Of Metaphors and Molecules

Figurative Language Bridging STEM and the Arts in Education

DANAH HENRIKSEN AND **PUNYA MISHRA**

ABSTRACT

STEM education in the United States is often described as being in a downward spiral, when assessed by competency test scores and lack of student motivation for engaging STEM disciplines. The authors suggest this arises from an overly instrumental view of STEM. While STEAM has arisen as a pushback paradigm, the application of STEAM in schools is challenging, and educators are often unclear about connecting STEM and the arts. The authors suggest envisioning STEAM through natural disciplinary interconnections. They focus on the integration of language arts and figurative thinking to blur the boundaries of STEM and the arts, and offer examples of figurative language—such as metaphor, linguistic etymology and synecdoche—for framing STEM teaching and learning.

> *The limits of my language mean the limits of my world.*
>
> —LUDWIG WITTGENSTEIN

> *We must be clear that when it comes to atoms, language can be used only as in poetry. The poet, too, is not nearly so concerned with describing facts as with creating images and establishing mental connections.*
>
> —NIELS BOHR

STEM TO STEAM: THE DIFFERENCES ARE MORE THAN A LETTER

Common rhetoric suggests that STEM (science, technology, engineering and mathematics) education in the United States is in crisis, with waning student performance on standards and decreasing interest in these disciplines [1]. This is despite increased attention to, and systemic glorification of, STEM in education, often at the exclusion of the arts.

To explain this disconnect, scholars have pointed to the siloed structure of school disciplines [2]. The arts are often sidelined as frivolous or discretionary to STEM goals, and students believe the disciplines are disconnected from each other and from their world [3]. Interest in the sciences plummets—and with it goes science literacy, artistic sensitivity and a sense of curiosity about the world.

The STEAM movement is an approach to integrating the arts into STEM. The common definition of STEAM is an educational approach where science, technology, engineering, the arts and mathematics are integrated for classroom learning and inquiry. The concept of STEAM is worthwhile. Yet STEAM application in schools is a mixed bag, with educators often unclear as to what STEAM might look like. In practice it is often reduced to dropping some art into a science lesson—in other words, popping an "A" in alongside the STEM [4]. There is nothing inherently wrong with this, as putting the arts into science lessons is one strategy for interdisciplinarity in learning—but it is only *one* strategy. Focusing on one strategy is limiting and misses a chance to explore deep interrelationships and interdisciplinary links.

This is not a critique of teachers or STEAM scholars but an acknowledgment that imagining creative disciplinary integration is not intuitive. The term "STEAM" may leave educators struggling with open-ended possibilities, or they may wonder how to integrate art into science if they have no arts background (or vice versa). We suggest broadening STEAM beyond disciplines to focus on areas of creative interconnections that span disciplines. While there are many areas that might be pursued, here we explore the use of figurative language in STEM.

Binding and Unbinding the Disciplines in Schools

Conventional STEM education often misses the richness of disciplinary intersections. Many learners go through mandated schooling failing to see the beauty in science [5]. They will not experience wonder at the clarity in an elegant geometric proof or a moment of awe in peeking through a

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See www.mitpressjournals.org/toc/leon/53/3 for supplemental files associated with this issue.

https://doi.org/10.1162/leon_a_01607

telescope to view the vividly etched rings of Saturn. Science literature is full of beauty and wonder-driven approaches [6], but few of these make it into schooling. By denying the artistic and emotional components of STEM, the field of education sets the stage for student disengagement [7].

Conventional schooling has ignored these aesthetic, creative perspectives for many reasons. To find efficient ways of teaching STEM, schools often adopt a functional, instrumental rationale for STEM. Science education has tried to emphasize science literacy—as in the 1989 publication *Science for All Americans* [8] or across educational benchmarks, such as the more recent Next Generation Science Standards [9]. Still, instrumental approaches prevail in practice. This happens partly because of the structure and origins of U.S. schools, which historically originated through an Industrial Revolution learning model. Conformity and rigidity are designed into the system. Conventional structures of U.S. schooling more closely resemble the narrow, scripted principles of behaviorist Edward Thorndike rather than the creative constructivism of educational philosopher John Dewey [10].

