Appreciating the Beauty of Science Ideas: Teaching for Aesthetic Understanding

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ABSTRACT: A large literature exists in which scientists describe their field as beautiful and the work they do as inspiring and passionate. Science teaching should strive to foster learning of substantive and powerful science ideas in ways that connect to the beauty inherent in those ideas. Our conception of learning science, that of learning for aesthetic understanding, achieves this goal by building on a framework of aesthetic experiences proposed by Dewey. This study is an articulation of the major components of aesthetic understanding, pedagogy designed to foster it, and the results of a pilot study designed to investigate its effectiveness. Responses to a survey and a semistructured interview are compared for students in two, fourth grade classrooms. The instructional goals were different in each classroom; one taught for the goal of aesthetic understanding, the second for the goal of conceptual understanding. Survey results indicate that the pedagogical moves were effective in scaffolding aesthetic understanding in treatment class students. More interesting, however, are student reports of the quality of the learning experience in the treatment class.
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INTRODUCTION

Understanding is a lot like sex. It's got a practical purpose, but that's not why people do it normally.

Frank Oppenheimer (as cited in Cole, 1997, p. 5)

The world looks so different after learning science. For example, trees are made of air, primarily. When they are burned, they go back to air, and in the flaming heat is released the flaming heat of the sun which was bound in to convert the air into tree. [A]nd in the ash is the small remnant of the part which did not come from air, that came from the solid earth, instead. These are beautiful things, and the content of science is wonderfully full of them. They are very inspiring, and they can be used to inspire others.

Richard Feynman (as cited in National Academy of Science, 1995)

BEAUTY AND INSPIRATION IN SCIENCE

A surprisingly large literature exists on the role aesthetics, creativity, passion, beauty, and art play in the lives and learning of scientists (Chandrasekhar, 1987; Dawkins, 1998; Dirac, 1963; McAllister, 1996; Poincaré, 1946; Root-Bernstein, 1989, 1997; Tauber, 1997; Wechsler, 1978). Scientists sometimes describe their work as beautiful and artful, citing these qualities as the motivating forces that often drive their work. As Poincaré describes, "The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful... intellectual beauty is what makes intelligence sure and strong" (pp. 366–367). An acute awareness of the beauty inherent in scientific ideas and scientific discovery necessarily draws us in to its study. To learn science from this perspective is best viewed as an integrated act, rather than solely cognitive or solely discursive. We believe this to be the most serious drawback of both conceptual (Brown & Clement, 1989; Clement, 1982, 1983; McCloskey, 1983; McCloskey, Caramazza, & Green, 1980; Posner, Strike, Hewson, & Gertzog, 1982; Rosnick, 1981) and discursive (Gallas, 1995; Gregory, 1990; Lemke, 1990) perspectives on understanding and find that a Deweyan, aesthetic perspective allows us to blend cognitive and discursive ways-of-knowing with all important affective and artistic ways-of-knowing into a more unified, holistic, human understanding.

Science educators frequently look to the science discipline for guidance as to the important subject matter ideas, behaviors, and dispositions to guide teaching and learning. Often, science within the discipline is characterized as highly analytic, logical, objective, and methodical. Pedagogy that draws from this characterization of science frequently asks students to step back, to be critical observers of objects, events, and the world. However, some scientists portray science with quite an opposing personality—one that draws us in, begs our creativity, passions, and emotions. This portrayal of science can be described using Dewey's epistemology in ways that break down false binaries such as objective vs. subjective, logic vs. intuition, thought vs. feeling, mind vs. heart, and think vs. feel. Dewey's epistemology refuses to separate these into discrete, distinguishable acts. Similarly, Cherryholmes (1999) writes, "When we give up the text/context distinction [or any other binary in his argument], we deny ourselves the luxury of looking at the world in fragments" (p. 42). To think is to feel, and vice versa. A large literature exists to support this claim in science and science learning (see Root-Bernstein, 1989 for a good start). We believe that the heart of a critique of conceptual and discourse-based understanding lay in their portrayal of science as something to be analyzed, stood back from, and acquired. From the perspective of aesthetic understanding, science learning is something to be swept-up in, yielded to, and experienced.[1] Learning in this way joins cognition, affect, and action in productive and powerful ways. It is more holistic in its substance and consequence. We draw from the work of scientists and philosophers of science to further support our claims and critique.

