Chapter 4
Getting to "Know" STEAM

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EXECUTIVE SUMMARY

This chapter describes the evolution of a personalized, arts-integrated approach to science curriculum inquiry which has been evolving since the 1990s—before even the national science standards, the acronym STEM, much less STEAM, appeared across educational horizons. It reads as ethnography and has been performed in community, in association with the most caring of souls, with the goal of achieving a more inclusive/empowering, aesthetic science education and a deep appreciation of the importance of the creative arts in the learning process. It presents two research-based iterations in STEAM education in practice: 1) the creation of arts-integrated middle school ocean science curricula and 2) the development of a pedagogical tool called the "Know"tation as a way for teachers and students to make learning visible and integrate the languages of science throughout the process of inquiry. The cases described in this chapter apply many features of the STEAM model developed in Chapter 1 of this book.

INTRODUCTION

How can we engage those students who struggle to read and for whom science informational text seems particularly threatening? I myself encountered this same challenge in my very first teaching job, where I was tasked with teaching physics to 35 older ninth graders who had previously failed the class. The football coach, their former teacher, declared that they were his "dummy class." "Don't expect too

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much from them," he said matter-of-factly. I was astonished. Certainly no one in that class was stupid! Yet, they had most definitely had been made to *feel* that way through tracking, neglect, and marginalization. The real kicker was that the more affluent students up the hall in the "gifted science class" had a nice lab with equipment and space to do experiments. We, on the other hand, had 35 desks crammed into rows in a small corner classroom and an old textbook none of my students could read. I was so mad I could spit. But I was also lucky. I had been trained in the arts, and I knew how to draw and to tell a story, and so used that as a way to connect with language we could all understand. Together, we drew and played with funny little cars, which we rolled down those crummy old text books. These kids started passing, and I started to get a sense of what it meant to *design* a science curriculum as an artist might.

What I did not realize then, as I do now from study of Elliot Eisner, John Dewey, Johann Pestalozzi, Maxine Greene, Richard Siegesmund, Liora Bresler, Bruce Uhrmacher, and other arts education researchers is that what I had observed in my students and myself was an *aesthetic* transformation.

Uhrmacher (2010) noted that a student who acquires "aesthetic capital" may feel or act differently – in a good and positive way. I myself, a brand new teacher, was so transformed by the way an artistic pedagogy turned around previously failing students that I set out to change science education. Ah, to be 25 again! I applied to the MEd program at the University of Hawaii, where I took graduate level classes in both the visual and performing arts as well as art and science curriculum theory. I became determined to identify the ways in which science and art share a common language and developed an experimental curriculum I called Teaching Science through the Arts—TSTA – at a time before even the acronym STEM had become popularized (Koester, 1989). I researched, developed, and then field tested curricula for teaching science through the creative arts of drawing, poetry, music, dance, creative drama, and fictional literature. In my master's thesis, I tentatively proposed that virtually any area of K-12 science could be taught through the arts. The lesson planning objective, I reasoned, was to match the art form to the dynamics of the science content being taught. Right off, I recognized that a science teacher who would implement the TSTA model would need to either personally acquire basic skills in multiple art forms, and/or collaborate with an art teacher specialist. Because I had significant arts training, I managed to create and field test about fifteen TSTA lessons as part of my final thesis. However, I did not have nearly enough data to propose a *theory* about best practices for teaching science through the arts. That process has taken nearly two more decades.

What follows is a true story that narrates the transformation of a science teacher into a researcher and the evolution of an idea into a curriculum model that is still growing and developing.

BACKGROUND

Creating As-If Worlds

A few months after completing my masters at UH, I returned to my home state of South Carolina with my hundred page thesis carefully packed in a special box. I had accepted a middle school science position and was eager to field test my arts integration techniques in a sixth grade physical science and eighth grade Earth science class. After only one week, however, my principal said that she had forgotten to tell me that I would be required to take my sixth graders through their first ever science fair projects. Oh, no! Which art form would possibly *match* the teaching of THE scientific method, something our curriculum dictated *all* students were to *learn*. I was full of dismay and fretted for nearly a week, when suddenly, the answer came to me as clearly as I imagined Archimedes' Eureka Moment had occurred to him. Late on a Sunday evening, after I put my two boys to bed, I began writing a "fictional" story about a twelve year old girl, who unwittingly let her father complete her entire science project – an impressive, meter tall electromagnet crane. Even worse, the girl had won *first* prize for work she had not done herself. Her best friend, who *had* done her own project, came in second. The next morning, I shared with my sixth graders the beginning of a story that later became the first of four science education novels, written over the course of two decades, and recently released in their third editions (Koester, 2015 b-e). Almost instantly, my students entered into the shame my young protagonist felt for cheating her best friend out of first place. We reflected at length on the importance of doing your own, honest work. They learned the steps of the experimental process by performing the "Science Rap," which I had written for them. To my amazement, nearly all of them eagerly dug into their own projects, determined to do their own work. That same year, one of my sixth graders, who was so shy that she rarely spoke, won first prize in the regional science fair. She, like the character in my story, later grew up to be a science teacher.

Who among us did not dread doing their first ever science fair project? Indeed, I was that twelve-year-old girl *and* the teacher who was now all grown up and trying to get my students to actually embrace this arduous task. In my creative drama classes at UH, I had discovered the power of creating *as-if* worlds in the science classroom (more on that in just a bit). The effect seemed extra-ordinary if that world came from a fictional trade book. I developed this hypothetical learning equation: Imaginative story (in a trade book featuring science content) + creative drama (with movement) → Learning + Engagement. To test my claim, I developed for my then fourth graders a lesson on digestion. I began by reading with them the trade book, *Gregory, the Terrible Eater,* by Mitchell Sharmat. This allegorical tale is about a goat named Gregory, whose parents think he is a TERRIBLE eater because he wants to eat foods like fruits, vegetables, eggs, and fish instead of the *normal* GOAT diet of shoes, paper, tin cans, coats, pants, etc. My students eagerly responded when I asked them to get on all fours and pretend to eat a pile of shoes like good little goats. But, oh my! I wish you could have seen the Oscar-worthy performances they gave when I asked them to refuse to eat as their parents demanded. The pawing and stomping and mournful bleating were hilarious. Some rolled on their backs and kicked their feet in the air in defiance. To add a musical performance component, we improvised an operatic, call and response exchange between a group of students, pretending to be goat kids (refusing to eat perfectly yummy shoes) and their worried goat parents. The "tune" we used was Beethoven's Fifth—da, da, da, daaaaaaa (Koester, 1989):

Kids: *We will not eat!*
Parents: *Oh, yes you will!*
Kids: *Shoes make me sick!*
Parents: *Don't talk like that!*
Kids: *We're feeling weak.*
Parents: *'Cause you don't eat.*
Kids: *It tastes like junk!*
Parents: *What will we do?*

Andersen (2004) has written that "the methods of drama in education have the potential to create 'as-if' worlds within the classroom that can foster *situated* learning" (p. 284). Andersen was referring to the cognitive psychology studies of Brown, Collins, and Duguid (1989) on the benefits of learning in *authentic* contexts, *situated* within a context with which one could personally relate. Andersen argued that through creative drama and the creation of *as-if* worlds, students could enter into simulations of what *felt* like authentic experiences. Through the vehicle of our imaginations, stories take us places where we might never, pragmatically speaking, be able to go—in spaceships to Mars; in deep sea submersibles to deep ocean hydrothermal vents, where giant tube worms with bright red tips twist and turn in front of the front window; and into science research laboratories, where people, like we may become one day, race to discover a vaccine against *Ebola*. We enter into deep, empathic relationships with a story's characters.

