given traditional, instrumental reasons to study science. This suggested that it is possible that even those with instrumental motivations to push participation in STEM might benefit from including an aesthetic perspective in their campaigns and curriculum.

A Rhetoric of Aesthetics for STEAM: Three Fractal Frames

In some form, the three studies described above speak to the importance of aesthetics in thinking and learning in the STEM disciplines. Moreover, it is a specific form of aesthetics that we are describing here; it is in an aesthetic experience in the Deweyan sense of the word. It is a perspective that sees deep commonalities between the artistic and the scientific. Describing the artist experience, Deweyan scholar Philip Jackson (1998) wrote:

> Our interactions with art objects epitomize what it means to undergo an experience, a term with a very special meaning for Dewey. The arts do more than provide us with fleeting moments of elation and delight. They expand our horizons. They contribute meaning and value to future experience. They modify our ways of perceiving the world, thus leaving us and the world itself irrevocably changed. (p. 33)

In the quote above, the phrase "interactions with art objects," according to the perspective we are constructing here, could be replaced by the phrase "engagement with STEM." We suggest that the STEM fields play the same role in our consciousness that the arts do; in that, as Dewey (1934) or Jackson (1998) suggests, they expand our vision of knowledge and learning and develop a wider perception and experience of the world.

It is this unity of the experiences that the arts and STEM disciplines create (in terms of Dewey's aesthetics) that we believe is the way in which STEM and STEAM are deeply and powerfully interconnected—where the aesthetic is the missing link between STEM and STEAM. The addition of the "A" to STEM is not just the addition of the arts to the curriculum. Instead, it is an awareness that the arts and the sciences are more deeply connected than traditional disciplinary boundaries reflect. They are connected in ways that integrate them as inherently humanistic enterprises which allow us to experience and engage with the world in profound and transformational ways.

We seek to coalesce these disparate themes (Dewey's ideas from *Art as Experience*, Girod's research on themes of beauty in science, and our own work described above) into a rhetoric of aesthetics, intersecting around STEAM learning. Though the three studies were broadly based on Girod's themes, we also over time began to develop our own framework to support a rhetoric. Girod's work, though important, offers these four themes, but provides little structure for how the themes flow into one another, and their interrelationships. In contrast, our rhetoric, described in greater detail below, seeks to capture the entire cycle of engaging in STEM practices: from curiosity to the process of seeking answers, to a sense of completion, that in turn leads to new curiosities to explore (see Fig. 7.1). This forms a

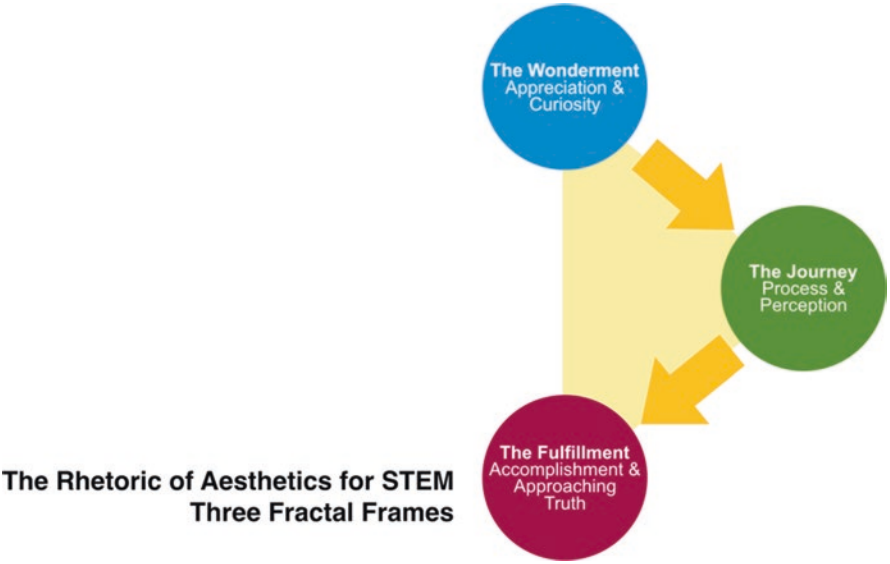

Fig. 7.1 The three frames that make the rhetoric of aesthetics

powerful virtuous cycle that seeks to maintain the same threefold sequence at different levels of learning—from the beginner to the professional scientist, mathematician, or engineer. We see this as a recurring fractal pattern, each phase informing the other. We call the three frames *The Wonderment*, *The Journey*, and *The Fulfillment* (see Table 7.1). We define and discuss each of these frames below and further define the subcategories that constitute each frame, in an aim to describe a rich picture of all that goes into an aesthetically driven vision of STEM.