When Einstein wrote, "I am a little piece of Nature" (Holton, 1973, pp. 366–374), his comment may not have seemed unusually illuminating. Certainly we are all little pieces of nature, made of similar stuff, with origins in distant stars and supernovae, but these thoughts remove Einstein's words from their intended meaning. Root-Bernstein elaborates,

> That which is true is what satisfies me after I have struggled with it, interrogated it, and pondered the meanings of its answers in light of my experience, my existence, myself. I become what I study, and when the I and It merge, understanding has been achieved (Root-Bernstein, 1997, p. 69).

In light of this, we see that Einstein was implying a merger, a joining of the I and the It in an effort to understand. We are all little pieces of nature and we must work to recognize and draw on that connection in ways that assist our understanding. Knowing in this way has been described as a synthetic process in which cognition, emotions, and actions merge; perception illuminated by multiple senses and sensations. This perceptual fusion is called *synaesthesis* by Richards, Ogden, and Wood (1925) and is described as "the simultaneous, harmonious experience of diverse sensory impressions from complex works of art resulting in a fusion of apparent opposites or unification of differences" (p. 7). Synaesthetes, people who experience this quality of perception, often describe numbers as particular colors, temperatures as particular tastes, and sounds as particular images (see Lemley, 1999, for a more recent discussion). Odin (1986) elaborates,

> Synaesthesia represents a degree of unified sensibility so profound that the boundaries of the senses actually merge, and the multivariate sense qualities—colors, sounds, flavors, scents, tactile and thermal sensations—all seem to melt into a continuum of feeling (pp. 256–258).

Many scientists have described similar multisensory experiences, similar to the way Einstein described himself as "a little piece of Nature," to include a joining of thought and feeling. Root-Bernstein (1996, pp. 66) expands on synaesthesia to something called *synscientia*.

> Synscientia means literally, knowing in a synthetic way, being able to conceive of objects or ideas interchangeably or concurrently in visual, verbal, mathematical, kinesthetic, or musical ways. Very simply stated, I have found no eminent scientist who simply solves mathematical equations or pours chemicals into test tubes and analyzes the results or catalogues chromosomal abnormalities. Scientists, or at least scientists who are worth their salt, feel what the system they are studying does. They transform the equations into images; they sense the interactions of the individual atoms; they even claim to know the desires and propensities of the genes.

Root-Bernstein proceeds with multiple examples of synscientia from scientists such as Jane Goodall, Dian Fossey, Ernst Mach, and Barbara McClintock. Similarly, we recall

[1] Conceptual understanding and discursive understanding are two frameworks within the teaching for understanding movement. Each of these puts something different at center stage; mental models for one and linguistic competence for the other. Aesthetic understanding is similar to these two in that we argue for ours as a model of understanding. However, an important difference is that aesthetic understanding places an appreciation for the beauty of science ideas and Deweyan aesthetic experiences at center stage. For a more thorough analysis and critique of the conceptual and discursive frameworks from the perspective of aesthetic understanding see Girod and Wong (2002).

Temple Grandin, autistic animal scientist at Colorado State University. As described by Sacks (1995), in *An anthropologist on Mars*, Grandin has a unique ability to put herself in the position of her animals–"I visualize the animal entering the chute, from different angles, different distances, zooming in or wide angle, even from a helicopter view—or I turn myself into an animal, and feel what it would feel entering the chute." So impressed with Grandin, Sacks continues, "... her sense of animals' moods and feelings is so strong that these almost take possession of her, overwhelm her at times. She feels she can have sympathy for what is physical or physiological—for an animal's pain or terror..." (p. 267). Grandin's ability to think and feel in multiple ways, her synscientific abilities, helped her to become one of the world's most highly regarded animal scientists, despite her autism.