Neuroscientists have determined that there is a scientific basis for the empathy we feel in *as-if* situations. In 1992, a team of researchers at the University of Parma, Italy, working with macaque monkeys discovered that the same brain cells fired when the monkeys performed a task (like picking up a peanut) as they did when the monkeys simply watched a person do the same task. They named these brain cells *mirror neurons* (Ehrenfeld, 2011). Neuroscientists became very excited about this discovery and soon found that human beings also had mirror neuron systems. Were mirror neurons the scientific explanation for empathy? Gallese (2005), an Italian neuroscientist, certainly thought so. He took a lead in the mirror neuron research and discovered that indeed, mirror neurons fire in our brains even when we just *imagine* doing a specific task. For example, we can look at a picture of a hammer, and the motor neurons that we would use to pick up a real hammer are excited. When we see another person smile, the muscles in our own face that control smiling light up on functional MRI. Gallese (2005) had determined that our brain can "model the acting body of other individuals." He called this phenomenon "embodied simulation" and conceptualized what was happening as a kind of *resonance* between bodies, which he theorized could be at the heart of all social cognition (p. 23-48, in Koester, in press).

Rollo May (1985) explained that artists portray their reality through *images*—poetic, aural, plastic, dramatic, and embodied. The processes described by science are a veritable gold mine for *imag*inative, empathic visualization. Their very names conjure wonderful images and possible as-if *situations.* Science words like evolution, metamorphosis, growth, decay, reproduction, birth, and symbiosis are just a few examples of the exciting events described in a life science class. The physical and Earth sciences provide just as many opportunities for artistic, creative expression and interpretation (Koester, 1989). I still take every kind of creative arts class I can. The process is invigorating and enlightening as long as you check your ego at the door. Just recently, I bumbled my way through an improvisational theatre class and came away understanding the power of "Yes, *and*" messages, as opposed to "Yes, *but*," which kills a scene. Every time I take a new art class, I come away with renewed appreciation of the work ethic of the performing artist and the importance of trying, failing, and being critiqued so that you might improve. The process is scary, too. There is no podium behind which to hide. A supportive, caring teacher makes all the difference between whether you will risk ditching your cover and discovering your inner artist (It's there somewhere!), or quit the class for fear of embarrassing yourself.

I am very fortunate to live and work in a state where I have received enthusiastic support for my experimental pedagogy by both science and art education professional organizations, as well as many colleges and universities. Beginning in 1993, I began giving workshops on teaching science through the arts at the South Carolina Science Council (SC2) annual meetings. In the first 1993 session, I shared videos of my students, who had choreographed their version of "The Tectonic Drag." The beginning verse went like this:

On the floor of the seas
are rifts and ridges,
that circle the world
like gigantic zippers.

I had written "The Tectonic Drag" as a poem to be choreographed. It was my way of trying to bring my eighth grade students into the deep, to the ocean floor, to the beginning, possibly of creation itself. Here's the chorus:

Let your arms go up and out and down;
they're convection currents going round and round.
Convection currents are the driving force that
push the Earth's plates along their course.
The plates are doin' the TECTONIC DRAG –
spreading, crashing, diving – making buildings sag.

The Ocean. Can we ever know its effects on us, or more importantly, our effects on it? We should give thanks to marine algae every single day for the oxygen we breathe! David Ballentine, a noted marine phycologist, believes that if all marine algae were to die, we would have less than one week to live (personal interview, 2007). These primitive life forms have been making oxygen for the planet for millions of years. Why do sponges produce natural antibiotics? We don't yet know. How many fish can be caught before their populations collapse completely and entire populations of all sorts of living things collapse? Do we dare find out? In Lloyd Alexander's novel, *Taran Wanderer*, the wizard Morda sneeringly observes: "I have seen enough of humankind and have judged them for what they are—lower than beasts, blind and witless, quarrelsome, caught up in their own selfishness" (in Koester, 2011). Alexander's novel creates an *as-if* world, inside of which students develop understanding of human impact on the environment and each other. Through the elements of narrative— challenge, conflict, and struggle—eventually resolution is achieved. When teachers learn to develop lessons that move through periods of dissonance and struggle, for which no one right solution is apparent, students will make creating some kind of resolution their own responsibility. They key words here are *making, struggle,* and *responsibility*. In real life, resolution is not always achieved. In real *science*, the struggle is to discover what it is we don't know. This theme of persistence in the face of struggle was most definitely the clarion call of Chapter 1 of this book.

DRAWING FROM THE WATER

On June 7, 2006, I was invited to attend the closing session of the first ever Conference on Ocean Literacy (C.o.O.L.), where a consensus of mostly marine scientists and government policy makers had gathered to review the draft of a publication called the *Seven Essential Principles of Ocean Literacy and Detailed Fundamental*

Concepts (http://oceanliteracy.wp2.coexploration.org/). I was very excited about attending this event, as my students and I had been participating in the field testing of National Oceanic and Atmospheric Administration (NOAA) extensive, virtual, and interactive *Ocean Explorer* marine science curriculum, being developed by the education department of their office of ocean exploration (http://oceanexplorer.noaa.gov/welcome.html). My eighth grade students sent real-time questions to NOAA research scientists, as they whisked about in deep sea submersibles. Images of giant tube worms beamed into my classroom. This educational technology was unlike any I had ever experienced as a science teacher, *and* it was free!

At the C.o.O.L gathering, the legendary oceanographer and first female aquanaut, Sylvia Earle, spoke. During our break, I even got to meet this great and gracious scientist and pioneering explorer. John Michel Cousteau, son of Jacques, reminded us that his father had always said that we will only protect what we love and understand. My heart and mind were stirring in the way they always do, right before I get an idea or make an important decision. I have learned to pay close attention when this happens, to be alert for the clue of what to do next. I didn't have to wait long. Suddenly, the lights went out in the conference hall, just as I had thought the meeting was about to close. Our attention was directed to a large screen on a side wall. Flickers of light played across the screen, and then, Woods Hole Oceanographic Institute scientist and deep ocean explorer Robert Ballard appeared. He was speaking with us via telepresence from a submersible on the bottom of the Aegean Sea! Ballard declared that the battle for ocean literacy (and hence the future of our planet) was to be won at the *middle* school because that's when we started "losing" our nation's science students. Wait! *I* was a middle school teacher! Was Ballard talking to me? Exhorting me to become some kind of ambassador for ocean literacy? I was certain he was! In spite of the fact that I had said I did not have another science education novel in me (I had been doing so for nearly 18 years by then), I vowed to write one *last* book, this time about the dire need for ocean literacy.

At about the same time, in Charleston, SC, my home, the SC Maritime Foundation had just launched a tall ship, the *Spirit of South Carolina*, a full scale replica of the 19^{th} century pilot schooner, the *Frances Elizabeth*. She was built as a sail training vessel to provide experiential education to South Carolina youth. While onboard, school students would learn about the math, science, and natural history of the surrounding waters, as well as how to work as a cooperative crew. The schooner was outfitted with the most modern ocean science equipment and technology. I was fortunate enough to join multiple school groups on several sailing experiences in the Charleston Harbor. Many of these children had never once been aboard any kind of boat, much less a nearly 100 foot, three-masted sailing ship! I determined to prominently feature this proud vessel in my new book.