1. **The Wonderment.** The first frame of aesthetics is that of the affective reaction—a sense of wonderment. It is the beginning of the aesthetic experience, building a sense of anticipation for future engagement. We see it has having two key subcategories: a sense of *appreciation* and a sense of *curiosity*. Both of these can vary a great deal depending on the knowledge of the individual. For instance, the appreciation of science or mathematics or engineering of a beginner would be very different from that of an expert.

   1.1 *Appreciation.* A cognitive-emotional reaction of awe, admiration, or respect inspired by feelings of astonishment, a sense of the sublime, or fear in nature and its understanding/explanation. In the beginning, appreciation may be for nature and the world, and as we learn more, our appreciation migrates toward the more abstract intellectual beauty and power of ideas and representations. Abstract concepts that help understand nature, in themselves, can inspire an aesthetic or affective reaction. This involves representations of the workings of nature, or explanations of its complexities, where one arrives at a theory and can finally exclaim admiration and appreciation. For instance,

Table 7.1 The three frames and their subcategories

#	Frames		Subcategories
1	The Wonderment	1.2	Appreciation
		1.1	Curiosity
2	The Journey	2.1	Process
		2.2	Perception
3	The Fulfillment	3.1	Accomplishment
		3.2	Approaching truth

Einstein's theory of special relativity leading to the iconic equation, E=mc^2, and Euler's formula, $e^{\pi i} + 1 = 0$, which has been called the most beautiful equation in mathematics, are some examples of appreciation that celebrate intellectual beauty. Laypeople and scientists alike can appreciate the beauty of many scientific phenomena, like a sunset, but scientific and mathematical knowledge can further lead to an appreciation of beauty in increasingly abstract ways (Girod, 2007). Appreciation can also lead to a sense of curiosity, a drive to learn more about something you appreciate, thereby paving the way for more scientific and mathematical knowledge.

1.2 *Curiosity.* A cognitive-emotional desire to seek, to anticipate, and to understand and/or solve problems or phenomena. This is the intellectual equivalent of an itch that must be scratched. The desire to learn about the unknown is, arguably, a fundamental human trait. We are capable of reacting to feelings of awe, admiration, and respect with sense of curiosity that kindles a desire to seek, anticipate, and solve problems and answer questions, in essence, to understand. Such moments of curiosity and anticipation are at the precipice of participation in STEM. Reacting to nature, one may feel like a detective who wants to solve new mysteries. In engineering, it may be the desire to tinker and play to construct new artifacts. This anticipation further fuels, organizes, and develops educative experiences (Girod & Wong, 2002). Teachers can tap into this feeling of curiosity and anticipation by creating experiences that inspire such emotional and cognitive responses.

2. **The Journey.** This is the *process* part of the STEM experience. It varies across the STEM disciplines, but across all are similarities in (a) learning the nature of the discipline, namely, norms, methods, knowledge, and purposes of discipline (Gardner & Boix-Mansilla, 1999) and (b) a process of socialization into the discipline, though again this has an important individual construct. This stage builds upon the Deweyan idea that "having an experience" can transform one's understanding of oneself and the world. As we have noted, Dewey (1934) viewed an educative experience as not just a question or a solution but a complex process—a journey. This second frame of the journey can be divided in two subcategories: the *process* and the *perception*.

2.1 *Process.* This is the experience of participating in STEM, where open scientific and mathematical inquiry itself can naturally turn to an aesthetic experience. Participating in the STEM-based inquiry, a learner works like a detective, aiming to solve the mysteries of the world using a sense of wonder as fuel and guidance. The act of exploration is, in itself, transformational. This can be an individual or group process that includes within it the act of finding and defining a problem and developing personal/shared strategies to solve it, leading to a shared sense of values and criteria for what is a good or bad solution. Throughout the journey, the process of going through the adventure becomes an educative experience, inspiring a deeper understanding of the world. This turns naturally into shaping how we look at the world—changing perceptions.