Synaesthesia and synscientia are certainly extreme examples, but we can learn important lessons from these ideas. A powerful, scientific understanding (similar to an artistic understanding) puts one in close personal contact with ideas that can (and should) change the way we think, feel, and act. Again, Root-Bernstein (1996, p. 72) writes, "inherent in the recognition that scientific creativity relies upon the same aesthetic tools of thinking as the arts is that the arts can be the source of skills and insights that science needs to progress." Although Root-Bernstein is referring to scientists and scientific progress within the discipline, we believe we should apply the same standards and suggestions for the teaching and learning of science in our schools. Teachers should strive for similar but developmentally appropriate experiences with beauty and aesthetic appreciation of science ideas. If we are to truly educate our children, we must develop both the scientist and the artist within them. As we have seen, science is not only the process of stepping back and analyzing the world with cold logic and rigorous methods. Science is also stepping forward in an attempt to "get inside" of objects, events, and ideas; it involves a surrendering to experience (Wong, Packard, Girod, & Pugh, 2000). One is incomplete without the other. As we believe science is most commonly portrayed as the former, we focus here on the latter and suggest educating the artist within young scientists. It is common for the science education community to suggest doing science as those within the discipline do, to be more faithful to the discipline of science, and to do and learn as scientists do (see Harding & Hare, 2000 for a recent discussion). If we really believe this, then, we should listen to what the creative process of science suggests and work to foster powerful, transformative, forward-looking, aesthetic, synscientific experiences within students.

Like Oppenheimer in the quote that leads this paper, we believe understanding is *not* most commonly driven by practical or instrumental purposes. The desire for understanding is driven by something more human. It is our nature to seek connections—connections to others, to the earth, and to important ideas. This sense of connectedness is not only at the level of individual cognition; it comes from a desire to know with one's heart *and* mind, emotions *and* cognitions, imagination *and* reason. Understanding *is* a lot like sex. We do it to feel connected in ways that tell us we are human. As Feynman suggests in the quote that follows Oppenheimer, we strive to understand for aesthetic reasons. Drawing from Dewey's naturalized epistemology and philosophy of aesthetics, we believe that teaching and learning should be guided by the having of meaningful experiences, connecting ourselves to the world and powerful science ideas through artistic metaphor, ending in the state we have defined as aesthetic understanding.

ON AESTHETIC UNDERSTANDING

Illustrated nicely by Feynman and others above, an aesthetic understanding is a rich network of conceptual knowledge combined with a deep appreciation for the beauty and power of ideas that literally transform one's experiences and perceptions of the world. Increasingly, philosophers and educators argue that the arts and aesthetics have lessons to teach us about ourselves and our world, affect and imagination, passion and cognition (Dewey, 1934/1980; Eisner, 1998; Garrison, 1997; Greene, 1995; Jackson, 1998). We believe we can teach science in ways that borrow from aesthetic and artistic ways-of-knowing, engaging more students with the beauty, power, and value of science ideas. Drawing heavily from the aesthetic theory of Dewey (1934/1980), our theory of aesthetic understanding accomplishes this in three ways.

Aesthetic understanding is transformative. Dewey has been read clearly on aspects of doing and undergoing. Action and reflection exist in concert and culminate in some unique end. It begins with effortful knowing: "A man does something; he lifts, let us say, a stone. In consequence he undergoes, suffers, something: the weight, strain, texture of the surface of the thing lifted." Dewey continues, "The process continues until a mutual adaptation of the self and the object emerges. . . " (1934/1980, p. 44). This transaction binds the two so closely that they may begin to merge in experience and outcome, "What is done and what is undergone are thus reciprocally, cumulatively, and continuously instrumental to each other" (p. 50). Learning can too be transformative in this way. Knowing changes the individual as well as the individual's world.

Feynman's quote illustrates the transformative nature of aesthetic understanding as he "sees" the event of combustion in a different and beautiful way. In an astronomy unit, a student named Robert explained, "I never realized everything was moving—the earth, the sun, the moon, the stars—everything is moving and it blows me away!" Realizing he would never view the night sky the same again, Robert added, "I never thought I'd become the kind of person who talked about and thought about such deep things." Aesthetic understanding literally transforms who we are and how we see the world.

Aesthetic understanding is unifying. An aesthetic experience is complete. It is often connected to a particular time and a particular event. It leaves us satiated while drawing us ahead to new experiences. It has a unique wholeness that we can call unifying. "Because of continuous merging, there are no holes, mechanical junctions, and dead centers when we have an experience" (Dewey, 1934/1980, p. 36). Dewey continues in description of this unique unity, "It is not possible to divide in a vital experience the practical, emotional, and intellectual from one another." What is central, however, is that it ends in deeper meaning; "the conclusion has value on its own account. It can be extracted as a formula or as a "truth," and can be used in its independent entirety as factor and guide in other inquiries" (p. 55). This has particular meaning for those in science as we depend on past insights to fuel those of the future.