I next applied for and received a research and development grant from the National Marine Sanctuary Foundation (NMSF). With these funds, I set out to research and have vetted the ocean science content for this book, a journey that took me into some of the finest aquaria and ocean science centers in our country—The Shedd (Chicago), The Baltimore Aquarium, The Monterey Bay Aquarium, The Sant Ocean Hall (Smithsonian Natural History Museum), and of course, The South Carolina Aquarium. I traveled to Puerto Rico, where Ruperto Serrano Chaparro, director of the Sea Grant Puerto Rico, introduced me to prominent marine ecologists and researchers, experts all in coral reef diseases and the phenomenon of dead zones. I snorkeled in the waters off the coast of Puerto Rico and also the island of St. John, and saw with my own eyes the devastation beneath the waves—the gray "boneyards" where once great, colorful "gardens" of coral thrived. And then, I spent three days and nights sailing on the *Spirit of South Carolina*, keeping midnight watches, mustering with the crew, and even practicing man overboard drills. I don't think I slept the entire time for fear of missing something!

By now, I was a very active member of both the South Carolina and National Marine Educators Association. I had learned that the breeding ground of the North Atlantic Right Whale, the most endangered of all marine mammals, was very near me at Gray's Reef National Marine Sanctuary, whose staff sent me classroom sets of information packets on this gentle giant.

In 1995, Daniel Pauly, principal investigator at the Sea Around Us Project, coined the term "shifting baselines" to describe changes which occur slowly enough that we barely, if at all, notice them occurring. As a result, our "baseline" of what is acceptable "shifts." For example, tomorrow's coral reef divers will come to see "boneyards" as the norm (https://www.ted.com/talks/daniel_pauly_the_ocean_s_shifting_baseline?language=en). I was fascinated with this concept. Could it be that science, technology, engineering, and mathematics had somehow played a role in the ocean's downfall? I suspected the answer was yes. Before I knew what was happening, my writing and my message took a critical turn. I started looking for what had been left *out* of the history books. Settlage and Southerland (2007) have written that teachers must be vigilant about the contents of the *null curriculum*. Foucalt (1977) declared that critical researchers in science education have a responsibility to show how dominant classes have manipulated truth to their advantage. I felt I surely must do the same with this new work. Indeed, my book would be "fiction," but my motivation for writing it had become deeply personal, rooted in my own repugnance of the racism I had observed growing up in the deep South as well as my passion for preserving and protecting the Ocean, upon which all life forms, from diatoms to despots, depend for their very existence.

Bill Bigelow wrote a chapter for Wayne Au's book, *Rethinking Multicultural Education* (2009) called "Once Upon a Genocide." He cited a need for books for young students which 1) portray what "the Indians might have been thinking about the arrival of the Spaniards" (p. 78) and 2) asks children to "think about how today's world was shaped by the events of 1492" (p. 84). I sought to answer both appeals. In my novel, I lay bare the crimes of imperialism, exploitation, murder, and racism by Columbus and the Spanish *conquistadores* who followed him. My long range action plan was to communicate at the school, community, and professional educator levels the importance of understanding that entire chapters of human history have been rewritten by minds bent on obfuscating the truth about the human and environmental exploitation and destruction set into motion in 1492. Through the medium of Art – using the rhythm of djembe drums, storytelling, and the "painting" of scenes in the mind's eye, where they would not likely be forgotten, I would attempt to tell the story of what really happened on and after that first "Columbus Day." I wrote and wrote and wrote and wrote. When I slept, the plot twisted and turned like sharks twirling inside the barrel of incoming waves. A translation of Christopher Columbus' 1492 journal sat on my bedside table. His scribblings about the Tainos *naïveté* read like a horror story:

They are like the other peoples I have found with the same beliefs, and they believed that we had come from heaven and they gave what they have for whatever they are given without saying that it is too little and I believe that they would do the same with spices and gold if they had any.

Finally, I was ready for the professional development phase of what I called L.A.S.T. Book Project— a Literacy-based, Arts-infused, Science-centered, Technology-driven ocean science curriculum for middle grade learners (and, the completion of my *last* book). I had just enough funding left to provide training and art supplies to two middle school teams. I created an application and selected two schools, whose faculty seemed most committed to entering in a year-long, collaborative, interdisciplinary effort centered on advancing ocean literacy. Both these schools' principals were fully on board, a factor shown to be of significant importance in the success of any professional development project (Loucks-Horsley, 1996). A year later, the South Carolina Science Council invited me to give a keynote about what had happened during the project.What an exciting November day in 2011 that was! Onstage with me was Tiffany, a middle school science teacher from one of the lowest income districts in my state. During our study, she had collaborated with Annie, the school's art teacher. Behind us, filling nearly the entire stage and the wall behind it was the arts installation their students had created. It featured a gigantic ocean creature, with the body of a fish and a human's head. In the first chapter of my book, entitled "The End and the Beginning," a young, twelve-year old girl, walking on the beach against an oppressive, northeast wind and freezing rain, had come across a dead

North Atlantic Right Whale, its gills ensnared with fishing lines and its dorsal fin jaggedly slashed by marks only a ship's propeller could have made. Spelunking into the whale's cavernous rib cage, the girl had discovered a small, beautifully crafted wooden box, inside of which she found a carved and polished stone amulet, with the head of a human and whale's body. It was a 500 year old carved amulet, a symbol of our human responsibility to preserve and protect ocean resources, but the girl did not know that yet (Figure 1).

As I was told later, as soon as she read this part of the story, Annie, the art teacher, sprang into action. "What if," she imagined out loud, "what if our students design and construct a giant replica of this human fish, constructed from the kind of debris that has harmed or killed so much of marine life?" What if, indeed! (Figure 2).

In a joyful act of collaborative making, Tiffany and Annie's students designed and then constructed their "trash" creature. Through their art, they communicated the ever growing threat of marine debris on ocean life. Students transformed other plastic bottles into schools of cheerfully colored fish (Figure 3).

Tiffany, Annie, and I were overjoyed with the results! The school principal arranged for there to be a special school assembly for the "unveiling" (Figure 4).

As a result of participating in this kind of arts-infused exploration of ocean science, students came to understand that humans have a responsibility for protecting and preserving the ocean. They also "got" that not all scientific discoveries result in good, and that the discovery of the Gulf Stream marked the beginning of an era of human conquest of the ocean and of their fellow human brothers and sisters. They engaged in critical thinking about critical matters by examining how their own history intersected with the history of ocean science and exploration (Figure 5).

Figure 1. The human fish, a metaphor for our responsibility to preserve and protect ocean resources

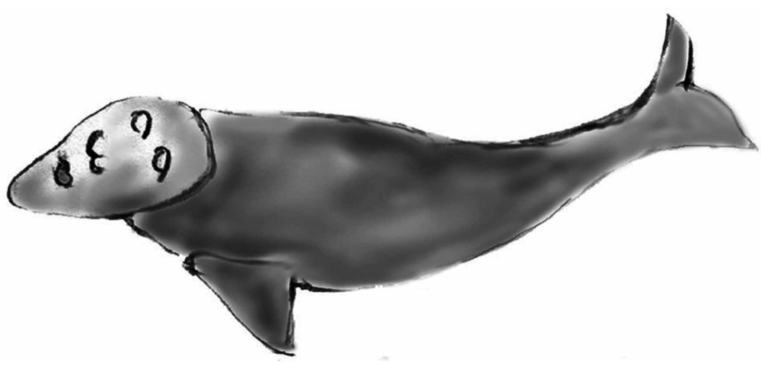


Figure 2. Students constructing a "fish" artifact from potential marine debris

Figure 3. Arts installation of "human fish "and colorful reef "creatures"

This ocean literacy action research project was my first sustained effort to bring science and arts teachers and their shared students *together* in the process of curriculum inquiry. Acting as role models and mentors, these teachers showed their students that deep learning can happen when balanced art/science teaching partnerships are formed. They cross-trained one another in the knowledge, skills, and

Figure 4. Art teacher, university researcher, and science teacher celebrate installation of STEAM marine education project

Figure 5. Atlantic Ocean currents associated with "New World" exploration, colonization, slave trade, and commerce by Europeans

practices of each other's teaching specialty, and each reported being transformed by the collaborative effort. What was happening at this school was a deeply *aesthetic* inquiry of human impact on the environment—a joyful, participatory, sense and arts-based form of learning described by scholars like Pestalozzi (1894/1973), Dewey (1938), Greene (2001), Eisner (1991, 2002), and Siegesmund (2010) as promoting inclusivity, democracy, and freedom.