2.2 *Perception.* This is the transformative experience of looking at the world while doing or having participated in explorations in STEM. Richard Feynman illustrates this in his story about a conversation he had with a friend who claimed looking at a flower as a scientist diminished experiencing its beauty:

> …I see much more about the flower than he sees. I could imagine the cells in there, the complicated actions inside, which also have a beauty…the science knowledge only adds to the excitement, the mystery and the awe of a flower. (as quoted in Sykes, 1981)

Feynman demonstrates that his understanding and appreciation of the world is fundamentally changed by his knowledge about biology, which in turn changes *him* and the way in which he interacts with nature. Even if one has not achieved a solution to their question, or does not fully understand how the nature works, their way of looking at the world has changed because of their participation in STEM.

3. **The Fulfillment.** The third frame is the feeling of fulfillment. It is the (possibly temporary) culmination of engaging in the STEM-related activity, temporary only because it often leads to new wonderments (appreciation and curiosity) and the start of a new journey (process and perception). The subcategories here are a sense of *accomplishment* and the discovery of *truth.*

3.1 *Accomplishment.* The feeling of pride at having reached the end of a curious exploration. For example, this may involve finding of an explanation or an answer for a problem/question and is often characterized by a sense of completion tempered with the knowledge that more phenomena remain to be understood and more problems remain to be solved. The sense of accomplishment can be seen as small feelings of fulfillment that emerge as a result of having reached a conclusive explanation of a curiosity. A curiosity in STEM might be big or small depending on the task involved and the intricacies of the journey it entails. However, all curiosities, big and small, eventually reach an end that gives a sense of having accomplished something. This sense may not be as powerful as an overarching sense of fulfillment but contributes toward it in small wins. For example, spending months figuring out a way to successfully land a rover on Mars does not have to end in a discovery of truth but gives a sense of having achieved a breakthrough solution that adds to the overarching sense of fulfillment.

3.2 *Approaching Truth.* This is the sensation of having genuinely engaged with the world and understood it on its own terms. It is a sense that we have conducted a reality check that the abstractions and constructions created help explain, exploit, and predict patterns and rules in the real world. It is a sense of accessing truths, of grasping how the world works, independent of us, however fleeting that feeling may be. It is the sense of getting an inside glimpse at the "grand design." There is sometimes the feeling of a spiritual, religious, or even mystical quality to this component of an aesthetic experience (see Fig. 7.2).

The Three Fractal Frames A rhetoric of aesthetics in STEM is made of these three key frames that we see as pieces of a recurring, recursive, spiral (akin to a fractal pattern), feeding each other through a cognitive-emotional transaction. Wonderment is not simply one beginning, just as fulfillment is not the end. Fulfillment leads to new appreciations, questions, and wonderment—leading to new processes and perceptions. The cycle has the potential to go on forever—deeper and deeper. This is what we mean by *fractal frames*; these three frames and their relationships continue as long as we have the energy to pursue these ideas.

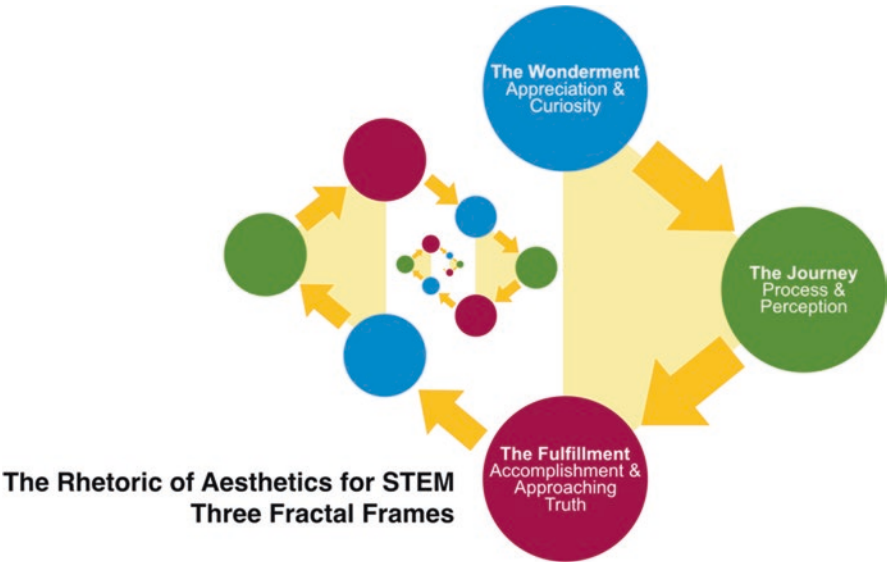

Fig. 7.2 The three fractal frames that make the rhetoric of aesthetics

Lessons for Practice: Designing a Rhetoric of Aesthetics in STEM

Moving from simply a rhetoric of aesthetics to its actual instantiation in curriculum or classroom practices is not a trivial task. Some might even consider it a wicked problem (Koehler & Mishra, 2008; Rittel & Webber, 1973). There are some particular challenges in developing a curriculum that values the aesthetic, primarily because it encourages an experiential nature that differs from traditional or common schooling approaches but also because it evolves over time. This requires that we move beyond thinking about content to considering a host of intangible elements that go into the experience that teachers of such a STEAM curriculum would face. In the section below, we articulate our approach broadly and then discuss specifics of how the revised threefold rhetoric we propose above plays out in the specifics of curricular enactment.

