

**From talking to seeing: Teaching science for aesthetic understanding in a fifth grade  
classroom**

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**Abstract**

This research compares and contrasts teaching and learning for the goal of discourse-based understanding and for the goal of aesthetic understanding, a new perspective on science learning. Drawing from the aesthetic theory of Dewey (1934) and biographical accounts of scientists, aesthetic understanding holds changed perception, changed action, and increased interest as the ultimate goal of learning. Through a quasi-experimental study examining the teaching and learning in two, fifth grade classrooms, the effect of these different learning goals is examined. Although each are powerful and effective instructional goals, teaching for aesthetic understanding is offered as a more effective means of fostering enduring, educative experiences.

Recently, a central goal of science understanding has become to talk like a scientist or to use the discursive norms of a science community (Gallas, 1994; Gregory, 1990; Lemke, 1990). Through this process, students come to use the semantic patterns and organizational schemes that effectively support canonical understandings of science ideas. Through learning to talk science, students adopt new identities associated with this particular community of practice (Lave & Wenger, 1991; Brickhouse & Potter, 2001).

It is the goal of this research to expand notions of science understanding to include ways of seeing and experiencing. Through lenses of powerful science ideas, students can be taught to literally see the world in new and dramatic ways. This newfound seeing leads to increased interest and, eventually, to changed action. These qualities are at the heart of a new kind of science understanding, that of aesthetic understanding (Author, 2001a, 2001b; Author & Wong, 2002; Author, 2002; Wong, Author & The Dewey Ideas Group at Michigan State University, 2001).

Although Lemke (2001) argues that learning to talk science subsumes goals of seeing and experiencing science, teaching and learning for aesthetic understanding focuses first on perception and aesthetic ways of knowing science as a means to build canonical understandings, and, finally, ways of talking or thinking about science. In fact, the differences between aesthetic, discursive, and conceptual understandings in science education have been debated elsewhere (Author & Wong, 2002; Journal of Research in Science Teaching, March, 2001), and can be thought of as only a matter of what appears in the foreground of learning, experience, talk, or mental models. It should not be misunderstood, however, that each perspective desires useful and profound understandings of the natural world. The avenues toward this end are what differ.

Taken from Dewey (1934), Jackson (1995, 1998), and Prawat (1993, 1995, 1998) learning for aesthetic understanding represents a powerful new goal for science instruction. In it, the goal of developing canonical understandings of scientific ideas is pursued first through expanded ways of seeing and being in the world. Drawing heavily from aesthetics and artistic ways of knowing, learning for aesthetic understanding is postulated as a viable alternative to learning science. This paper provides a lengthy articulation of pedagogy designed to teach fifth grade science for aesthetic understanding and then draws comparisons against fifth graders learning for the goal of a language-based understanding or ways of talking about science. Because of the unique theoretical perspective and the subsequent pedagogical treatment, both will be articulated simultaneously in a brief discussion.

### **Expanding Perception**

Learning for aesthetic understanding suggests “seeing precedes believing.” This is not a new idea as we see it referenced by the forefather of American pragmatism, Charles Sanders Peirce, “the elements of every concept enter into logical thought at the gate of perception” (1934, Vol. 5, p. 131). From this, we must teach students how to see the world through science ideas before their ways of thinking and speaking will conform to canonical understandings. Because so much of science is visual, the act of appreciating aesthetic beauty and the insights of science can be fostered through refined ways of seeing (Csikszentmihalyi & Robinson, 1990; Jackson, 1998). Many scientists describe with vivid imagery their perception and appreciation for science ideas (Badash, 1987; Chandrasekhar, 1987; Dirac, 1963, 1980; Fischer, 1999; Flannery, 1990; Heisenberg, E., 1984; Heisenberg, W., 1971; Hoffman, 1987, 1988a, 1988b, 1989; Holton, 1973; Huxley, 1991; McAllister, 1996; Osborne, 1964; Root-Bernstein, 1989, 1997; Root-Bernstein &

Root-Bernstein, 1999). For this reason treatment class pedagogy also has the goal of expanding student perception through an act called re-seeing.

### Re-seeing

He who has once seen the intimate beauty of nature cannot tear himself away from it again. He must become either a poet or a naturalist and, if his eyes are good and his powers of observation sharp enough, he may well become both (Lorenz, 1989, pg. 237).

Much of what we see in the world is generalized and simplified. This is the result of processing and mental imagery that, for the most part, serves us well in our ordinary lives. However, as many naturalists attest, we often fail to look closely and carefully at our world. Above, Nobel-prize winning biologist Konrad Lorenz describes the intimate connection between deep perception and excellence in science while simultaneously acknowledging that deep observation falls typically in the domain of art. He and many other scientists understand the role of careful observation – observation beyond what is normal or natural for most. Dewey (1934) wrote that ordinary living, routine, un-observed interaction with the world causes us to lose touch with the uniqueness and originality found in the world, “apathy and torpor conceal this expressiveness [of ordinary objects] by building a shell about them” (p. 109). Art, however, “throws off the covers that hide the expressiveness of experienced things.” Dewey (1934) continues, “it 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 varied qualities and forms” (p. 110). Like art, science ideas have the potential to reveal and renew. We, however, must become proficient in the act of seeing science through artful eyes.

Re-seeing is an attempt to focus our perception on the nuance and detail of the world. It 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 understand this?" In learning for aesthetic understanding, 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 its 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. Gertrude Stein made similar comments regarding attempts to understand modern art. Stein described the change in the perception of an innovative artwork as follows: "It looks strange and it looks strange and it looks very strange; and then suddenly it doesn't look strange at all and you can't understand what made it look strange in the first place" (Wheeler, 1983, pg. 185). Through the process of re-seeing one comes to appreciate and find value in modern art where before there was none. By this, we gain an understanding of art previously lacking.

Re-seeing, with its roots in Peircean (1934) epistemology and Deweyan (1934) aesthetics, can be used as a central activity in classrooms (Author, 2001a, 2001b). Variations on re-seeing might have students imagine themselves as different people, objects, or in different events, times, or settings to gain perspective on the phenomenon or object of study. These activities lead naturally into conversations on point-of-view, evaluations of usefulness, beauty, and so forth, as science and art get returned to their shared origin. Re-seeing is a naturally pragmatic and aesthetic activity, one we believe most scientists and artists engage in constantly. Niko Tinbergen, another naturalist, describes the power of re-seeing to reveal new and unique insight as well as educate our aesthetic senses.

