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ABSTRACT

A large body of literature exists in which scientists describe their field as beautiful and the work they do as inspired 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. The conception of learning science in the study, that of learning of aesthetic understanding, achieves this goal by building on a framework of aesthetic experiences of understanding, pedagogy designed to foster it, and the results of a pilot study designed to investigate its effectiveness. Statistical results suggest a positive effect from the pedagogy experiences of learning for aesthetic understanding. (Author/KHR)

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 inspired 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 paper 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. Statistical results suggest a positive effect from the pedagogy and, even more interesting, are the voices of students as they describe their experiences learning for aesthetic understanding.

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, pg. 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 suprisingly 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" (pg. 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 and Clement, 1989; Clement, 1982; Clement, 1983; McCloskey, 1983; McCloskey, Caramazza, and

Green, 1980; Posner, Strike, Hewson, and Gertzog, 1982; Rosnick, 1981) and discursive (Gallas, 1994; Lemke, 1990; Gregory, 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 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 (pg. 42, 1999). 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 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 swept-up in, yielded to, and experienced.[1] Learning in this way joins cognition, affect, and action in productive and powerful ways. It is a 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" (in Holton, 1973, pgs. 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, pg. 69, 1997).

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 et al. (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" (pg. 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 (1962) 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 (pgs. 256-258).

Many scientists have described similar multi-sensory experiences, similar to the way Einstein described himself as "a little piece of Nature," to include a joining of thought and feeling. Root-Bernstein 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 (1996, pg. 66).

Root-Bernstein proceeds with multiple examples of synscientia from scientists such as Jane Goodall, Dian Fossey, Ernst Mach, and Barbara McClintock. Similarly, we recall Temple Grandin, autistic animal scientist at Colorado State University. As described by Oliver Sacks in *An Anthropologist on Mars* (1995), 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..." (pg. 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 adult 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 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" (1996, pg. 72). 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 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 et al, 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 and Hare, 2000 for one 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've 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; 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. Aesthetic understanding accomplishes this in three ways.

Aesthetic understanding is transformative.

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.

Part of aesthetic understanding is developing 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.

Aesthetic understanding is compelling and dramatic.

Aesthetic understanding 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 <u>and</u> it demonstrates an empowering way of perceiving and interpreting the world through science ideas. In the eloquent words of Maxine 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 two 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 will describe 5 main guidelines to artistically craft pedagogy followed by an extensive example of pedagogy to foster aesthetic understanding.

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 re-capture or re-animate 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 your 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 proposal 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.

Given the theoretical framework of teaching for aesthetic understanding and the pedagogical strategies outlined above, the following research questions were asked:

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?

The research

In an effort to answer these very exploratory questions, all fourth grade classes in a Midwest, urban elementary school were targeted. 56 children in two classrooms participated including 31 girls and 25 boys. Children in this area come from predominately lower and lower middle class neighborhoods, almost even distributed between African American and Caucasian students. The instructional program in both classes was intentionally reorganized from learning that was for conceptual understanding to learning that was designed for the goal of aesthetic understanding.[2]

Three units were covered across ten weeks of instruction. Both prior to, and at the conclusion of all science instruction, a measure of aesthetic understanding was administered. The instrument included a vignette about a girl named Sarah who learned about friction and found it to be powerful and important to her. Although her 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 eight questions that investigated the degree to which they have had experiences similar to the one described in the story. Each question on the measure relates 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. The measure is appended.

Because it was not the intent of this research to make comparisons against learning that is designed for conceptual understanding, we did not find a control population necessary. We were only interested in exploring the learning of these particular students as the goals of their science instruction were shifted. We can, however, draw general conclusions regarding prior student learning for conceptual understanding as this was the instructional goal prior to the study. In fact, at the conclusion of each unit, students still responded to a traditional test of conceptual understanding. Although we make brief references to these scores, comparisons between aesthetic understanding and conceptual understanding was not the focus of this research.

Student responses were recorded on a 5-point Likert-type scale (1 = no, 2-5 = increasing gradations of yes, where 2 is "yes, somewhat like me" and 5 is "yes, definitely a lot like me.") and the following results were obtained.

Table 1: Responses to vignette questionnaire

Question	Mean response	T-test
3. Have you ever had a powerful learning experience in science like the one Sarah had (student in vignette)? If so, how similar was it?	Pretest = 1.35 St.dev. = 0.88 Posttest = 2.55 St.dev. = 1.04	t-value = 3.39 2-tail sig. = .001
4. 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?	Pretest = 1.20 St.dev. = 1.02 Posttest = 2.50 St.dev. = 1.80	t-value = 3.38 2-tail sig. = .001
5. Have you ever learned something in science that made you think differently about yourself? If so, how differently did it make you feel?	Pretest = 1.00 St.dev. = 1.64 Posttest = 1.80 St.dev. = 1.40	t-value = 1.71 2-tail sig. =.09^{NS}
6. 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?	Pretest = 1.70 St.dev. = 1.88 Posttest = 2.50 St.dev. = 1.48	t-value = 1.77 2-tail sig. =.08^{NS}
7. 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?	Pretest = 1.80 St.dev. = 1.68 Posttest = 2.50 St.dev. = 1.52	t-value = 1.49 2-tail sig. =.15^{NS}
8. 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?	Pretest = 1.80 St.dev. = 1.00 Posttest = 2.70	t-value = 2.09 2-tail sig. = .05