A similarly inspiring and highly synergistic art/science education collaboration was simultaneously taking place at the second school enrolled in The L.A.S.T. Book Project. Sadie, the eighth grade science teacher, and Shannon, the school visual arts teacher, had received permission from their principal to create a special projects art/science class. Over coffee one afternoon, Sadie, Shannon, and I had hatched the idea to literally *draw* their students into the plight of the nearly extinct North Atlantic Right Whale. Shannon would teach them the elements of design and the art of batik so that they might eventually work together to create a large mural in celebration of this endangered and majestic animal. Meanwhile, in her science class, Sadie would teach about human impact on the ocean, especially our impact on the lives of once thriving ocean animals. The topics in the science curriculum included, among other things, overfishing, shifting baselines, coral reef bleaching, global warming, harmful algal blooms, dead zones, and the power of youth. On my first day meeting with this combined class, we talked about the potential impact of the mural as an art form to communicate profound and important messages. I asked students to contemplate a projected image of Picasso's *Guernica* (1937). This mural displays the tragedies of war through its graphic display of the suffering of innocents, killed by Nazi bombs on the town of Guernica during the Spanish Civil War. As such, Picasso's mural also became a symbolic call for peace (http://www.pablopicasso.org/guernica.jsp). We talked about how artists need to develop deep knowledge of their subjects before they can make powerful art about them. They agreed that Picasso clearly must have witnessed and known a lot of suffering to have so strongly portrayed the devastation of war.

I then showed them an image of a beached North Atlantic Right Whale, brought to an ignoble death by becoming ensnared in commercial fishing tackle and with propeller gash wounds across its dorsal surface. Many exclaimed, "It's the whale in the book we're reading! They're going extinct!" Sadie, who was also in the room with us, jumped up and said, "That's right! And now it's our turn to try to do something to save this whale."

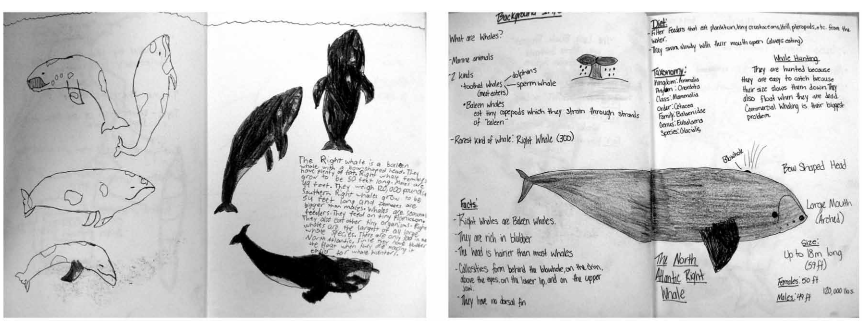
Next, I shared a video which was similar in effect to this newer NOAA release: http://oceantoday.noaa.gov/whalecall/ . The students were thoughtful and quiet. Shannon and Sadie stood up and explained that we were all going to work together on a special art/science project with the goal to learn as much as possible about North Atlantic Right Whale and then to create art that symbolized its *right* to live (pun intended). Next, I told them about Leonardo da Vinci, an artist/scientist who said that to draw something is to know it. Clearly, we could not draw from a live whale, but the staff at Gray's Reef National Marine Sanctuaries (http://www.graysreefnmsf.org/), a breeding ground for these whales, generously sent us a set of huge posters depicting the anatomy of these magnificent mammals. I placed a poster on each art table, and Shannon distributed brand new sketchbooks and drawing pencils, paid for by the NMSF grant. In addition, Gray's Reef specialists made available to us a wide array of educational materials, now accessible at http://graysreef.noaa.gov/education/materials/welcome.html.

Over the next week, in both science and art class, students were challenged to design their own sketchbook journal entries, depicting their growing knowledge about the North Atlantic Right Whale (Figure 6).

We then scheduled a class during which all students rotated around the art room to offer appreciative critique of each other's sketchbook entries. Shannon and Sadie announced to the students that they were now ready to make art about and *for* this whale—art as an act of care. Shannon tasked each student with drawing a mural design in their sketchbooks, which they would soon draw again with white crayon on a 40 x 40 cm^2 of canvas. The paper sketchbook would be their "experimenting" space, where they would practice batik techniques before moving on to the more expensive canvas. Shannon was engaging her students in the art studio habit of mind involved with *developing craft* through practice (Hetland, Winner, Veenema, & Sheridan, 2013). In this stage of inquiry, students engaged in trial-and-error reasoning as they experimented with cause and effect. This stage of "messing around" or "playing with the material" is no different than the tinkering an engineer does as he or she works through the elements of a design process. It's an essential part of the work-in-progress. In this case, the amount of water added to the acrylic paint was a very important independent variable. So was the kind of brush and how tightly the fabric was stretched. Students *had* to know it was okay to make a big mess at first. *"Mess" is as much a part of the nature of art practice as it is of science. Insights evolve as mistakes get made.*

Before they started, Shannon modeled all the techniques she would expect her students to practice and learn. She held up a canvas square for them to see and then drew an abstract design on the cloth with her own crayon. Then she demonstrated

Figure 6. Student sketchbook entries representing the characteristics of the North Atlantic Right Whale



several different kinds of mistakes that might occur in the process, and said that they would likely make them, too. She emphasized that artists need to *engage and persist* at the task at hand (Hetland et. al, 2013). Prior to this stage in the project, we had engaged in many other art studio habits of mind, characterized by such evocative verbs as *observe, envision, integrate, express, differentiate,* and *connect worlds* (Hetland et. al, 2013). I thought, *would that more science classes functioned like art studios!* Shannon's students then entered the *work* stage. I noticed, too, that everywhere were signs reminding the students to take care of their studio and their materials. *Truly, this was a space suffused with caring messages.*

One of the most significant ways that Shannon and Sadie demonstrated care for their students' feelings and made their curriculum inclusive was the decision to invite them to make a quilt, pieced together from *every* student's mural design (Figure 7).

The class voted unanimously on one of their classmate's designs, a gifted artist named Rose (pseudonym), who later earned acceptance to the public magnet high school of the arts (Figure 8).

Rose was also appointed to oversee the final mural's completion as general "contractor" of an artifact that was to measure 3.5 meters in length and 0.75 meters in width. Bringing the project to completion would require students to work collaboratively through issues of scale and proportion and practice making precise measurements.

Rose was a born leader. She expertly organized her classmates into work crews, each with its own sub-contractor. Pictured here are members of the measurement and layout team (Figure 9).

Rose made sure that every single classmate participated in the painting of this mural. Here she is, putting on the finishing touches, just before we presented it at the National Marine Educators Association (NAEA) meeting in Savannah, Georgia (Figure 10).