We often felt that there is not less, and perhaps even more, beauty in the result of analysis than there is to be found in mere contemplation. So long as one does not, during analysis, lose sight of the animals as a whole, then beauty increases with awareness of detail... I believe that I myself am not at all insensitive to an animal's beauty, but I must stress that my aesthetic sense has been receiving even more satisfaction since I studied the function and significance of this beauty (Tinbergen, 1958/1969, pg. 154).

Root-Bernstein (1997) has argued that students simply cannot come to fully understand and appreciate science if they cannot understand and appreciate its aesthetic qualities. We imagine most science teachers spend very little time discussing and appreciating the aesthetic qualities of science and scientific ideas. However, as Richard Feynman describes, the results can be equally provocative and productive.

Poets say science takes away from the beauty of the stars – mere globs of gas atoms. I too can see the stars on a desert night, and feel them. But do I see less or more? The vastness of the heavens stretches my imagination – stuck on this carousel my little eye can catch one-million-year-old light. A vast pattern – of which I am a part... what is the pattern, or the meaning, or the *why*? It does not do harm to the mystery to know a little about it. For far more marvelous is the truth than any artists of the past imagined it. Why do the poets of the present not speak of it? What men are poets who can speak of Jupiter if he were a man, but if he is an immense spinning sphere of methane and ammonia must be silent (Feynman quoted in Gleick, 1992, pg. 373)?

Re-seeing is a central activity in the process of learning for aesthetic understanding.

Centering learning on the act of re-seeing and expanded perception is a central element in

teaching for aesthetic understanding. In addition to re-seeing, teachers must modify curriculum, activities, and their own behavior to support learning for aesthetic understanding.

### **Additional Refinements in Teaching for Aesthetic Understanding**

#### Refining Curriculum

A misgiving Dewey (1934) expresses is that “when an art product once attains classic status, it somehow becomes isolated from the human conditions under which it was brought into being and from the human consequences it engenders in actual life experience” which in turn renders the general significance of the product “almost opaque” (p. 3). As a result, the product fails to expand perception and vitalize experience. The same could be said of the “classics” that comprise our curriculums. When intellectual products attain classic status, they become isolated from the conditions in which they had an original significance and from their potential consequences for everyday experience. As a result, their importance is mindlessly accepted but not fully appreciated. Too often, science teaches concepts, rather than ideas.

Dewey (1933) explains that concepts are established meanings (“classics”) whereas ideas are possibilities that must acted upon and tried out. Concepts are forms of knowledge. Ideas are ways of being in the world. They are inseparable from human experience (Wong et al, 2001). Hence, we see one of the primary duties of the teacher to be the crafting of concepts into living ideas so that the content may become a catalyst for transformative, aesthetic experience.

In an effort to recover ideas from concepts, the teacher teaching for aesthetic understanding in this research chose to use metaphor to teach generative ideas. He found that metaphors require students to imagine and explore how new learning fits with experiences in the world. Metaphors lend themselves well as lenses through which to re-see the world. For example, erosion can be understood conceptually as a continuous and powerful degradation of



the earth's features that results in both useful by-products and incredible scarring of the surface of the earth. Through metaphor, this degradation was characterized as a war being waged between forces that destroy (wind, running water, chemical reactions...) and features of the earth that try (without agency, of course), in vain, to resist destruction. Weapons are employed (grains of sand, oxidizing reactions...), casualties are had (river valleys, soil, and river deltas), and even pockets of resistance are found (craggy mountain peaks and other erosion resistant features). The metaphor of the erosion battle allowed students to quickly see and experience the very heart of an understanding of erosion. Activities were structured to employ the lens of the erosion battle in re-seeing the world.

#### Refining Teacher Behaviors

Model aesthetic understanding. Recall the Feynman quote offered previously 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 high degrees of inspiration and appreciation for the beauty of science ideas.

Model aesthetic value. All teachers have been asked by students "Why do we have to learn this?" A simple but elegant question, most teachers lack an answer personally satisfying to themselves or students. A teacher teaching for aesthetic understanding, modeling aesthetic value of ideas would respond '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.' Of course, a teacher must be prepared to defend such a glowing and fluffy statement with powerful science ideas and subsequent powerful learning. A good opportunity to model aesthetic understanding exists in relating experiences re-seeing. The teacher who consistently

and genuinely shares experiences re-seeing the world through science ideas models the perceptual power for ideas to expand our understanding of the world. Modeling is powerfully educative.

In summary, pedagogy employed in the treatment class is designed to bring about changed perception, increase desires to investigate and experience the world with new ideas, and feel excitement and interest where before there was none. To do this, a teacher must organize content around ideas, must model the power for these ideas to inspire and renew perception, provide opportunities and encourage students to experience the world in new ways, and consistently highlight the aesthetic and artful side of science and scientific ideas. These are the strategies that guided pedagogy in the treatment class.

Given the goal of teaching for aesthetic understanding and the pedagogical treatment designed to do so, this research was guided by three research questions. First, would teaching for aesthetic understanding, in the ways described previously, encourage student to adopt new ways of seeing, thinking, and acting – effectively coming to an aesthetic understanding? Second, if it is possible to teach for aesthetic understanding, how will the quality of this understanding vary across students? Third, what can be learned by comparing and contrasting learning for aesthetic understanding against learning that is designed to foster language based or discourse-oriented science understanding? The following research study was designed to investigate these questions.

### **The Research**

This research was conducted in an urban elementary school in a large, Midwestern city. The student population was a heterogeneous mix of Caucasian and African American students from mostly working class families. Two fifth grade classrooms (28 students in each class) and

the teaching and learning that occurred in each were examined. Across an 18-week period, three instructional units were taught on weather, erosion, and the structure of matter in both classes. On average, science instruction took place twice a week for 60 minutes at a time. Because of imminent state testing and a rigid curriculum and pacing guide, the two classes were taught on almost the exact same schedule. In fact, the two classes used many of the same activities, assignments, and lab activities. All students in both classes took the exact same tests of canonical scientific understanding, as per state content standards. The only significant differences between the two classrooms were the instructional goals pursued by the two teachers. The treatment class was taught for the goal of aesthetic understanding while the control class was taught for the goal of a discourse-based understanding.