Exemplifying a STEAM-Based Aesthetic Framework Within Teacher Professional Development We will contextualize our discussion within a specific STEM-focused teacher professional program (the MSUrbanSTEM program; msurbanstem.org), which was a yearlong blended professional development fellowship experience for STEM teachers in Chicago Public Schools. Two authors of this chapter have worked closely with 124 in-service Chicago teachers/fellows, across 3 different cohorts spanning 3 years. The yearlong fellowship program focused on STEM and leadership, using John Dewey's philosophy of learning by doing and experiencing, along with Mishra and Koehler's (2006) TPACK-based approach to repurposing technology in practice. One of the many purposes of the fellowship program was to provide teachers with approaches to take leadership in their individual contexts, to find compromises and strategies for implementation between their instrumental curricula of STEM and a rhetoric of aesthetics.

The instructional team worked closely with the teachers/fellows, both face to face and online, throughout the yearlong fellowship. The program began with 11 days of face-to-face work in summer and was followed by online components that spanned the school year, with 4 full-day Saturday meetings (two in each semester). Fellows worked on a range of projects during the year, what we describe as micro-design projects, macro-design projects, and reflections on the total package of implementing both TPACK and aesthetic understandings (Koehler et al., 2011). The rhetoric of aesthetics played a key role in the design and enactment of the curriculum (as described in greater detail below), in an attempt to bring more STEAM to these teachers' STEM.

In considering the rhetoric of aesthetics and its role in curriculum development, we must remember what Dewey said about experiencce when he wrote that "The belief that all genuine education comes about through experience does not mean that all experiences are genuinely or equally educative" (Dewey, 1938, p. 25). An experience is a transaction that happens between an individual and the variable of elements of their environment and the world around them. It is not just a psychological phenomenon that happens exclusively "within" us but rather that experience takes place in the world itself. It is made up of our continuous interaction and participation with objects, situations, and events that constitute our environment.

As we consider the role of the aesthetic in teaching and learning, one of the first things to consider is the fragility of the aesthetic encounter itself, which means that the nature of the aesthetic is such that it requires elements to work together in a holistic, synergistic, and coherent manner, as it is easy for the intended experience to fall apart. Thus we, in the MSUrbanSTEM project, took great care to consider (in so far as possible) every aspect of the instructional system, to create an environment where risk-taking and failure were acceptable, where wonder and new ways of looking at the world were emphasized, and where beauty and truth (in the STEM disciplines) were valued and celebrated.

This meant the MSUrbanSTEM program needed to have certain characteristics that would allow the rhetoric of aesthetics to play out successfully in an interactional and transactional way for the teachers. These characteristics included consideration of the following factors: the curriculum or the program had to be *unified*, in that the coursework was integrated and coherent, and strongly connected to practice. It had to emphasize *combinatorial creativity* (or a view that creativity emerges when different elements or disciplines combine in unique ways), through a focus on repurposing technology and using new lenses on the curriculum. It was built on the idea of *deep play*, which is an active, collaborative engagement with rich problems of practice and a focus on finding new ways of seeing the world and new approaches to teaching. Finally, and most importantly, the curriculum and its instantiation in the classroom context needed to have a *dramatic quality*, or a compelling narrative driven by wonder and curiosity and aesthetics qualities we have described above.

In the section below, we describe, briefly, how each of these elements played out through the yearlong program. It is important to point out that though we tease apart these elements in our writing, it is much harder to do so in practice. In practice these elements are interconnected and work together to create a coherent whole, which is often greater than the sum of its parts. As this is only one chapter, we cannot include a complete description of how the aesthetic played out in the entirety of the program. But to exemplify these ideas to some degree, we take the fractal frames informing our rhetoric of aesthetics and provide examples of how each of them is intentionally integrated within the MSUrbanSTEM program.