Figure 7. Student's paper and canvas mural designs (left) and assemblage of class quilt

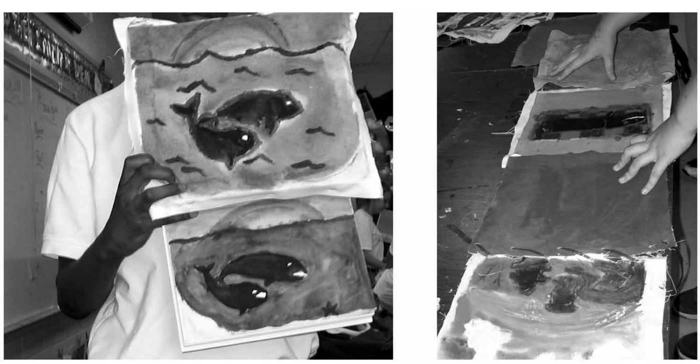


Figure 8. Winning North Atlantic Right Whale mural design on paper and cloth

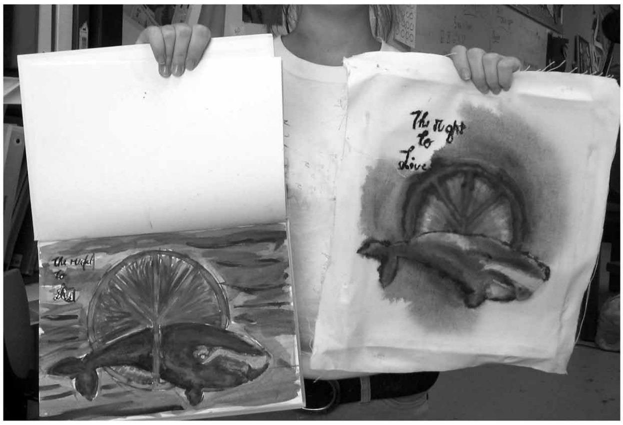
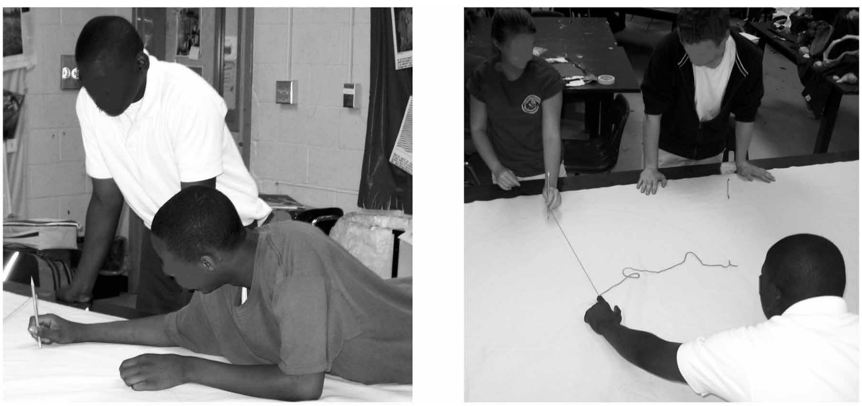


Figure 9. Mural measurement and layout team



THE MANY FACES OF STEAM

What Is STEAM Anyway?

In 2011 or so, while I was working on this ocean literacy project, I discovered that a pedagogy called STEAM had been "invented" (though I would argue that Leonardo da Vinci had prior rights to that patent). Regardless, I regarded this "newcomer" on the educational landscape as a fantastic harbinger of promising reform. When I began a literature review, however, I grew increasingly concerned that there seemed to be no consensus on just what STEAM was and, most especially, what it was not. My list of questions was long: Which teachers *did* STEAM—art, science, ELA,

Figure 10. Rose puts the finishing touches on the mural, entitled, "The Right to Live!"

social studies, all, some? Did it "happen" after school, or during? If both, how were the versions different from one another? Were specific art forms or science/STEM content areas being privileged over others? What did STEAM look like when it was "working"? What steps were being taken to make sure that STEAM was not just one more task being added to the already overtaxed art teacher's planning book? Were science, STEM, and arts teachers co-constructing project-based lessons? What kind of academic rigor did STEAM pedagogy offer? Further, how were the engineering, technology, and mathematics components being addressed? What kinds of STEAM might be funded? Would competing interests jockey to brand their own versions of STEAM as educational commodities, thus achieving, at best, an isolated impact vs. a collective one? This competitive market strategy seemed counter-intuitive to me. Dewey (1938) challenged us all to consider what conditions have to be satisfied in order that education become a "reality and not just a name or slogan" (p. 116).

Full Disclosure

I myself have never been much for semantics, especially where educational acronyms supposedly signifying some collection of agreed upon skills, knowledge sets, and practices are concerned. Whatever you want to call what it is I am trying to communicate here is fine with me. I am at your service, whether you represent an organization that labels itself as doing science, STEM, STEAM, TSTA, or something similarly catchy. We are all together in this business of educating. I have seen that a collaborative and collective STEAM education supports teachers and students so that both Science/STEM and the Arts actually matter to all stakeholders (Koester, in press). I further believe that STEAM in which the arts are used as "handmaidens" in the service of science/STEM is *not* STEAM. Likewise, when science/STEM content understanding is not an integral part of a more Arts-based version, this is *not* STEAM either. It's something else. The most glorious explosions of STEAM learning I have witnessed emerged when art and science teachers worked together, each celebrating the gifts of the other and joining in the collective goal of effecting deep learning and appreciation of the importance of their respective areas of human endeavor.

Project Draw for Science

Just before I began The L.A.S.T. Book ocean literacy project, I had accepted a position as an adjunct professor at the College of Charleston, teaching science methods for preservice teachers, grades 2-8. I very quickly discovered with a pre-test that most of the elementary pre-service and many of the middle grade candidates lacked deep science content knowledge, especially in the physical sciences. I told them about my first ever teaching job, how I had used drawing to first deepen my own knowledge of physics, and how teaching through drawing had resulted in positive academic turn-arounds. I shared Leonardo da Vinci's claim: *To draw something is to know it.* We studied the maestro's detailed drawings of anatomy, machines, and the movement of water. I then asked these pre-service science teachers to consider the corollary claim: To *know* something is to be able to draw a simple picture explaining it. Immediately came cries of protest, "Not if you can't draw!"

"A valid point," I acknowledged. Let's test my claim *and* your counterclaim. I reached for a bag I had brought with me and withdrew its contents. "Here is a loaf of bread and a jar of peanut butter," I announced. "Using them as a visual reference, can you draw a simple picture that explains how to make a peanut butter sandwich? The drawing only has to be *readable*—not a da Vinci masterpiece," I added. They could all readily complete this task, each in his or her own way. I continued, "Could you argue that you have now used drawing as a kind of *language* to communicate your understanding of how to make a PB & J sandwich? Could I (as your teacher) readily determine from your drawing whether your understanding was well developed (or not)? They agreed with both propositions and quickly surmised that if they did indeed have knowledge about a concept or procedure *and* they had a visual reference, they could produce a simple explanatory diagram—even if they were not gifted artists.