Table 1 shows the design of the research project followed by a brief description of each phase.

**Table 1: Research design and timing schedule**

<u>Research Phase</u>	<u>Data gathering procedures</u>
Time <sub>1</sub> – Before any science instruction	Student interviews investigating prior aesthetic experiences and aesthetic understanding in science
Time <sub>2</sub> – Time <sub>4</sub> (instructional cycles, 3 units)	Pre-test of conceptual understanding Post-test of conceptual understanding Enduring post-test of conceptual understanding (administered one month after end of instruction)
Time <sub>5</sub> – After all science	Student interviews investigating emerging aesthetic understanding with half the class Student interviews of aesthetic understanding

instruction

Time<sub>1</sub> was used to establish positive relationships with children in both classes in an effort to reduce any novelty effect from the presence of the research team. All students in each class were interviewed regarding their previous aesthetic experiences with science. The classes were also established as not unusually dissimilar in that no students were "tracked" into the classes based on extenuating circumstances (like perhaps ability, participation or interest in certain kinds of activities, gender, or behavioral record).

During time<sub>2</sub>, time<sub>3</sub>, and time<sub>4</sub>, three different units were taught and both teaching methods and student learning were studied. During each of these cycles, a pre-test of conceptual understanding was administered, an instructional unit was taught, and a post-test of conceptual understanding was administered. One month after instruction ended, the post-test was re-administered in both classes to investigate enduring conceptual understanding.

At the conclusion of each instructional unit, students in each class were interviewed to investigate the quality and quantity of their aesthetic experiences with science ideas. In an effort to explore the effect of interviewing, which may have reinforced values related to aesthetic understanding, only half the students in each class were interviewed after each instructional cycle. The effect of these interviews was explored statistically using ANCOVA modeling which showed the effect of the interview to be insignificant [ $F(54) = 1.024, p = .21$ ].

Interviews were semi-structured and open to changes as situations and students pursued questions related to their interests and experiences. The same students were interviewed after all three instructional cycles. All interviews were conducted by a third party researcher, rather than

either of the classroom teachers. The interview protocol follows the core elements of aesthetic understanding including changed perception, increased interest and excitement, and changed action. A generalized interview protocol is appended as A.

Time<sub>5</sub> was used to conduct exit -interviews regarding student aesthetic understanding of each of the three units. We chose to interview students after each instructional cycle as well as at the beginning and end of the research study as we believe it may take some practice to become able to or grow proficient at developing one's aesthetic understanding. Throughout the study all interviews were conducted in pairs of students. Students were paired in ways that matched students of approximately equal science achievement, based on prior records. Because several questions in the interview related to subject matter, we tried to reduce situations in which students of dramatically different abilities were paired as this may have created discomfort. The length of the interviews varied from 15 minutes to 40 minutes each. The majority of data comes from student interviews but student work, content standards, teacher lesson plans, and classroom observation notes were also used as data in this research.

Before an examination of the effect of teaching for aesthetic understanding, a brief description of control class pedagogy, pedagogy designed to foster a discourse-based understanding, is necessary.

### **Control Class Pedagogy**

The control class was taught by Ms. Parker, runner-up teacher of the year for this school district the previous year. Although a self-proclaimed poor science teacher, Ms. Parker held very strong beliefs about what it meant to know science and how to best teach and learn science. In an informal interview she stated plainly, "For me, science is about understanding a particular way to talk, a way of thinking about and speaking about the world around us." Ms. Parker

structured her science lessons in a fairly routine way; first reading from the science textbook, posing questions and conducting an instructional conversation about material presented, and then assigning a short writing assignment in which students were typically asked to review, apply, or hypothesize about a situation using their emerging scientific understanding.

The heavy emphasis on science as a way of talking was consistently supported through Ms. Parker's use of chorale responding. At the end of most science lessons, Ms. Parker would review with students by asking them questions to which they would respond in unison. Additionally, students were frequently reminded to "use your science words" in discussions or descriptions of their experiences. Students seemed to enjoy Ms. Parker's style and responded to her enthusiasm with vigor and engagement. She had few discipline problems and, by her account, students typically met or exceeded her expectations for learning.

Significant student learning occurred in each class but the quality of that learning diverged sharply along the axes of aesthetic and discourse-based understanding.

### **The Effect of Teaching for Aesthetic Understanding**

Interview questions typically asked students to provide examples of changed perception, action, or interest as a result of new learning. The raw number of examples provided were tallied independently by two researchers. Inter-rater reliability was .95 in identifying discrete examples and discrepancies were discussed and a final score was agreed upon. Raw counts of student examples therefore serve as a rough proxy for the level of aesthetic understanding reached by individual students. Table 2 shows the number of student reported examples for interview questions and total aesthetic understanding for two students in each class as well as the class average number of examples. Each of the students is described further in detailed case analyses. See<sub>1</sub> corresponds to the "changed perception" interview question at time<sub>1</sub>, while excite<sub>1</sub>

corresponds to the “increased interest and excitement” interview question at time<sub>1</sub> – and so forth. A single score was recorded for time<sub>4/5</sub> so as not to confuse students participating in mid-instruction interviews and those who did not. Not surprisingly, the treatment class averages far exceed the control class average for the level of overall aesthetic understanding.

**Table 2: Total aesthetic understanding**

	See <sub>1</sub>	See <sub>2</sub>	See <sub>3</sub>	See <sub>4</sub>	Exci <sub>te<sub>1</sub></sub>	Exci <sub>te<sub>2</sub></sub>	Exci <sub>te<sub>3</sub></sub>	Exci <sub>te<sub>4/5</sub></sub>	Act <sub>1</sub>	Act <sub>2</sub>	Act <sub>3</sub>	Act <sub>4</sub>	Avg Item Score
<b>control student</b>	1.42	1.31	1.31	1.35	1.69	0.46	0.77	1.08	4	1.31	0.85	0.92	1.373
<b>Jill</b>	3	2	2	2	1	1	1	1	4	0	0	0	1.42
<b>Joe</b>	2	2	0	2	2	1	1	2	4	2	2	2	2.00
<b>Avg</b>													

<b>trea</b>	1.3	2.92	3.23	2.59	1.44	1.92	2.46	2.26	3.89	2.54	2.69	2.44	2.47
<b>tme</b>													3
<b>nt</b>													
<b>stud</b>													
<b>ent</b>													
<b>Margie</b>	4	2	3	2	3	2	2	2	4	3	3	2	2.67
<b>Tyler</b>	0	3	3	2	2	2	2	2	4	3	3	2	2.33
<b>r</b>													

An independent samples t-test confirms total class differences as statistically significant [t(54) = 4.24, p < .001]. On its own, this is uninteresting. More provocative, are detailed analyses of student reported experiences learning for aesthetic understanding, and comparison against the experiences of control class students.