Aesthetic understanding depends on developing a similar coherence of parts, pieces, ideas, and concepts. For example, as one learns about individual elements of the periodic table, the entire table is better understood as a series of relationships and continuities. Individual elements and relationships between elements merge in a unified and dramatic way, disclosing secrets, and allowing one to see the beauty inherent in the structure of chemistry. A deep understanding of the periodic table is quite aesthetic and leads one into future experiences with a transformed and more unified vision of chemical relationships.

Aesthetic understanding is compelling and dramatic. Aesthetic experiences are necessarily saturated with emotion. In recalling a great meal, or the drama of an outstanding novel, we can hardly separate our emotions from the psychological aspects of the event. Emotion, cognition, and even action become fused. This quality of experience gives it both unity as well as drama. Art and aesthetic experience ". . . quickens us from the slackness of routine and enables us to forget ourselves by finding ourselves in the delight of experiencing the world about us in its varied qualities and forms" (Dewey, 1934/1980, p. 104). This renewed seeing, if you will, provides drama to ordinary events and interactions and compels us into further engagement with the world.

Aesthetic understanding similarly draws students into the world through intellectual interactions and explorations. It is common for these students to think about science ideas outside class, to search for examples and illustrations of ideas, and to tell others about what they've learned, relishing in the excitement and engagement of looking at the world with wider eyes.

Aesthetic understanding teaches content *and* it demonstrates an empowering way of perceiving and interpreting the world through science ideas. In the eloquent words of Greene (1995), students become more "wide-awake" to the world, appreciating beauty and structure in new ways. This is what aesthetic understanding adds beyond more traditional learning. How can one teach in ways that foster aesthetic understanding?

Pedagogy has been developed across a period of 2 years designed to facilitate a high degree of aesthetic understanding in elementary science students. As compared to the students and school in which this research was conducted, the pedagogy was developed and refined in a similarly urban, Midwest elementary school with similarly diverse students.

The teacher plays a unique role in teaching for aesthetic understanding. A useful metaphor for describing her job is to imagine her as an artist in a studio trying to shape curricular ideas and experiences for children in artistically pleasing and aesthetic ways. Her job is to position students in the path of potentially unfolding aesthetic experiences. She does this first by structuring the curriculum in ways that assist or support transformative, aesthetic experiences. Pugh (1999) describes this process as "artistically crafting" more traditional pedagogy into pedagogy to foster aesthetic understanding. Briefly, we describe five guidelines to artistically craft pedagogy.

Crafting content: Too often science is portrayed as content to be known rather than experiences to be relished. Most science ideas were at one time exciting and powerful but have since come to be embodied in bold-faced words, with exceedingly clean and tidy definitions. Take, for example, the idea of a heliocentric solar system. Long ago this was a frightening, provocative, even terrifying idea—one that forced students to think about the world and their place in it, very differently. Today, however, the notion of a heliocentrism is taken for granted as something always known or understood. Heliocentrism has lost its artistic power to shape our understanding in profound ways. The first step in teaching for aesthetic understanding is to recapture or reanimate existing content into the artful and compelling ideas they are (or were at one time).

Crafting dispositions: While teaching for aesthetic understanding a teacher should ask students to be more imaginative and creative as they wonder about the potential of ideas. Students should ask more, "what if..." style questions such as, "What if this rock could talk? What story could it tell of its travels?" Students should be pushed to imaginatively explore the power of science ideas in ways similar to Einstein's famous thought experiments. Investigating the potential of ideas to transform takes time and opportunities. Teachers must provide rich opportunities to explore, wonder, and begin to make sense of science ideas and their power to alter our perceptions of the world.

Emphasis on the artistic expansion of perception: Our brains are amazing. With just a quick opening and closing of our eyes, one can gather a great deal of information about our surroundings—color of the room, approximate number of people in it, something of the objects in the room. This ability to rapidly recognize and interpret our surroundings is vital to our existence. However, it also serves to blur perception. Too much of what we see in the world is generalized and simplified. We often fail to look closely and carefully at our world. "Re-seeing" is an attempt to focus our perception on the nuance and detail of the world. Re-seeing requires that we look carefully when we might be tempted to assume we see everything. Re-seeing is also a disposition that causes us to ask questions of what we perceive such as, "What's really going on here? Why do things look the way they do?" And "What kinds of things do I need to know more about to really re-see this?" During the course of an astronomy unit, a student named Edie exclaimed excitedly, "I did some re-seeing last night!" While getting into her mother's car, she noticed the moon and it's features. "I could actually see different shapes and things on the moon and you could tell that it was just a shadow that made it look like a fingernail." For probably the first time in her life, Edie looked carefully at the moon and wondered why it looked like it did—she "re-saw" the moon. Re-seeing, with its emphasis on Dewey-like perceptual metaphors, can be used as a central activity in teaching for aesthetic understanding.