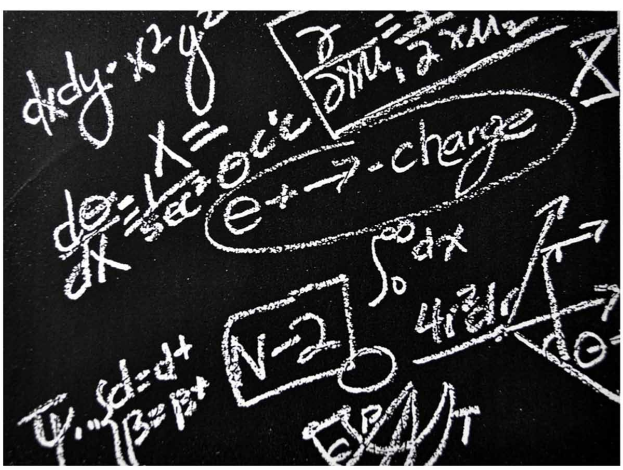
I explained to these science-teachers-to-be that few science teachers whom I had trained had ever been afforded any training in the graphic art of visually organizing text and images on a single page. Often their notes are splattered across their classroom white boards like symbolic vomitus (Figure 11).

Student versions of these notes are often even more confusing and certainly do not invite later study. Why? Because there is no story—nothing to make the scribbles (strange symbols written in a strange language) *mean* something. The result is complete semiotic breakdown (Koester, 2015).

Finson and Pederson (2011) have argued for the importance of “visual data” in science and posited that a “comprehensive understanding of a problem and potential solutions to it are possible only when one knows not only particular skills in visualization, but also in knowing the right questions to ask” (p. 71). I regard this claim as a cause to action (in Koester, 2015a). I ask, “Why is the drawing of science understanding not afforded at *least* equal status with telling and writing, especially in teacher education programs?” Michael Polanyi (1966) has said that we all know more than we can tell. I challenged my pre-service science students to find evidence to support Polanyi’s claim throughout their student teaching experience. Over time, I began to imagine an action research project that asked the following question: What if drawing were conceptualized as science language *and* as a legitimate means of formatively assessing science “knowing”? I placed parentheses around the prefix “knowing” to remind one that the very nature of science involves a constant re-testing and revision of what we *think* we “know” based on the evidence we may have at a given time (Koester, 2015a).

In 2012, with funding and support by the University of SC Center for Science Education, I began the Project Draw for Science research with five teachers from the poorest to the most affluent districts in our state, all of whom self-identified as not

Figure 11. Teacher science notes that are visually chaotic in their presentation



being able to reach their struggling readers and wanted to learn how to teach through drawing. They exhibited deep levels of care for their students and took part in this study with no remuneration at all. After seven months, the students who made the most significant improvement were either struggling readers and/or special needs students. When asked to explain how it was that learning science through drawing affected them, these same students replied with responses like, "It makes me feel like I'm getting help. It helps me think way better than just listening does. It makes me feel joyful and energetic!"

I knew from the years leading up to this new study that the science teachers I had trained felt empowered when they learned the art of visually organizing content for and with their students. They also confessed that creating drawing repertoires as part of their lesson preparation deepened their own content knowledge. The process of teaching science through drawing which I had developed to this point began with first learning basic drawing skills and the elements of graphic design, followed by identifying only the most important science vocabulary words for each concept. Struggling readers, especially those with dyslexia—some 20% of learners (Shaywitz, 2003)— benefit greatly from having new words syllabicated and pronounced out loud as they are written. Inviting students to create illustrated flash cards for new terms is very helpful for English Language Learners. At the "advanced" level of teaching science through drawing, I teach educators how to combine creative drama techniques, scriptwriting, and drawing to effect what I call the Performative Narrative Drawing (Koester, 2015a).

As the beginning of the Project Draw for Science study (http://merriekoester.wix.com/project-dfs), I began an earnest quest to deepen my own understanding of science *language*. My readings took me straight into the important work of Jay Lemke (1999, 2002). Never had I come across a scholar who had had so keenly studied the qualities of science classroom discourse practices and the many ways in which a student could become completely overwhelmed by the multiple and simultaneous de-coding processes required in a science classroom setting. Lemke determined that at any one time in the teaching and learning of science, students were bombarded by not one, but four different languages: WORDS, IMAGES, SYMBOLS, and ACTIONS, all part of a single science *sign system,* which must be integrated if any kind of significant sense making (other than just low level memorizing) were to be achieved (2002).

I was thrilled by Lemke's semiotic portrayal of a science teaching/learning *system*, as it was an important missing ingredient in my own model, which was, at that time, more about "what's" and "how's," but not so much about how those dimensions were integrated. Two epiphanies immediately occurred to me: 1) Lemke's emphasis on *contextualizing* the languages of science was essential practice and 2) we science teachers, myself included, use too many words in isolation from the mathematical symbols, images, and actions associated with the rest of the science inquiry.

The Art and Design of the "Know"tation

I set out, as part of the Project Draw for Science research, to construct and field test a graphic visualization tool for the teaching and formative assessment of science content learning. I visualized a one-page composition which integrated all of Lemke's four science languages: 1) science terminology (the WORDS); 2) explanatory drawings (the IMAGES); 3) the equipment and procedures used during an investigation (the ACTIONS); 4) and mathematical equations, icons, graphs, and tables (the SYMBOLS). I would call this pedagogical tool a "Know"tation. Its purpose was to tell the *story* of situated, contextual, science inquiry as it unfolded in real-time in the classroom. While there would be no one *right* way to design the "Know"tation, the relationship between the four science languages should be readily apparent and the meaning capable of being "read" (Koester, 2015). Depending on the stage of inquiry during which it was created, the "Know"tation might have more words than symbols, but all designs would feature a prominent explanatory and narrative image. Further, an image might serve multiple purposes, such as depicting an experimental procedure (an action) and/or explaining a phenomenon (such as why the sky is blue). Criteria for formative evaluation could be assessed using the developmental terms like Emerging, Proficient, and Mature along criteria that would include scoring the following: Misconception Quotient (out of 5), Graphic Design, Creativity, Language Integration, and Clear Meaning Conveyed. I am still developing the evaluative component of the "Know"tation and enthusiastically welcome all feedback and suggestions!

The readability of a "Know"tation or any graphic design comes from the arrangement of its elements. My favorite book on the subject of visual note design is Mike Rhode's *The Sketchnote Handbook* (2013). I discovered Rhode's work when I enrolled in an online course called "Rockstar Scribe" (https://become-a-rockstar-scribe-at-school-or-work.teachery.co/register) as a way of improving my own graphic visualization skills (before trying to teach it myself). In the Project Draw for Science capacity building training, we began by considering four essential elements of page design: 1) typography, 2) images and their placement, 3) white space, and 4) hierarchy and flow between the elements. We practiced making different kinds of directional arrows and icons for bullets (Figure 12).

We also reflected on the importance of creating a clear visual path through the composition. Rhode (2013) presented several readable "pathways," which I have represented here (Figure 13).

Even teachers with very deep content knowledge readily recognize that unless they employ the elements of design in their graphic representations of content, the result can be rather chaotic (Figure 14).