### **Representative Case Studies and Comparisons**

Two students were selected from each class to represent roughly average student experiences learning science during the course of this research. One boy and one girl were chosen from each class to represent a more balanced view of student experience. The two students from the treatment class, Margie and Tyler, have average scores of aesthetic understanding roughly in the middle as compared to the rest of their class (Margie = 2.67; Tyler = 2.33; class mean = 2.47). The two students from the control class, Jill and Joe, however, represent students with slightly higher than average scores of aesthetic understanding (Jill = 1.42; Joe = 2.00; class mean = 1.37). Control class students with slightly higher than average scores were chosen for two reasons. First, had we not chosen students with slightly higher than average



scores, corresponding case analyses would be very short, providing little insight into control classroom learning. Jill and Joe, however, with higher than average scores, offer more. Second, particularly in the case of Jill and Margie, the nature of their responses is dissimilar. Their case analyses illustrate this difference. Jill, therefore, was chosen to purposefully “match” the case of Margie, in terms of quality of studiousness as compared to her classmates. The cases of Margie and Jill are presented first with some discussion of the contrasts between them. The cases of Tyler and Joe are presented next, again, with some discussion of their contrasts. All four students participated in time<sub>2</sub> and time<sub>3</sub> interviews – another reason they were chosen for case study analysis. In summary, students were chosen because they are comparable in terms of quality of learning (prior student achievement, attention to school work, conscientiousness regarding school success), gender, and prior experiences learning science. The reader should consider Margie and Jill, and Tyler and Joe, very similar prior to science instruction.

#### Margie: Treatment Class, Emphasis on Changed Perception

Margie is one of the brighter, more academically conscious students in the treatment class. She listens attentively, completes all her assignments, and turns everything in on time. She appears to value school and works hard to do her best. Although Margie claims she likes science stating, “Yeah, science is pretty neat but math, music, art, reading, and PE are better.” Nonetheless, Margie works hard in class and might be considered a model student.

As students began the unit on weather Margie was quickly taken by the powerful metaphor of “atmosphere as ocean of air” that focused initial instruction. She reported thinking about the ocean of air as she played outside over the weekend and described wondering how “it’s strange that you don’t feel all that air pressing down on you.” Margie described how she pretended to “swim” around her yard relishing in the experience of imagining the air around her

as liquid water. By the end of the weather unit, Margie described more profound instances of changed perception. After having learned to think about weather as energy moving around, trying to find equilibrium, Margie described this experience, “My little brother got in a fight with my mom and there was so much energy in our house until he went outside and then the energy went back down. I thought about how that was kind of like a hurricane with lots of energy.” Margie began to see hurricanes and violently moving energy where none had existed before.

Across the course of the second unit, in which students learned about erosion, Margie continued to report experiences in which her perception of the world had changed. One afternoon, during students’ snack time, Margie was found intently staring at a potato chip she held between her fingers. She was carefully scratching a fingernail down the length of the chip and observing the tiny particles of potato chip falling to her desk. “I was just thinking about how this is kind of like erosion. My fingernail could be like wind or rain or glaciers or something slowly scraping off the land. I’m causing potato chip erosion!” Although Margie did not report viewing erosion as a war between forces trying to destroy the world and objects resisting destruction as it was framed at the beginning of the unit, she clearly found erosion captivating. Margie offered 6 examples in her post-erosion interview of situations in which she thought about, or saw evidence of, erosion.

During the final unit, on the structure of matter, Margie experienced even more extreme changed perception. The unit was framed in terms of “the dance of the little lumps.” This line was taken from a short video viewed in class in which molecular motion was described as a dance that changes characteristics as energy increases and phases change. Margie described her experience in the bathtub, “I was taking a bath and I had this fizz-ball thing but it wasn’t working. It was supposed to fizz but it didn’t so I imagined what the molecules were doing. I

thought maybe they weren't dancing fast enough so I added some hot water." Not knowing how her fizz ball was supposed to work, we cannot evaluate the accuracy of her connection. What's important, however, is her effort to make a connection to her experience.

Later, in the same interview Margie described eating a bowl of soup over the weekend. "I was about to take a bite of soup when it hit me how strange it was that the dance in my soup was going so much that some of the molecules jumped out into the air. I could see the steam rising so I knew there was evaporation and condensation. Then I imagined what a boring dance it must be in my spoon." Margie described the molecular organization in three different states – gaseous soup vapor, liquid soup, and solid spoon – in the metaphor of dance. The lens of dancing molecules compelled Margie to try to help her mother perceive their lunchtime soup differently, "I tried to get my Mom to re-see the soup but she didn't want to."

Margie represents a compelling case in which a student came to see the world differently through the eyes of particular metaphors. The activity of re-seeing seemed particularly powerful for Margie as she described attempts to do so on several occasions. The power of Margie's learning does not stop at changed perception. She is moved to explore, investigate, look for examples, and even to teach others what she has learned about science. In fact, Margie was so taken by the metaphor of "ocean of air" that she tried to re-create the experience of coming to appreciate it with her family members. "After we learned about the 17 miles of air I went home and got my little brother and my little cousin to lie down out in the front yard. I told them about the 17 miles of air pressing down on them and how they were at the bottom of an ocean of air." Her enthusiasm for enhanced perception is rich evidence of her aesthetic understanding.

Jill: Control Classroom, Emphasis on Language of Science

Jill and Margie are similarly good students with high levels of interest and ability in school. Although Jill does describe learning science as interesting and offers several examples of how her learning helped her to act in new ways, the quality of Jill's stories are quite different from Margie's.