Model aesthetic understanding: Recall the Feynman quote that begins this paper in which he artfully describes the process of combustion. Feynman exemplifies what it means to have a well-developed sense of aesthetic understanding of the process of combustion and, likewise, teachers must model ways-of-knowing that incorporate a variety of avenues for engagement, specifically inspiration and appreciation for the beauty of science ideas. More than just modeling this artistic connection, teachers must model their appreciation and value for the transformative power of science ideas.

Scaffold efficacy and identity beliefs: As students engage with science through this unique portrayal, they will inevitably experience a wide range of emotions and dispositions. Teachers must capitalize on and scaffold the development of dispositions that indicate an emerging sense of science identity and efficacy beliefs regarding students' ability to appreciate and come to a rich level of aesthetic understanding. Aesthetic understanding forces us to see and think about the world in very unusual ways and initial attempts in this regard must be received in a nurturing way.

THE RESEARCH

Method

Given the theoretical framework of teaching for aesthetic understanding and the pedagogical strategies outlined above, a pilot study was designed with the following research questions in mind:

1. Does teaching for aesthetic understanding work, or, do the pedagogical strategies outlined previously help students to develop scientific understandings that include the qualities described by the theory of aesthetic understanding?
2. How will students talk about their experiences learning science for aesthetic understanding?

A quasi-experimental study was designed in which two, 4th-grade classes (ages 9 and 10) in an urban, Midwest elementary school were targeted. The two instructional programs differed in their goals: one was taught for a conceptual understanding, the other for the goal of aesthetic understanding.[2] Three areas were covered across ten weeks of geology instruction

[2] We do not intentionally imply that these two kinds of understanding are exclusive of one another. On the contrary, a significant quality of aesthetic understanding is conceptual understanding. In fact, treatment group (class taught for aesthetic understanding) average end-of-unit test scores of conceptual understanding were roughly equal to control group scores before, during, and after treatment. This suggests that teaching for aesthetic understanding has no cost in terms of conceptual understanding. In fact, more recent research has shown that students learning for aesthetic understanding actually retain knowledge much longer, forgetting less over time (Girod, 2001).

including fossils, weathering and erosion, as well as rocks, minerals, and volcanology. Although before-instruction instruments were not administered, the school in which the two classrooms are situated does not use any type of tracking that would direct students into one class rather than another.[3] For this reason, we can expect the two classes had students with similar distributions of attitude toward science, ability, existing dispositions toward beauty and art, ... and so on. At the conclusion of science instruction, a measure of aesthetic understanding was administered to all students in both classes and each treatment class student was interviewed to investigate the quality of their aesthetic understanding.

Subjects

A total of 56 children participated (28 in each classroom) including 31 girls and 25 boys almost exactly evenly distributed across the two classrooms. Students in this school came from predominately lower and lower middle class neighborhoods fairly evenly distributed between African American and Caucasian students.

Measures

The measure of aesthetic understanding was composed of a survey that included a vignette about a student who learned about friction and found it to be powerful and important. Although the learning is not labeled as an example of aesthetic understanding, it was designed to be a clear example of just that. Students in both classes were read this vignette and then asked to respond to a series of nine questions that investigated the degree to which they have had experiences similar to the one described in the story. Because students at this age are acutely aware of gender roles and stereotypes, boys were read a vignette about a boy and girls a vignette about a girl.

Each question on the measure related to some element of aesthetic understanding such as a perceived transformation of person and world, learning that brings unification or coherence to aspects of the world or science, and something of the compelling and dramatic nature of learning in this way. Although we did not include the measure in its entirety, a female version of the vignette is appended as A.

Treatment class students were also interviewed individually at the conclusion of the 10 weeks of instruction. The interview protocol was semistructured and allowed for a great deal of individualization as students raised issues and experiences unique to their learning. The protocol can be imagined as an extension of the survey in which students are asked to elaborate on and extend their responses. As with the survey, the interview protocol follows the structure for aesthetic understanding as outlined previously. The protocol is appended as B.