Instrumental reasoning positions science as a tool rather than a personally motivating, beautiful subject. This happens when we push participation in STEM fields because they offer high-paying, stable professions, or because such reasoning feeds a patriotic rhetoric where STEM helps nations dominate international competition. Such rhetoric was ingrained during the U.S.-U.S.S.R. space race in the 1960s, where STEM was a tool to win international competition [11]. Influential reports, such as *A Nation at Risk*, affirmed a sense of war and competition as the true value of education, by opening with, "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" [12]. Even well-intended approaches, like President Obama's STEM for All, consistently emphasize STEM in instrumental ways—e.g. to "land a good-paying job," or "offering every student the hands-on computer science and math classes that make them job-ready on day one" [13].

STEAM emerged as pushback to such instrumentalism. To design creative, real-world lessons across the sciences and arts, education must emphasize interdisciplinary interconnections. Some STEAM scholarship gives examples of such connections. For example, one strategy involves *using design as a framework* for problem framing across the arts and sciences [14]. Another is to *build a rhetoric of aesthetics* in classrooms to foreground curiosity, awe and wonder [15]. Other scholars suggest *active-learning approaches*, with a focus on *art-studio models of instruction* [16]. One of the most consistently suggested STEAM strategies is *project-based learning*, using *real-world examples* where students engage in work that naturally crosses disciplines [17].

In this article, we suggest taking a *linguistic turn.* Figurative language illuminates ideas in the arts—but is also fundamental to how creative and influential scientists operate.

Figurative Language in Thinking

Educational psychology emphasizes how prior knowledge builds mental connections for new knowledge [18]. Language is the symbol system through which we understand new ideas or connect them to prior knowledge. As Lakoff and Johnson note, "Our ordinary conceptual system, in which we both think and act, is fundamentally metaphorical in nature" [19]. Figurative language, which is common to the arts, is also important to STEM. Linguistic tropes can provide educators another learning bridge across art and science. This includes metaphors and analogies as well as other aspects of language.

Tropes of Language in the Arts and STEM

Figures of speech extend beyond language arts courses to help us make sense of our world. Expressions like "falling in love" or "time is money" are *metaphors* that pervade our everyday understanding. *Similes* make comparisons, like "quiet as a mouse." *Hyperbole* highlights a point, like emphasizing hunger by proclaiming, "I'm starving!"

Every work of art involves figurative thinking, because art is always a representation. In poems or fictional stories, one object or idea often communicates something else. In movies, sculptures or paintings, artists rarely replicate reality exactly as it is. Instead they demonstrate something new or interesting about an idea, scene or object by viewing it through the lens of something else. For example, Rene Magritte probed the nature and process of representation of the world across both language and art.

In a scientific example, Isaac Newton's analogy—comparing our moon to a ball thrown so hard that its descent misses the earth and passes into orbit—allowed him to diverge from the Aristotelian notion that a body has one kind of motion. This generated the idea of a forward-falling composite motion of objects in orbit [20]. These examples reveal how figurative language can allow for the creative, interdisciplinary learning that students need.

DRAWING ON LANGUAGE ARTS FOR STEM

We share a few illustrative examples of figurative learning connected to STEM, starting with the concept of *metaphor* (in multiples), then expanding to less common language tropes such as *synecdoche* and finally exploring the power of *etymology* to connect the arts and the sciences.

Multiple Metaphoric Meanings

Metaphors abound in science and mathematics. The number line is itself a metaphor. Numbers have no inherent need to be placed on a straight line heading to infinity from left to right. Yet this is a fruitful mapping that allows us to understand relationships and manipulate numbers. Other examples include seeing the heart as a pump, or viewing energy conservation as akin to balancing account books or considering DNA as the "code of life" to be "translated" into building proteins.

Yet there are problems in taking classroom metaphors too far. They are imperfect vehicles for knowledge, because ab-

Fig. 1. Multiple metaphors for energy. Illustration by Punya Mishra. (© Punya Mishra)

stractions may miss details or overemphasize similarities. A solution to this would be to enrich concepts with *multiple* metaphors. For example, the concept of energy is fundamental across multiple science disciplines. In biology, energy is part of photosynthesis/nutrition, while in chemistry it relates to chemical bonds, and in physics it involves kinetic/potential energy. Students seeing the same idea within different disciplines may not understand these differences or connect multiple uses of the same word to its conceptual richness [21].

Rachael Lancor suggests that there is value in using multiple metaphors [22]. She notes six key conceptual metaphors for energy, including: (a) Energy, like money, can be accounted and tracked; (b) energy can take different forms and change from one to another; (c) energy can flow like water through a pipe; (d) energy can be carried by organisms as well as inanimate entities like electrons; (e) energy, like oil in a faulty machine, can be lost; and (f) energy can be stored in devices such as a battery or a wound spring.