	St.dev. = 0.98	
9. 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?	Pretest = 1.25 St.dev. = 1.66 Posttest = 2.40 St.dev. = 1.48	t-value = 2.63 2-tail sig. = .01
10. 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?	Pretest = 1.50 St.dev. = 1.48 Posttest = 3.00 St.dev. = 1.88	t-value = 3.87 2-tail sig. = .001
11. Total measure of aesthetic experience (sum of questions 1-8)	**Pretest = 11.65** **St.dev. = 3.42** **Posttest = 19.95** **St.dev. = 2.82**	**t-value = 3.98** **2-tail sig. =.001**

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 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 learning science are with the idealized one described in the vignette. The responses on the eight items were correlated with this self-rating and yielded a correlation of .93. This gives us some measure of confidence in the reliability of student responses.

These results show that, for the most part, students experienced clear, and in some cases, profound progress toward the three conditions of aesthetic understanding. The items that don't bear out as significant (items 3-5) all tend toward aesthetic understanding and are very near significance. There were no significant gender or ethnicity effects. This data suggests 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, and the teacher's instructional journal. These students were chosen because they represent common experiences among the students. All names are pseudonyms.

The subject matter referred to in these case studies is rocks and minerals. Rather than allow traditional concepts like the rock cycle and erosion and weathering guide the unit, the teacher employed a narrative lens allowing "the telling of rock stories" to be the goal of the unit. 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 re-focusing the content, the teacher also employed the pedagogical strategies outlined earlier. The vignettes come mainly from this geology unit in which telling rock stories was the goal. 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 new-found 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 post-instruction interview, Leo told 12 rock-related stories in just over 15 minutes. 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 post-test 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's 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 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) 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 about the world.

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 post-instruction interviews 90% of the students (50 of 56) 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 which 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. What 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: Measure of Aesthetic Understanding

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 the 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.

Mark the answers on your paper that best describe your reactions to the story. Remember, the story is just an example. You could have an experience like Sarah with lots of different science ideas.

1) Have you ever had an experience in science class like Sarah? (circle one)

   Yes **No**

   If yes, what science ideas or concepts were you studying at the time?

   ____

   If yes, how similar was your experience to Sarah's? (circle one)

Pretty much the same	**Mostly the same**	**A little the same**	**Just barely the same**

2) Sarah saw the world very differently after she learned about friction. Have you ever learned about something in science and then seen the world differently because of it? (circle one)

   Yes **No**

   If yes, how differently did you see the world? (circle one)

Totally	**Quite a bit**	**A little**	**Only a tiny bit**

differently	**differently**	**differently**	**differently**

3) Learning about friction even made Sarah think differently about herself. Have you ever learned something in science that made you think differently about yourself? (circle one)

Yes **No**

If yes, how differently did it make you think about yourself? (circle one)

Totally differently	**Quite a bit differently**	**A little differently**	**Only a tiny bit differently**

4) Have you ever learned about something in science class and then thought about it all the time like Sarah did? (circle one)

Yes **No**

If yes, how often did you think about what you learned?

Several times a day	**Once a day**	**Only a few times**	**Just once**

5) Have you ever learned about something in science and then told other people about it like Sarah did? (circle one)

Yes **No**

If yes, how often do you learn something in science and then tell other people about it like Sarah did? (circle one)

Almost everyday	**Once or twice a week**	**Once or twice a month**	**About once or twice a year**

6) Have you ever learned about something in science and then tried to see examples of it outside of class like Sarah did? (circle one)

Yes **No**

If yes, how often do you try to see examples of things you learned in science outside of class? (circle one)

Everyday	**A couple times per week**	**A couples times per month**	**Once or twice all year**

7) Have you ever learned about something in science and then tried to learn more about it outside of class like Sarah did? (circle one)

Yes **No**

If yes, how often does this happen to you?

Everyday	**A couple times per week**	**A couples times per month**	**Once or twice all year**

8) Have you ever learned about something in science that really helped you to understand a whole bunch of other things like friction did for Sarah? (circle one)

Yes **No**

If yes, how often does something like this happen to you? (circle one)

Everyday	**A couple times per week**	**A couples times per month**	**Once or twice all year**

9) Think about how you generally learn things in science class. Typically, how similar is your learning like Sarah when she learned about friction?

Not similar at all **VERY similar**

1 2 3 4 5 6 7 8 9 10

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Footnotes

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[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 Author (2001).

[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 remained consistent before, during, and after treatment. This suggests teaching for aesthetic understanding has no cost in terms of conceptual understanding. We expect future research, designed to investigate this specifically, will demonstrate that, in fact, conceptual understanding is actually enhanced when goals are shifted to teaching for aesthetic understanding.

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