RESULTS

Student responses were recorded on a 5-point Likert-type scale (1 = no, 2–5 = increasing gradations of frequency or quality of experience). Table 1 shows the results of student responses.

Although we did not specifically ask students if they "saw beauty" in science ideas, the analytic framework of aesthetic understanding is grounded in the aesthetic theory of

[3] In checking with school administrators and counselors assigned the task of "drawing" students into classrooms at the beginning of the year, we did find that two sets of cousins had been purposefully separated into different classrooms. We maintain that results should be held as tentative but interesting and compelling enough to warrant further exploration.

TABLE 1
Responses to Aesthetic Understanding Vignette

Instrument Question	Mean (SD) Control ($n = 28$)	Mean (SD) Treatment ($n = 28$)
1. Have you ever had a powerful learning experience in science like the one Sarah had (student in vignette)? If so, how similar was it?	1.35 (1.09)	2.70 (1.12)
2. Have you ever learned something in science and then seen the world differently because of it? If so, how different did you see the world?	1.20 (1.24)	2.60 (1.14)
3. Have you ever learned something in science that made you think differently about yourself? If so, how differently did it make you feel?	1.00 (1.41)	2.15 (1.49)
4. Have you ever learned something in science and then thought about it all the time outside of class? If so, how often does something like this happen to you?	1.70 (1.49)	2.70 (1.34)
5. Have you ever learned something in science and then told other people about it? If so, how often does something like this happen to you?	1.80 (1.40)	3.20 (0.83)
6. Have you ever learned something in science class and then tried to see examples of it outside of class? If so, how often does this happen to you?	1.85 (1.31)	2.85 (1.23)
7. Have you ever learned about something in science class and then tried to learn more about it outside of class? If so, how often does this happen to you?	1.25 (1.41)	2.70 (1.49)
8. Have you ever learned something in science class that really helped you to understand more about the world? If so, how often do you learn something like this?	1.50 (1.40)	3.05 (1.05)
9. Think about how you generally learn things in science class. Typically, how similar is your learning like Sarah when she learned about friction? (scale from 1 to 10; 1 not at all similar to Sarah, 10 being very similar to Sarah)	6.90 (2.25)	7.65 (2.08)
Total score of aesthetic understanding (sum of items 1–8)	11.65 (7.22)	21.95 (5.55)
Test of significance	t-value = 4.18	2-tail sig. = .001

Dewey and the having of aesthetic experiences, experiences in which the beauty of ideas is necessarily experienced. We felt anything more direct would be excessively leading.

As with any self-report instrument, we had concerns regarding the accuracy of student responses. As a check in this regard, students indicated on a scale from 1 to 10 how similar their typical experiences of learning science are with the idealized one described in the vignette (item 9). The responses on the eight items were correlated with this self rating and yielded a correlation of .72. Although not as high as we would like, it does give us some measure of confidence in the reliability of student responses.

These results show that, for the most part, students in the experimental classroom experienced clear, and in some cases, profound progress toward the three conditions of aesthetic understanding. All items tend toward the treatment classroom and no gender or ethnicity effects were found. This data suggests that the pedagogical strategies seem to be effective at facilitating the kinds of experiences and aesthetic understanding that we had hoped it would.

We now turn to three students and their descriptions of the aesthetic experiences they underwent (or not, as in the case of James) as a result of aesthetic understanding. These vignettes are based on student interviews, student writing (from class assignments), and the teacher's instructional journal. These students were chosen because they represent common experiences rather than atypical ones.

Rather than allow traditional concepts like the rock cycle and erosion and weathering to guide the geology unit, the teacher employed a narrative lens allowing "the telling of rock stories" to be the overarching goal. The idea was that rocks are keepers of interesting and exciting stories that give us clues to the earth's past and the local geology of the region. Knowing a few simple geologic principles allows one to unlock these secrets and tell the *story of the rock.* In addition to refocusing the content, the teacher also employed the pedagogical strategies outlined earlier. Names of the students represented in the vignettes are, of course, pseudonyms.