Figure 12. Elements of graphic design, which enhance visual "flow"

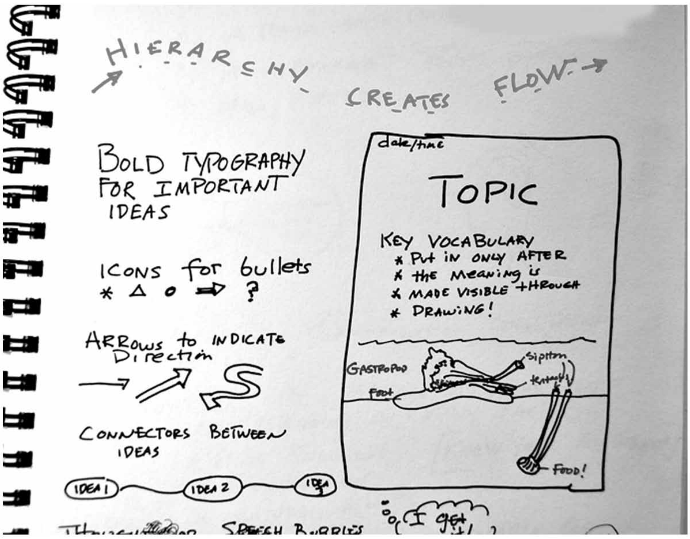


Figure 13. Visually "readable" pathways through a graphic representation

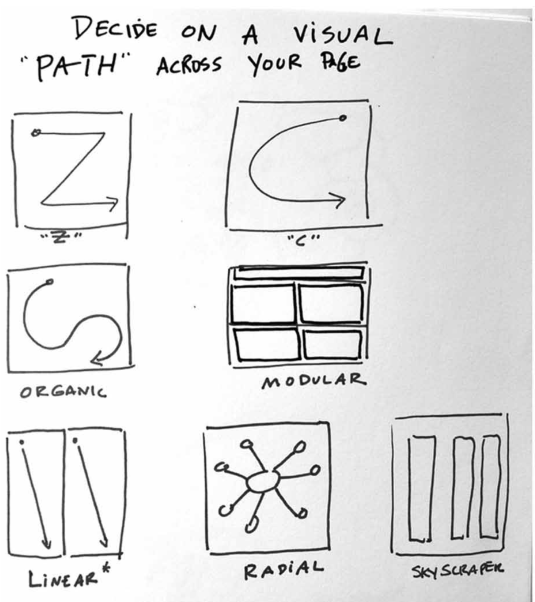
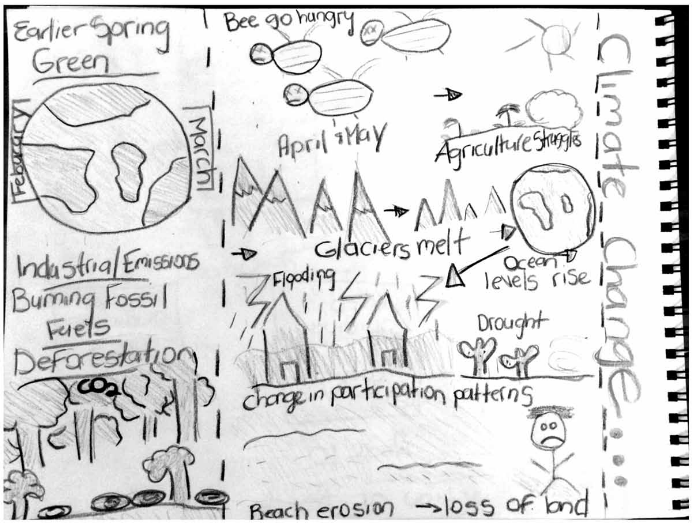


Figure 14. Pre-training attempt by teacher to create a visual explanatory model of climate change



In very short order, teacher participants progressed to making "Know"tations during each stage of 5E science inquiry (Bybee, et al., 1989). One teacher, "Ms. Maya"—most of whose students were reading well below grade level—created *Explain* "Know"tations with her students on large post-it note sheets, which they later used to review for their end-of-year standardized tests (Figure 15).

Unlike *Explain* "Know"tations, which are mostly words and images, with perhaps some symbols, *Explore* "Know"tations feature words, images, symbols, and actions, thoughtfully integrated through the applied use of graphic design elements to tell the story of an actual experiment in progress (Figure 16).

In every way, we came to regard the design of "Know"tations as acts of jointly performed critical making—as public artifacts to be shared and revised as needed and through whose *construction*, students learned to integrate the languages of science.

The Problem of Teacher Content Knowledge

The process of teaching science through drawing and visual thinking is not without its drawbacks. Hashweh (1987) has shown that poor content knowledge significantly impacts teaching, and is a source of misconceptions directly communicated to students (Cochran,1991, p. 12). I have discovered that one of the best ways for teachers to identify weaknesses in their content and procedural knowledge is what I call the "back-of-the-napkin-test." This can be a liminal experience for many teachers.

Figure 15. Large, poster-sized Explain “Know”tation with a large prominent image and only key words

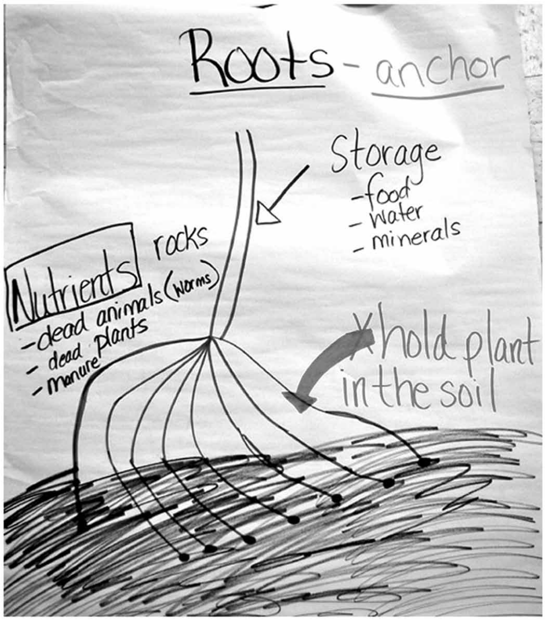
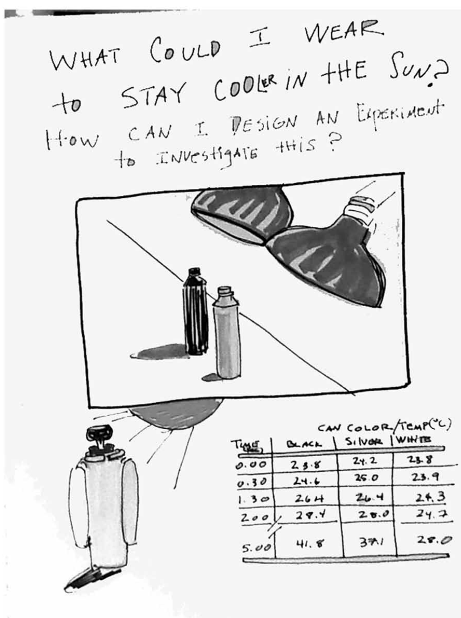


Figure 16. “Know”tation created during the Explore phase of inquiry. Note that all four languages of science are featured here.

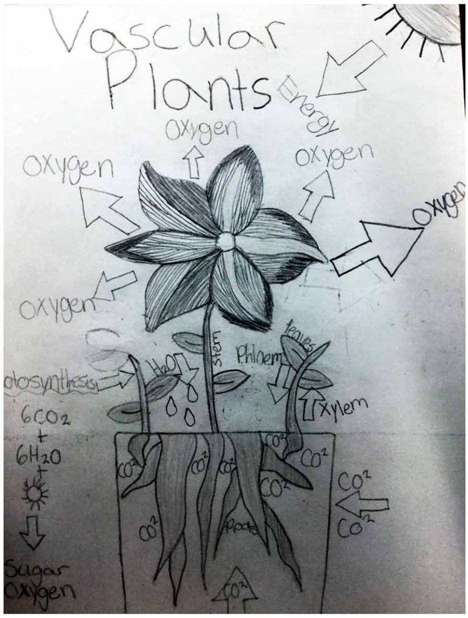


What they quickly discover is that (even if they say they have zero drawing *talent*) they are more than capable of making a simple explanatory drawing of a subject they know well and about which they care. However, when tasked to draw about a science subject which they understand poorly, the napkins quite often remain blank, and teacher faces furrow with scowls. Only a few moments later, they more or less confess that they do a terrible job of teaching about their weak areas. Right away, they also realize that (if they are to actually *teach* science through drawing) they must draw their way into deeper relationship with their most dreaded content area. As was stated earlier, many middle school science teachers have quite under-developed content knowledge about the physical sciences (Figure 17).