The Wonderment (Appreciation and Curiosity) One of the tasks done at the beginning of each day is what we call the sharing of a World of Wonder moment, i.e., WOW! moment. These WOW! moments were introduced by the instructors and consisted of sharing something in the world around them that intrigued them or made them wonder.

For instance, one teacher/fellow shared and discussed a similarity she saw in patterns of bubbles in a bowl of lentil soup boiled on a gas stove and a specific atmospheric pattern known as "cloud trains." Both these phenomena had been independently observed by one of the instructors (and authors of this chapter). Upon digging deeper, the similarity between these two phenomena was revealed.

The teachers/fellows were promoted to do this at the start of every day, in order to encourage the practice of wonder in themselves (ideally leading to an instantiation of it in their teacher practices). Though this began somewhat slowly, as the days went on, the fellows began to share a wide range of examples that they had been observed in their own lives: from how traffic is controlled in Chicago's express lanes to how the new soda-creation machines actually work and from how many more steps a shorter person will take in their lifetime compared to someone taller to wondering whether people are differentially attractive to mosquitoes.

As these examples indicate, the kinds of problems that arose were diverse and deeply personal (for instance, the one about number of steps taken in a lifetime was suggested by a teacher who was herself quite short and self-confessedly had to almost run to keep up with others even while walking). Even more interesting than how they practiced the activity in the professional development sessions was how the fellows took up and integrated this practice into their own classrooms. Some of our teachers/fellows used our activity "as is" with their science students, while others created variations for their unique contexts. For example, one teacher/fellow created a "Wall of Wonder" in their classrooms, which was a bulletin board where students could post questions that intrigued them—they would then collectively choose to investigate them further. Essentially, this activity promoted the fellows to be more present in the world to view it from an interdisciplinary-aesthetic STEAM sense of science and wonder. Through this they could see the world as a source of questions and mystery (the emotional component) *and*, at the same time, amenable to analysis and understanding, often through a disciplinary lens (the cognitive component).

The Journey (Process and Perception) One could argue that the WOW! activity above was key to learning and investigation in STEM. That said, the fellowship provided teachers multiple opportunities to engage in the inherent pleasure in the experience of *doing* STEM in an aesthetic, real-world, interdisciplinary way. This included such activities as visits to Chicago's Museum of Science and Industry where the teachers/fellows were prompted to look at the exhibits through the lens of their disciplinary interests or having them engage in a mini-maker fair, where they constructed a range of artifacts using everything from maker kits, mini-circuits, straws, and Play-Doh. The idea of "engineering" a solution to a problem was actively promoted in multiple ways. For instance, the teachers/fellows created musical instruments using whatever real-world objects they could find around them. In each case, the idea was to engage our teachers/fellows in authentic STEAM-related experiences to explore the aesthetic pleasure and beauty of *doing* work in the sciences. Our teachers/fellows took these ideas and implemented them in their classrooms as well, in various ways. Specifically, in their yearlong projects, many of our teachers/fellows took on key aspects of what it meant to do science, mathematics, and engineering; and they had their own students engage in the actual process of *doing* STEM. In that sense, the perception of science shifted from being a narrow, cold, or rigid mechanical task into one of activity, excitement, engagement, and creativity.

The Fulfillment (Accomplishment and Approaching Truth) Achieving a sense of accomplishment, or a feeling of engagement with the world, or approaching some kind of truth, is difficult to achieve in a classroom context. But at least experientially, there were moments in the MSUrbanSTEM program where it appeared that we had genuinely, even if for a moment, gotten there. We provide one such example below.

A few days into the program, one of the instructors (and co-author of this chapter) introduced the statistical concept of the "long tail" in business and education to the students. That led to a discussion of power laws and what those curves mean in the real world. At that point, the idea of Benford's Law came up. Benford's Law, also known as the first-digit law, is a counterintuitive fact that notes how in all kinds of listings of numbers in the real world, the digit 1 tends to occur as the first or leading digit far more frequently than expected. This is true of sets of numbers as disparate as electricity bills, stock prices, lengths of rivers, physical constants, population numbers, and so on. This "strange" result led to a great deal of discussion, until two teachers/fellows took up the challenge of explaining it to the entire class. They approached it from two very different directions—one going with an intuitive sense of numbers and growth and the other using mathematical formulas for power curves and exponential growth. Through that process, the entire class experienced and learned to appreciate the way abstract mathematical ideas can take what initially appear to be anomalous phenomena in the world and make sense of them through the language of mathematics, with relatively intuitive and clear outcomes of mathematical principles. Here, there was a sense of accomplishment in grasping some fundamental truth about the world and a sense that the world had opened itself up for investigation and revealed its "grand design."