Brieana

Bright and bubbly, Brieana's learning typifies aesthetic understanding. "Most people think rocks are... just junk. Most people think rocks are all the same and not interesting. Most people don't think about their stories." Brieana described several occasions in which she had recently found a rock and wondered of its story (origin and cooling history, erosion and weathering history, ...). Brieana's perception of rocks changed entirely until finally she explained, "I used to skip rocks down at the lake but now I can't bear to throw away all those stories!" Rocks were no longer dull and ordinary. They had taken on new meaning, beauty, and power as their secrets were revealed. Individual rocks had been transformed into miniature history lessons—dramatic and intensely evocative in their story.

Soon the power of her emerging aesthetic understanding (as related to rocks and simple geology) began to spill over into other areas. Brieana stated, "I've been thinking about the number 2. Where did it come from? A guy just didn't say, 'here's two.' I want to know about its story. It seems to be important—two shoes make a pair, two ears, two hands, two arches at McDonald's." Rock stories and her aesthetic understanding soon evolved into a full-blown narrative perspective on the world. She was "infected" by the power of story and found great aesthetic value in its consequences. "Thinking about the stories of things is a great way to learn. It makes things more interesting and gets you to think about stuff you've never thought of. I like it." Story, as it began in application to rocks, had moved beyond her school experiences. Brieana relished how her newfound narrative perspective on the world made the "familiar seem strange" and it captivated her deeply.

Brieana's case seems to suggest a connection between her developing aesthetic appreciation for the power of story and her developing sense of conceptual understanding of geology concepts. Generally a good student in other subjects, Brieana did not usually excel in science. However, in this geology unit Brieana's emerging value for story compelled her to engage more deeply than she may have in the past. As a result, she scored 84% on her end of unit test of conceptual understanding; a full letter grade higher than her average science unit grade in the past.

Leo

Leo was slightly less successful than Brieana in coming to a well-developed aesthetic understanding. Previously quite unsuccessful in school both academically and socially (in fact, Leo was expelled shortly after this research), Leo found success in his ability to imagine the *lives* of rocks. Leo had no trouble imagining himself as a molecule swimming in molten lava, trying to form crystals. It appeared as though he was just being silly as he "swam" around the room with his eyes shut exclaiming, "It's hard to swim in molten lava. If it cools too soon, I won't form crystals!" His learning is aesthetic in the degree to which emotion and cognition are bound up in these experiential moments. His ability to relate to subject matter ideas in ways that join cognition and affect facilitated his ability to develop an aesthetic understanding and aesthetic value. In addition, Leo seemed to experience content in ways that allowed him to more clearly see himself and his identity in relation to subject matter ideas. This narrowing of the gap between self and science proved very powerful for Leo. In a postinstruction interview, Leo told 12 rock-related stories in just over 15 min. The entire time he held a rock in his hand, touched it to his face, and even rubbed it on his lips. Through rocks and their stories, Leo was able to connect to academics and his teacher in ways he had not previously. Although Leo just barely passed the posttest of conceptual understanding (61%, class average 76%), for the first time in his experiences as a science learner (perhaps as a learner at all), Leo came alive with energy, interest, and action for learning. Perhaps, if given the opportunity to develop his faculties for acquiring aesthetic understanding, Leo would grow to be a more academically successful and engaged student.

Leo represents a situation in which conceptual understanding and aesthetic understanding do not seem to be linked. We argue, however, that given the opportunity to learn science more frequently for aesthetic understanding, Leo would develop his skills at appreciating beauty, and the motivational ramifications of these appreciative experiences would begin to bootstrap his emergent conceptual understanding.

James

James was an outstanding student who always read the directions, raised his hand when he had a question, and wrote in complete sentences. James was generally considered to be one of the brightest students in class and was always willing to work hard to perform well on assignments. Perhaps his high expectations and almost rigid ideas about how to "do school" left James unable to "undergo" (Dewey, 1934/1980) aesthetic experiences, failing to allow them to work their transformative power. James simply did not come to value story as an important idea, he explained, "thinking about rock stories is interesting but I don't really think about rocks differently than I did before. I am sort of interested in rocks and sort of not. I used to look for good rocks to skip but that's about it. I still do that. Now, I can say what kind of rock it is and even tell my parents about it if they want but mostly I just skip them." Although James was successful in traditional ways (attained one of the highest scores on the end-of-unit test), how successful was he in having a truly educative learning experience—not successful at all from the perspective of aesthetic understanding.

Again, James represents a case in which conceptual understanding and aesthetic understanding are not linked. Unlike the scientists described at the beginning of this paper, James acquired a strong conceptual understanding but simply failed to come to an appreciation for the beauty of science ideas. Unfortunately, we believe James represents a common endstate in science learning. Students who do develop a strong conceptual understanding infrequently develop their aesthetic senses and values as well. This can be attributed to the minute amount of time and energy put into these goals.