Using multiple metaphors allows students to appreciate the richness of a construct and the complex relationships where it occurs. Figure 1 contains a visual representation showing how multiple metaphors can enhance STEM through language arts, with opportunities to create visuals through artistic representation. Having students do their own creative representations of metaphor can provide natural art and language "hooks" to STEM education.

Synecdoche across Scales

Synecdoche is a figure of speech in which a part of something describes the whole. For instance, we say "ABCs" for the alphabet or "set of wheels" to represent a car. This part-whole relationship is also key to understanding mathematical and scientific ideas on complex systems and self-similarity. Synecdoche or self-similarity have always been part of human thinking, with examples spanning fields like biology (the tree-like growths of broccoli and cauliflower), geography (the structures of coastlines), mathematics (fractals) and physics (atomic energies) [23].

Self-similarity, or a pattern across scales of magnitude, is common in the world. Examples may include everything from an ant colony to a rainforest, from the human brain to the contemporary mega-city. Science has discovered that, although these systems may exist at extremely different scales, they maintain certain properties—such that parts of the system may resemble the whole. Interestingly, ideas of self-similarity are present in literature and art as well—for example in the stories of Jorge Luis Borges or the art of M.C. Escher.

In teaching fractals or complex systems, educators may find it useful to start with everyday examples (such as broccoli and tree-branching) and then let students zoom in or out across different scales of magnitude—from twigs to branches to trees—to demonstrate how a part represents the whole. Similarly, complex systems such as the networks in ant colonies can be compared, by zooming in, to the circulatory system in our bodies—or by zooming out, with the streets and physical networks in cities. Making visual or artistic creations, such as in Fig. 2, allows students to play with ideas, considering how synecdoche occurs across scales, with opportunities to re-see the world.

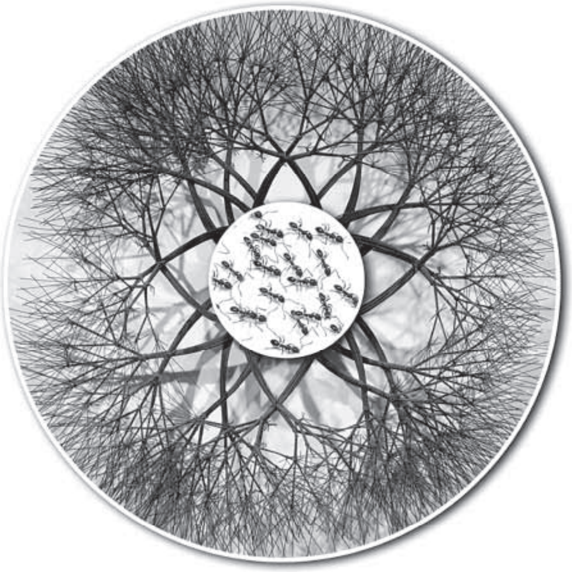

Fig. 2. Complex systems are dynamic, self-organizing, evolving networks that can operate without central control (e.g. ant colonies, rainforests, human brains or cities). Illustration by Punya Mishra. (© Punya Mishra)

Etymology of Language

There are opportunities in STEM to uncover connections in the etymology of language. This allows us to unpack language as an art to enrich understanding of science. For example, in mathematics, the term "radical" describes the root of a number. In traditional math, students receive a basic textbook definition such as, "The nth root of a number x, where n is usually assumed to be a positive integer, is a number r which, when raised to the power n yields x." They might learn such basic terminology stripped of context—and then proceed to the next operation.

However, bridging the concept of a radical into language arts, a teacher might ask students to conduct an investigation into the etymological meaning. This reveals definitions involving the idea of a "root." One definition of radical is "relating to or affecting the fundamental nature of something." This goes beyond math to the idea of a "root" issue—in mathematics, but also more broadly. Students might discuss how a person described as a "radical" is one who wants fundamental change at the "root" of something.

Further, a student-led search into this etymology demonstrates that the word is grounded in the Latin *radix* or *radic* (again meaning "root") and in late Middle English (which refers to something "forming the root" or something "inherent"). This explains another familiar connection to a common vegetable—the radish, a root vegetable. In this one example, we can unpack the creative linguistics underlying the etymology of a term, to show connections across disciplines.