Where Margie used her science knowledge to see ordinary objects and events differently, Jill related stories in which she used her science knowledge to verify or confirm her own understanding. When asked if she thought about anything differently at the end of the weather unit Jill had this to say, "Yeah, I think about the clouds differently than I did before. I like to go outside and look at the clouds and try to name them like stratus, cirrus, cumulonimbus and so on. Then I come back inside and get out my science book to see if I was right." The task for Jill seems to be to confirm her knowledge of the terminology of science while Margie almost never uses formal science words to describe her experiences. This trend toward science terminology and confirmation of her own science learning continues with Jill, "I like to go outside and feel the temperature and wind and try to predict the weather for tomorrow. I guess about the fronts, and the highs and lows and then I go look at the forecast in the paper and see how close I am." Predicting the weather is a radically different goal than seeing weather anew.

Jill's method of learning science by seeking confirmation in the world and checking her accuracy continue into the next two units. After she learned about erosion, Jill was asked if it made her think differently about anything or see anything differently than she had before. "I guess I look at sediments differently now than I did before. Before I didn't know that there was clay, sand, silt, gravel and so forth." Again, we see the tendency to report on terminology as clay, sand, silt, and gravel are simply ways to classify the sizes of sediments. Certainly Jill's

push to understand terminology is a factor of the values in Ms. Parker's classroom. As described previously, Ms. Parker frequently asks students to use their "science words" and gave assignments that emphasized the language of science rather than powerful ideas and ways of looking at the world, as in the treatment class. In this way, Jill is quite perceptive in identifying, and then adopting, the values of her classroom teacher.

By the end of the third unit, we were not surprised when Jill described an experience in which she thought about science outside of class. "My little cousin didn't know about solids, liquids, and gases, so I told him all about how the molecules move in each one. I also told my Aunt which metals stick to magnets (magnetism was not taught in this unit). She didn't know that either so I had to tell her." Jill's attempts to learn science and personalize its content are consistently grounded in attempts to use the language of science properly and efficiently. Jill appears not to have found the control class science instruction particularly stimulating or interesting enough to lead her to further inquiry. When asked if learning about science had made the world a more interesting and exciting, Jill responded, "Horses and rainbows make the world seem more exciting, not science." This is a profound statement for such a young student and it illustrates a common problem that science teachers, and perhaps all teachers, face. Students rarely find school subject matter interesting or compelling to study (Zahorik, 1996). Of course, we hypothesize that this is a result of emphasis on concepts and a discourse-based understanding, rather than ideas and changed perception via teaching for aesthetic understanding.

Unlike Jill, students in the treatment class responded quite differently to the question of increased interest and excitement. Tyler, for example, seems to find a great deal of excitement in science ideas alone. As with Margie and Jill, Tyler will be contrasted by Joe in the control class.

## Tyler: Treatment Class, Emphasis on Excitement and Action

In the interview before instruction began ( $time_1$ ), Tyler described only one time in which he learned something in science class that proved to be unusually powerful or illuminating. He referred back to this example throughout the first interview as evidence of learning that was exciting, causing him to ponder science outside of class. His exact words were, “Well, one time I learned about pigs’ eyes and I thought about how my eye was pretty much the same.” Needless to say, Tyler’s example is conservative in its vigor. Across the course of this research Tyler began to more thoughtfully articulate reasons for his science engagement.

After learning about air pressure at the beginning of the first instructional unit Tyler reported, “I thought about the 17 miles of air pressing down on me, that was cool to think about when I was walking around. It made me feel strong!” From the first day of learning for aesthetic understanding Tyler demonstrated a knack for getting the most from metaphoric descriptions. Later, during the weather unit, as weather was framed as energy searching for equilibrium, Tyler made this metaphoric connection, “Just like when you eat food and the food breaks down into energy and that energy starts to move around inside your body, that’s just like the weather, the energy gets moved around.” Upon further exploring his connection to digestion it was apparent that Tyler grasped the notion that “ingredients” make up weather just as “ingredients” make up food and these ingredients have the potential to unleash energy in the form of glucose or ATP in the case of digestion, or hurricanes, tornadoes, and thunderstorms in the case of meteorology. “Weather as energy” helped Tyler make a connection to something he knew about – digestion. This is an excellent example of how ideas can be used to bridge the gaps in our understanding and help us to see phenomenon through different eyes and make new connections in our understanding.

Tyler seemed to have his most powerful learning experiences with the study of erosion. Tyler reported 6 instances in which he thought about, noticed, or sought out evidence of erosion outside school. “I was walking home and I saw grass growing up through the sidewalk. I could see the little roots and I could tell they were causing erosion. Then I kept walking and I saw a big hole, kind of like a ditch, and it was all rocky and wet and the water was all filled up in it and I thought about how it was making erosion down there.” In an effort to elicit responses from the other student with which Tyler was being interviewed the interviewer stopped Tyler from continuing to tell another story about erosion. After listening to his fellow interviewee for about 30 seconds Tyler stated excitedly, “Hurry up! I’ve got more to talk about. I could go on about erosion for days!”

Toward the end of the interview Tyler was asked why he believed learning about erosion proved so powerful for him. He attributed his enthusiasm to his teacher claiming “He tells us about erosion. He says ‘EROSION BABY!’” excitedly gesturing as he had seen modeled in class. It seems reasonable that Tyler derived a sense of motivation and engagement through a dramatic teaching style but we also offer a supplemental explanation. As articulated earlier, Tyler seems adept at connecting metaphoric ideas presented in class to his own experiences and emerging conceptual understanding. After a short walk around the school building to look for examples of erosion, Tyler stated quite matter-of-factly “On the trees, the fungus is like erosion.” When pushed to expand on his idea he stated, “Fungus eats trees and if there’s too much fungus it can kill the tree. That’s like erosion.” Again, although fungus on trees is not exactly analogous to erosion, as there is no moving away and re-deposition of sediments, but the concepts are similar. Fungus breaks down tree bark just as the elements wear down rocks and fungus will, if left unchecked, potentially kill the tree just as the elements will eventually wear

away rocks. Once again, Tyler successfully translated ideas into his own world, and found them to be generative and compelling.