DISCUSSION AND CONCLUSIONS

Brieana, Leo, and James represent decreasing degrees of successful aesthetic understanding. Their words speak clearly in this regard. They each felt varying degrees of the power of aesthetic experience and its potential to offer them transformed views of themselves and the world, more unified visions of the world, scientific concepts, and relationships, and more compelling ways of thinking.

What we find to be most significant in this research is not that we were able to foster aesthetic understanding to a statistically significant degree but how students experienced their learning and subsequent value for science ideas. In fact, in postinstruction interviews, 89% of treatment students (25 of 28) indicated that the realization that rocks, and all things, have stories that we can reconstruct is a valuable and enriching way to think about the world. As represented by both Brieana and Leo, it is this value that teachers should strive to foster and learners should strive to feel for subject matter ideas. It is this aesthetic value that helps us to live more richly fulfilling lives.

Additionally, we believe teaching for aesthetic understanding works to collapse or merge in-school and out-of-school learning experiences in ways that blur the lines between formal and informal learning. An important quality of aesthetic understanding is the way new ideas move students out into the world, beyond the walls of the classroom to enriched experiences and interactions with the world. The results of this "moving out" is apparent in Brieana's and Leo's descriptions of their experiences.

We believe the goal of school and education should be more than to get a good job, to educate responsible citizens, or to prepare children to compete in a global society. We believe education should serve to foster aesthetic experiences and facilitate aesthetic and artistic ways of viewing, acting, and living in the world. We believe the goal of education should be to foster aesthetic understanding of important and compelling ideas—in this case, science ideas. The pedagogical strategies we employed seemed to facilitate these kinds of experiences, and the valuing of ideas that emerged seemed connected to reasons or explanations beyond the purely instrumental. Which teacher has not cringed as students ask "When are we ever going to use this?" or "Why do we have to learn this?" What a powerful response if teachers were to reply "You learn this because we hope it will bring more pleasure, beauty, and inspiration to your life. We hope you find value in its power to transform your mind, heart, and world." We believe learning of this nature, and the motivation that follows from it, are intense, dramatic, and aesthetically pleasing. We believe teaching and learning for aesthetic understanding represents science education at its very best.

APPENDIX A: MEASURE OF AESTHETIC UNDERSTANDING VIGNETTE (FEMALE VERSION)

Listen carefully as I read this story to you about a student who learned important things in science class.

In science class, Sarah learned about friction. She learned that when objects move there is always some friction where two objects rub together. She watched carefully as her teacher pushed a book across the table and described the friction that tried to slow the book down.

She felt as if she could actually see the friction between the table and the book. She learned that friction is everywhere and wanted to learn even more about it. Sarah took her science book home and read about friction to her mother. She even looked in her older sister's science book for more information about friction. Soon Sarah could tell the difference between sliding friction and rolling friction, she learned that friction causes heat just like when she rubs her hands together for warmth. Sarah began to see friction everywhere she looked. Her baby brother slipped and fell down in the kitchen and Sarah knew he fell because there wasn't enough friction between his feet and the floor. She realized that when people go skiing or ice-skating they try to reduce the friction so they can go faster. She also began to understand why some trucks have big knobby tires—to provide more friction in the mud! Sarah thought about friction a lot. She even thought about herself differently—as just another object trying to create or reduce friction to move around in the world.

APPENDIX B: SEMISTRUCTURED INTERVIEW PROTOCOL

Interview Questions

1. Would you be interested in learning more about geology? Why or why not? Were you interested in geology before we studied it? Are you now? If so, when did it become interesting to you? If not, why not?
2. Have you been able to use your new knowledge about geology outside of school? If so, how? If not, why not?
3. Have you had a chance to share your knowledge about geology with anyone else? Have you used the idea outside of class? If not, why not?
4. Do you see the world differently now that you know about geology? Do you think you'll continue to learn more about geology? Why or why not?
5. Are you excited about using your knowledge of geology? Why or why not? If so, in what ways?
6. Is thinking about the story of things an interesting thing to do? Why or why not?
7. Do you ever imagine yourself as a geologist thinking about geology? If so, tell me about it? Do you feel differently about yourself because of this?

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