A similar connection exists between a linguistic arrangement called a *chiasmus* and chromosome division. Linguistically, an example of a chiasmus was in President Kennedy's inaugural speech where he famously said, "Ask not what your country can do for you—ask what you can do for your country" [24]. President Kennedy (or his speechwriters) loved phrasing sentences in this way. In the same speech he stated, "Let us never negotiate out of fear. But let us never fear to negotiate." In a later speech to the United Nations, he said, "Mankind must put an end to war, or war will put an end to mankind" [25]. The root of the word *chiasmus* is the Greek term meaning *diagonal arrangement*. In linguistics, it describes two successive clauses or sentences where key words or phrases are repeated in reverse order, sometimes known as criss-cross figure of speech.

In cell biology, a chiasmata is the contact point between two chromatids of a chromosome during meiosis. There is an exchange of genetic material between chromosomes, in what is known as a chromosomal crossover. Chiasma also comes from the Ancient Greek *khiazein*, which means "to mark with the letter chi." The Greek letter chi's (χ) shape captures the linguistic structure of chiasmus and also the physical connection between two chromatids of a chromosome. A specific form of chiasmata is a "chi structure." Thus etymology, linguistics and biology intersect, allowing deeper understanding of word meanings and richer connections in learning.

Such examples afford teachers an entry point to connect language arts (and more) to the sciences. Figure 3 is one simple visual example of how one could represent these ideas, although students might create a multitude of visuals of their own.

STEM disciplines are grounded in linguistic moves with creative connections. Such playfulness and experimentation with language offers a path to more meaning and connectivity in STEM learning.

CONCLUSION

Whether teachers use the more common literary elements of metaphor or analogy or expand to possibilities including synecdoche, hyperbole, pun and personification, the key is to make transdisciplinary connections and take STEM out of a narrow box.

During a research interview, National Teacher of the Year finalist and STEM educator June Teisan [26] described this idea in her teaching:

> When creating a lesson I ask, what do I want kids to walk away with? What's the essential kernel of truth? . . . For example, germination is important for them to know, but I'm going to talk about it as sprouting. I might frame it so that a seed itself is like a baby; and it has its lunch and the mother plant wrapped it up and sent it off. It's going to travel out into the world, through the air, or on the water, or on somebody's fur. So kids can see that as a picture in their head. . . . Those kinds of abstractions, they help you file away the rust and get down to the gold. Everybody loves a story.

Enactment of language arts in STEM learning may "file away the rust to get down to the gold" of an idea. In other disciplines, we use such abstractions or explorations to understand complicated things. The purpose is the same here. STEM domains are richer and more connected than school curricula often recognize—and figurative language or other transdisciplinary conceptual hooks may reveal this to students.

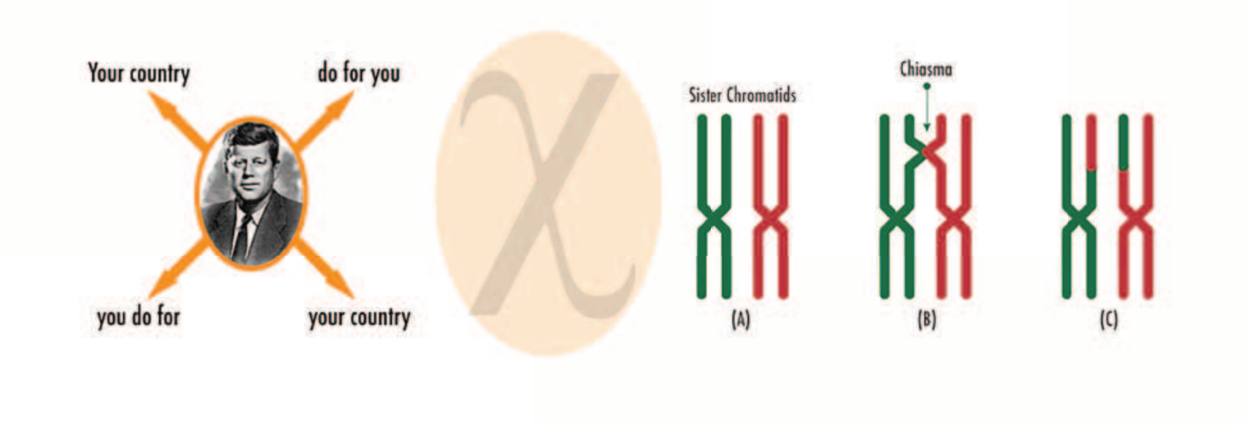

Fig. 3. Chiasmus, chi and chiasmata. Illustration by Punya Mishra. (© Punya Mishra)

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Manuscript received 28 August 2017.

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