Tyler did not report on learning experiences quite as enthusiastically during the final unit on structure of matter. Although he did report several instances in which he thought about molecules, he only reported one extensive story to illustrate his learning. “One day, in the summer, we had a little family reunion. My family, they always eat chocolate and they leave it around outside and the chocolate melted inside their cups so they put it in the refrigerator to freeze it back into a solid. I was thinking about the molecules and how they were dancing when they were solid and then liquid and then solid again.” Tyler literally thinks and sees the world differently, through the lenses of powerful science ideas.

Tyler is now contrasted with Joe who seems to derive his enthusiasm from more instrumental values.

#### Joe: Control Class, Emphasis on Instrumental Value

Before any instruction began, Joe was asked why a student might want to learn science. Joe responded, “A kid might want to learn science to learn something interesting.” His response was provocative because it seemed to imply that other subjects were somehow less interesting. In an effort to explore this, we asked three other students the same question. All three children responded with instrumental explanations – “so she can do good in high school,” “so she can be a scientist later,” and “so he can get a job.” Like Jill described earlier, Joe seemed well situated to continue to learn science in powerful and aesthetically pleasing ways – ways other than purely for instrumental purposes. Unfortunately this was not the case.

When asked if he had learned anything unusually interesting or exciting during his study of weather, Joe reported, “I think probably learning about the clouds was the most interesting



thing we did. I learned all the names of them.” As with Jill, Joe reports the act of labeling and naming as the most salient and meaningful activity. The treatment class students reported power in expanded perception and the control students reported power in labeling and categorizing. What’s important about this difference is not which activity is better but that they are simply different activities, one instrumental in nature, the other experiential.

As instruction continued Joe maintained this new-found instrumentalist position toward science learning. “I used to wonder what clouds were made of but now I know they’re just made of condensation” and “I first thought erosion was about gravity and weather but then I learned it could be about lots of other things too.” We see a glimpse of Joe as a “wonderer,” perhaps a proclivity toward aesthetic understanding, but his wonderment is used to answer very practical questions – what are clouds made of and what factors affect erosion. By the time Joe was interviewed at the conclusion of the third science unit (time<sub>4</sub>) he didn’t mention a single instance in which he felt his learning to be powerful, generative, or even particularly interesting. We asked him, for example, if he had tried to learn more about the structure of matter and molecules on his own. Joe responded, “I suppose a person could check out a book on that stuff but I wouldn’t. I don’t care about it.” His comment here, at the end of the third unit, is remarkably similar to a comment made at the conclusion of the second unit, “Erosion isn’t too exciting.” An unfortunately pessimistic view for a student of any age.

In our opinion, the most interesting differences between Tyler and Joe are the reasons they offer for why science is, or is not, powerful. As discussed earlier, Tyler’s reasons are related to increased interest, action, and inquiry. Joe’s reasons are largely instrumental in that science gives him words to describe the world and his experiences in it. Again, the difference

seems to be related to differences in the values of the different classrooms and their related pedagogy.

### **Elaborated Analysis of All Student Responses**

All student interviews were analyzed and coded into categories that emerged during data analysis. Categories were reduced, integrated, and solidified in the method of grounded theory (Glaser & Strauss, 1967). Final categories were checked against the entire data set by having three different researchers re-categorize student responses. This method yielded an inter-rater reliability of .92. It should be noted that a small number of student responses simply defied categorization. In most cases these student responses were bizarre or outlandish in ways that did not contribute to the analysis. In this case, these responses were excluded from the analysis.

What follows are three tables that further classify student responses along similar themes. At the end of each table are descriptive statistics for each data set as well as results of independent samples t-tests used to determine if the number of responses different significantly between classrooms. Three illustrative student examples are provided for each sub-category (when possible) and some discussion follows each data set.

**Table 3: Student responses to question of changed perception**

**Interview question: Did learning about X help you to see the world differently in any way?**

<u><b>Control class</b></u>	<u><b>Treatment class</b></u>
<b>Linguistically oriented responses</b> <b>(responses specific to science words)</b>	<b>Linguistically oriented responses</b> <b>(responses specific to science words)</b>
I learned that transpiration comes from trees.	We learned about maritime weather.
I learned the three different types of precipitation.	I learned that patina is green rust and erosion.
I learned all the different names of the clouds like stratus, and nimbus, and cirrus.	I learned that sublimation is from a solid to a gas.
<b>18 category examples</b>	<b>10 category examples</b>
<b>Conceptually oriented responses</b> <b>(responses specific to science concepts)</b>	<b>Conceptually oriented responses</b> <b>(responses specific to science concepts)</b>
The rain hits the mountains and a little bit of the mountain is worn away. That's erosion.	Spinning of the earth causes morning and night. I think about that.
As more and more erosion happens it keeps wearing down the earth.	I learned that the most dangerous part of a hurricane is actually the water and how the water can do all the damage.
Clouds are actually just made of water vapor.	I learned that the state of matter depends on the energy in the molecules.

## 28 category examples

### 3 category examples

**Experientially oriented responses**  
**(responses specific to student**  
**experience)**

I didn't know that there's a battle between the two airs (warm air and cold air) and that's what makes a tornado.  
When I'm outside I think about where the wind might be coming from.

**Experientially oriented responses**  
**(responses specific to student**  
**experience)**

I look up in the sky and see energy moving around.  
I guess I knew about erosion before but I didn't really know it was all around us, happening all the time. I see it everywhere I go now.  
It's almost like I can just sit here and look at the walls and see the molecules moving and dancing. I see molecules all the time now – well I don't really see them of course!