Conclusion

In this piece, we have aimed to promote a model of learning within the STEM disciplines that is predicated upon aesthetic ways of knowing, thinking, and exploring the world. We suggest that bringing such an aesthetic sensibility into the arena of STEM provides us with a lens for STEAM, which spans the arts, sciences, and many other disciplines. Our view of STEAM, in this way, allows the value of interdisciplinary learning to emerge in contexts that value the very impulses that make us human—including curiosity, excitement, inspiration, exploration of ideas, testing and probing the world, and appreciating beauty (in the world and in the explanatory structures we create).

We have aimed to construct our argument along several lines of theory, drawing on classic educational philosophers such as Dewey (1934), to more recent works that bridge education and aesthetics (Girod, 2007), to principles of human psychology (Gopnik, 2000), and to work that explores the history of science and technology or accounts of STEM practitioners (Chandrasekhar, 1987; Orrell, 2012;

Root-Bernstein & Root-Bernstein, 1999). We have built upon all of these ideas to make a clear case for the value of employing a rhetoric of aesthetics in STEM teaching and learning—to draw us toward a more STEAM-based view of learning.

Moving beyond theoretical exploration, we also have shared several accounts of recent studies from our own lines of inquiry, which help us to think more about how these constructs play out in research. Each of the three studies we described, in connection with our rhetoric of aesthetics, have helped us develop some practical considerations for teaching STEM in a more aesthetic manner. The rhetoric of aesthetics that we have developed out of this work is focused on the threefold fractal frames of *The Wonderment*, *The Journey*, and *The Fulfillment*, to help us paint a picture of STEAM which reflects how people might feel and experience STEM in ways that inspired practitioners often do.

In the provision of any set of frames or lenses for viewing subject matter, it is important to consider what these mean for teacher-practitioners, since teachers are the mediators of experiences that learners have in schools. We discuss and expand on what this rhetoric has looked like in an example of STEM teacher professional development—showing examples of how these frames The Wonderment, The Journey, and The Fulfillment have been instantiated for teachers. Furthermore, these frames have (at least in our preliminary experiences) helped teachers to rethink and redefine their lenses for STEM—moving them toward a more aesthetically driven STEAM perspective and changing their own view on science to manifest a personal rhetoric of aesthetics in how they look at the world.

The blending of aesthetic ways of knowing with STEM disciplinary teaching and learning was always the driving force of this work—in the research, practice, and theory pieces that we propose here. Along the way, it became clear that this rhetoric of aesthetics for STEM could provide a uniquely appropriate lens for thinking about STEAM. The terminology for STEAM is still relatively new in the arena of educational research and literature. However, the foundations of STEAM can be found in the work of Dewey, who proposed a much more interdisciplinary, experiential, and aesthetically driven view of curricula and student learning.

Our work here draws upon some of the foundational ideas about learning, as well as the accounts and descriptions of how actual STEM experts often experience these disciplines in inspired ways. Such ways of knowing focus on concepts that are as integral to the arts as they are to the sciences, as well as to all disciplines of human knowledge. This reveals a sensibility for STEAM rooted in STEM learning experiences that include more authentic or real-world learning experiences or the blending and blurring of disciplinary lines and which integrate activity, curiosity, and more emotional connection to the complexity of STEM. All of these elements marry well with the ways in which scholars have begun to think about STEAM recently (Bequette & Bequette, 2012; Boy, 2013; Brophy, Klein, Portsmore, & Rogers, 2008; Jolly, 2014, 2016; Piro, 2010; Radziwill, Benton, & Moellers, 2015).

In our proffered frames and rhetoric, there is nothing dramatically new or wildly inconsistent with existing underpinnings of learning and human psychology. But what we do offer is a subtly new interpretation of—and practical or theoretical frame for—understanding STEAM as an aesthetically driven approach to STEM. We share a construction and constellation of ideas to help teachers and students consider and explore STEM in ways that uphold their sense of beauty, wonder, awe, curiosity, and the inherent pleasure of figuring things out. Through this, the aim is to give them the opportunity to experience new knowledge much in the way that artists, scientists, mathematicians, and the most inspired thinker across disciplines do. If we need such creative, inspired, and interdisciplinary problem-solvers to become involved in STEM areas, then education must consider an approach that speaks clearly to this need.

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