Part of the work I do through long-term professional development is to advocate for the creation of standards-based drawing repertoires. Along the way, we work very hard to uncover and reflect upon the misconceptions that many science teachers commonly believe about the content they are teaching (Koester, in press). Critique of student drawings is also essential. The evidence of both learning and *mis*-learning is right there, but can easily be missed by the teacher who becomes distracted by the aesthetic appeal of a student's work. For example, an artistically gifted student produced a visually appealing, explanatory drawing about photosynthesis, incorrectly depicting oxygen being given off by *flower* and carbon dioxide being taken up by the roots. Her teacher was so impressed with the quality of the drawing that he failed to notice the misconceptions. This finding was not an isolated one at all. Accordingly, we are developing a theory of "aesthetic masking" (Figure 18).

Figure 17. The Back-of-the-Napkin Test. Teacher draws a "blank" for physical science concept

Figure 18. Aesthetic masking of student misconceptions about photosynthesis



CONCLUSION: C'ING STEAM

In the conclusion of *Science Teachers Who Draw: The Red Is Always There*, I set forth a tentative model for teaching science as caring, non-prescriptive, aesthetic inquiry, one whose goal is achieving a pragmatic level of science literacy for all students, regardless of their reading ability. I believe that an aesthetic paradigm in general and drawing instruction in particular should not only be included in science teacher education programs but become the subject of further participatory action research and professional development efforts. Shulman (1987) concluded that the more we learn about teaching, the more "we will come to recognize new categories of performance and understanding that are characteristics of good teachers, and will have to reconsider and redefine other domains" (p. 13). Lederman's (1992, 2007) reviews of the research on the teaching of the Nature of Science ultimately concluded that the "instructional approach, style, rapport, and personality of the teacher are all important variables in effective science teaching" (2007, p. 845). An aesthetic orientation to teaching implies that teachers can't just script and *direct* student learning, they must, *with* students, jointly *produce* learning *performances*, at the end of which they must also assess student emotions and *feelings* about what just happened (or didn't). Indeed, feedback is crucial, but it can't just be about whether students have memorized the content. Conquergood (1998) has stated that the performance paradigm privileges 'an experiential, participatory epistemology' (p. 27), and believed that only through shared emotional experiences can a performance achieve transformation (in Koester, 2015, p. 186).

I have come a very long way from that twenty-something young woman, whom a class of very bright non-readers inspired to change her way of being a science teacher. They were with me when I developed a pedagogy I called TSTA. They are with me now as I tentatively call what I am doing STEAM. I could not have made this journey without the support of those who believed that what I was doing mattered. All along the way, I have been building tribes. I seek to develop practice-embedded educational research (PEER) projects of the kind that have been called for by Catherine Snow in her 2014 Wallace Foundation Distinguished Lecture for AERA, published in 2015. This PEER work would be characterized by a constellation of C's: *Caring Collaboration* among *Content* specialists, *Cultural relevance*, *Cross-training, Curating*, *Creative process*, *Community*, and the achievement of a *Collective* impact. Participants in this project would collectively build a professional STEAM teaching/learning community characterized by the sharing of lessons that have "worked" for them, as well as obstacles they may have encountered in the process. I am hopefully optimistic about the possibilities!

A democratic and inclusive science education must work to decrease inequalities and achievement gaps. To date, non-dominant culture and low SES students are often tracked into the lowest level classes with the least highly qualified teachers and with consistently low expectations made of them (Oakes, 2005, in Koester, 2015). The result can be complete semiotic breakdown and loss of human capital. Who knows how many of these students might otherwise have actually *enjoyed* the study of science had they also been assigned to experienced educators who established *ways into* meaning-making that did not depend on the written or verbal expression of a "foreign" language. Indeed, I imagine such abandoned students shaking their heads in disgust, declaring, "Forget science! How can I be in your community if I can't speak your language or understand your sign systems?" Who can blame them? The Lakota had much to teach us all: "*Mitakuye oyasin.* We are all related."

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KEY TERMS AND DEFINITIONS

Aesthetic Energy: A renewable form of human energy characterized by the presence of openness, care, empathy, emotional connection, sustained acts of noticing and awareness, and flexible, creative ontologies and epistemologies (from Koester, 2015).

Aesthetics: In this book, I have employed Baumgartner's original *sense*-based conceptualization of this term together with Pestalozzi, Dewey, Greene, and Eisner's more ontological characterizations of aesthetics as being purposefully empathic and caring, interactive, connective, feelful, and centered around the practice of keen noticing the particular qualities of something, whatever that may be (from Koester, 2015).

Art/Science Integration: A curriculum and/or creative design task that features time for artistic, personalized exploration and interpretation of science content and phenomena as well as critique of public artifacts that employs the use of the languages of both art and science (from Koester, 2015).

Art: Throughout this chapter, art has been conceptualized as it was *before* it was subsumed by the wave of empiricism that emerged in the 18th century—as any act of making that involves intellectual judgment. Art is the medium through which human beings develop their intuitive and creative potential, regardless of the domain inside of which (like science or teaching) it is practiced (from Koester, 2015).

Deep Education in Science: Is about bringing students into an awareness and appreciation that science can uniquely help them understand three things: 1)what is happening in the world under study, 2) how this happening affects them, and 3) how they themselves affect the happening. Deep learning is enhanced when topics are explored through aesthetic inquiry (from Koester, 2015).

"Know"tation: A play on the word *notation*, I created this term for two reasons: 1) to communicate the reflexive, generative nature of science as a domain of knowledge and practice, and 2) to encourage both teachers and students to visually organize their understandings of science concepts, interactive experiences, or phenomena according to the principles of graphic design. The goal of the "Know"tation is to show on a single page, through an aesthetically pleasing combination of words (typography), drawings, and white space, the story of a teaching/learning experience in science so that an uninformed viewer can "read" that story. In every case, "Know"tations should be collaboratively assessed for the presence of misconceptions and revised until the visual "story" as closely as possible re-presents the most accurate level of "knowing" about that science subject. "Know"tations can be created at every stage of the 5E learning cycle (from Koester, 2015).

Mirror Neurons: These are specialized brain cells that fire whether we see or imagine someone else perform an action *or* do the action ourselves (from Koester, 2015).

S.T.E.A.M School: A participatory action research setting in which teachers with fluency in either S.T.E.M. or the Arts (or both) would form a curriculum building team. First, they would "cross-train" each other and then together create innovative and integrative curriculum for teaching and learning that is congruent with both S.T.E.M. and the Arts standards. Such "schools" could form and function within all levels of K-20 education, including and especially in teacher education programs. An underlying assumption would be that all curricula would be culturally relevant (from Koester, 2015).

Science: A special, usually highly objective way of observing, interpreting, and describing the world, as well as the body of knowledge that results from that study (from Koester, 2015).

Semiosis: The meaning-making process, contextually situated in lived experience. In Peirce's theory of signs, semiosis depends on the triadic interaction between an object in the world, a sign or symbol that re-presents that object (or phenomenon), and the way(s) a person in a given culture or situation interprets that contextual sign. *Semiotics* is the study of meaning-making processes (from Koester, 2015).