### 2 category examples

**23 total examples**

**Mean = 1.38**

**SD = 1.33**

### 61 category examples

**99 total examples**

**Mean = 5.77**

**SD = 2.24**

$$t(54) = 6.85$$

$$p < .0001$$

Recall the overarching student question is if learning helped them (the student) to see the world differently. While examples listed as experiential and conceptual lend themselves well to this characterization, it is difficult to see how responses listed as linguistic in nature support a different quality of perception. Rather than try to infer what students meant or may have been thinking in response to the question of changed perception, we simply coded the responses provided by the students. A total of 28 linguistic examples were given by students, all similarly oriented toward language, science words, and appropriate use of terminology. Whether this new terminology really affects perception is unknown. An interesting statistic is that where only 10% of treatment student responses were of this linguistic sort ( $10/99 * 100 = 10\%$ ), 78% of control group students' responses were linguistic ( $18/23 * 100 = 78\%$ ). This is not surprising as treatment class pedagogy focused on the act of seeing the world differently while the control class, as the vignettes showed, focused primarily on linguistic aspects of science learning. In support of this, 62% of the treatment class student responses were experientially oriented, heavily emphasizing changed perception and experiences in the world ( $61/99 * 100 = 62\%$ ) while only 9% of control class student responses were experiential in nature ( $2/23 * 100 = 9\%$ ). The smallest difference between classes comes in examination of student responses coded as conceptual in nature. Here, responses had to draw on conceptual knowledge that led to new ways of looking at the world. Treatment class student responses were 28% conceptual ( $28/99 * 100 = 28\%$ ) while control class

students reported 13% conceptually oriented responses ( $3/23 \times 100 = 13\%$ ). Overall, treatment class students averaged 5.77 instances of changed perception against the control class student average of 1.38 [ $t(54) = 6.85, p < .001$ ]. It seems the pedagogical emphasis on changed perception was effective.

Table 4 shows student responses to the interview question related to increased interest and excitement.

**Table 4: Student responses to question of increased interest and excitement**

**Interview question: Did learning about X make the world seem more interesting and more exciting? Why?**

<u>Control class</u>	<u>Treatment class</u>
Egocentric (responses with a connection to feeling smart)	<b>Egocentric (responses with a connection to feeling smart)</b>
Learning all the different names of clouds made me feel smart.	It makes me feel smart because my family didn't know about erosion and now I do.
It felt good to tell my mom about the molecules because she didn't know.	It made me feel good to tell my mom about the molecules and the dance. She had never heard about the dance.
I never knew about the different things that caused erosion.	I feel like the a weather genius now!
<b>6 category examples</b>	<b>22 category examples</b>
Perceptually enticing (responses with a connection to seeing anew)	<b>Perceptually enticing (responses with a connection to seeing anew)</b>
Thinking about how the energy is related	I don't know why exactly but thinking

to the state of matter is interesting. I like to think about how hot stuff has faster molecules.

about hurricanes and tornadoes made things more interesting.

It's made me have more questions about stuff like why does the energy move around and stuff.

Thinking about the nothing in matter makes it more exciting. That's an exciting way to think about stuff.

### **1 category example**

**Explanatory power (responses alluding to significant new learning)**

**Knowing about how the molecules move faster and faster as they get more energy makes it easier to see why hot water can burn you and steam can burn you too. If the molecules are moving that fast then they can probably hurt you more.**

### **37 category examples**

**Explanatory power (responses alluding to significant new learning)**

Now that I know about erosion it helps me to understand why when we bring wood in from the wood shed and its all falling apart – it makes sense now because its kind of like eroding.

Before I thought 'why did the workers make the road so bumpy' but now I know it didn't start out that way – its erosion!

I understand how if you start with ice and just keep making the molecules move faster and faster and faster then you'll get

a liquid and then a solid. They're (the molecules) dancing faster and faster!

**1 category example**

**8 total examples**

**Mean = .23**

**SD = .57**

**9 category examples**

**68 total examples**

**Mean = 3.62**

**SD = .65**

**t(54) = 9.43**

**p-value <.0001**

Similar to the analysis for question one above, question two reveals a related trend. The difference between treatment and control students' responses is smallest when comparing responses that are conceptually oriented (having explanatory power). In both classes, 13% of student responses were conceptually oriented in their claim of interest (treatment group,  $9/68*100 = 13\%$ ; control group,  $1/8*100 = 13\%$ ). Cautious claims should be drawn from this similarity as the raw numbers are very low. However, it suggests that emphasis on changed perception in the treatment class had no great effect on conceptual knowledge.

Student responses that correspond to perceptual interest and excitement vary greatly between classes, 54% in the treatment class ( $37/68*100 = 54\%$ ) to only 13% for the control class ( $1/8*100 = 13\%$ ). Again, this shouldn't be surprising as treatment class pedagogy focused on changed perception. A number of student responses also corresponded to some notion of egocentric satisfaction in learning science. It is in this category that we see the most disparity. Treatment class students responded with egocentric reasons 32% of the time ( $22/68*100 = 32\%$ )



while control class students gave egocentric responses 75% of the time ( $6/8 * 100 = 75\%$ ). Again, it seems reasonable that a discourse-based perspective on understanding, with its attention to participation and identity affiliation, would foster more participatory-type responses, responses coded as egocentric. It is as though learning for a discourse-based understanding somehow fostered stronger self-centered orientations while teaching for aesthetic understanding fostered more idea centered orientations, increasing interest and excitement. Again, mean treatment class examples ( $M = 3.62$ ) for excitement outpaced mean control class examples ( $M = .23$ ) to a statistically significant degree [ $t(54) = 9.43, p < .001$ ].

Table 5 categorizes student responses regarding changed action. Responses lends themselves to a scale from less of a commitment to changed action (thought about science idea or told others about science idea) to more of a commitment (sought further inquiry or experiences with science idea). In this way, responses were coded to the highest level of commitment – i.e. a student who pursues further inquiry scores at the highest level of commitment, subsuming the previous two levels.

**Table 5: Student responses to question regarding changed action**

**Table 5: Student responses to question regarding changed action**

**Did learning about X (subject matter studied) lead you to pursue more about X on your own? Did you try to find examples of it? Find out more about it? Tell others about it? Wonder about it? Etc...**

<u>Control class</u>	<u>Treatment class</u>
<b>Thought about X/told others about X (lowest level of action)</b>	<b>Thought about X/told others about X (lowest level of action)</b>

I told my mom that when it rains stuff can be eroded and the chemicals in the rain can erode stuff too.

I told my mom about erosion because I wanted to let her know.

My sister didn't know the sun was bigger than the earth and I told her that and that it was a star.

I told my mom that erosion happens all the time and that we should watch out for it.

I told my cousin that he was 99% nothing and he thought I was putting him down – saying he was boring or something.

I told my whole family that there's 17 miles of air pressing down on them.

### **39 category examples**

### **23 category examples**

**Searched for examples of X (a more active level)**

I went outside with my science book and tried to see the different kinds of clouds. I tried to find examples of all the different kinds.

**Searched for examples of X (a more active level)**

At recess I look around on the blacktop for weeds and bugs and stuff that might be causing erosion.

I went outside like we did in class and felt the wind and tried to find out where the high pressure was.

I wanted to see melting so I put an ice cube on the table and watched it melt. I tried to re-see the ice cube while it melted.

**28 category examples**

**1 category example**

**Pursued further inquiry or experiences regarding X (most active level)**

I put books about weather and volcanoes on my Christmas list.

I went to the library to try to find a book about different states of matter. I couldn't find one.

I had a question about why it gets colder up on top of mountains so I waited until you got back so I could ask you.

**Pursued further inquiry or experiences regarding X (most active level)**

I went home and check it out on-line and I found way more stuff that was cool. I

found stuff on the sizes of tornadoes and I read stories of people who had lived

through tornadoes. I showed my mom but she wasn't all that interested.

My mom bought me this weather kit so I can measure air with it. I usually just do

the air temperature.

I made my little brother and my little  
cousin lie down outside and I told them  
about the 17 miles of air.

**3 category examples**

**27 total examples**

**Mean = 1.00**

**SD = 1.47**

**17 category examples**

**84 total examples**

**Mean = 4.54**

**SD = 2.60**

**t(54) = 8.22**

**p-value <.0001**

We see 85% of control student responses to the question regarding changed action were at the lowest level of commitment ( $23/27*100 = 85\%$ ) while only 46% of the treatment student responses ended here ( $39/84*100 = 46\%$ ). Moving up the scale, 4% of control class student responses discuss seeking examples of science ideas in the world ( $1/27*100 = 4\%$ ) while 33% of treatment class responses were about seeking examples ( $28/84*100 = 33\%$ ). Only 11% of control class responses correspond to the highest level of commitment indicating only three students sought further experiences with science ( $3/27*100 = 11\%$ ). However, 20% of treatment class student responses, corresponding to 17 examples, were indicative of this highest level of commitment to changed action. The mean treatment student action score ( $M = 4.54$ ) was much

higher than mean control action score ( $M = 1.00$ ) to a statistically significant degree [ $t(54) = 8.22, p < .001$ ].

### **Discussion: Shifting Norms and Values**

In applying this more fine-grained analysis of student responses to each of the three interview questions we see that not only the raw number of student examples or responses is quite different, but also that the quality of these responses is different as well. Treatment group students tended to respond in ways that correspond to the highly perceptual and experiential nature of the pedagogy while control students responses were largely linguistically and instrumentally oriented. In other words, analyses of student responses are not surprising given the nature of the pedagogy in each class. However, large differences in the quantity of student responses was found, suggesting the methods of teaching for aesthetic understanding were effective.

One of the most interesting results of this research is illustrated by data regarding the degree to which students achieved a level of aesthetic understanding. Having read the text above, one might be led to ask which students are more likely to be successful in the degree to which they come to have aesthetic understanding? Or, what does aesthetic understanding depend on? ANCOVA modeling, controlling for entry-level aesthetic understanding (as documented by time<sub>1</sub> interviews), with predictors of treatment, gender, ethnicity, prior student achievement (as indicated by teacher ranking), and whether the student participated in between-unit interviews, offers only the pretest of aesthetic understanding [ $F(54) = 4.33, p < .05$ ] and the treatment [ $F(54) = 8.61, p < .001$ ] as statistically significant predictors of post aesthetic understanding. In most classrooms in which conceptual understanding is the valued outcome, prior student achievement would likely predict conceptual understanding. In fact, in both treatment and control classrooms,

pre-test of conceptual understanding was statistically significantly related to post-test scores of conceptual understanding (average correlation for the three unit tests was  $r = .66$ ,  $p < .001$  in the treatment class and  $r = .68$ ,  $p < .001$  in the control class. However, changing the goals to teaching for aesthetic understanding eliminates prior student achievement as a predictor. In fact, prior aesthetic understanding is just barely significant as a predictor of post aesthetic understanding at the  $p < .05$  level. In other words, when the values shift to aesthetic understanding, the playing field becomes much more level for students of various levels of prior achievement, as well as for female and minority students (recall that neither bore out as statistically significant predictors of post aesthetic understanding). Although prior achievement predicts success on tests of conceptual understanding, it is not useful in predicting which students will come to a high level of aesthetic understanding. The act of shifting values from conceptual understanding to aesthetic understanding seems to have profound results in terms of which students are successful learners.

It should be noted that statistical analyses comparing conceptual understanding between the two classrooms favor a statistically significant effect for aesthetic understanding on enduring conceptual understanding, identical pre-tests administered one month after instruction ended. These results are not the topic of this research report; they are reported elsewhere (author, 2001b).

If neither prior student achievement, nor any of the other predictors mentioned earlier, effectively predict aesthetic understanding what student qualities might? First, the degree to which a student is able to reach a high level of aesthetic understanding likely relates to student creativity and ability to think imaginatively, using metaphor and analogy, to see the world in new ways. Metaphor and imagination connect ideas and the world to what's possible in new ways of

thinking, seeing, and acting. Highly creative and imaginative students might be more able to use metaphor and imagery to more successfully change their actions and perceptions.

Second, related to creativity, students who are more willing to reserve judgement or to remain open to the possibility of ideas to re-orient their perceptions of the world. If, for example, a student finds a particular metaphor or subject matter idea too absurd to warrant use, that student will likely close herself off from the experience of learning for aesthetic understanding. Students more willing to surrender to the experience of changed perception, and experiencing the world anew, will likely achieve higher levels of aesthetic understanding.

Third, a likely predictor of aesthetic understanding is the degree to which a positive interpersonal relationship exists between the teacher and the student. A more positive interpersonal relationship would likely involve higher levels of trust and interest in one another resulting in more successful student learning, of any type. This raises the issue of identifying predictors that are unique to teaching for aesthetic understanding and not simply predictors of more effective learners or learning environments. Again, these are topics which need further systematic investigation in future research.

## **Conclusions**

This research suggests that teaching for aesthetic understanding is possible and has different and desirable outcomes from teaching a discourse-based pedagogy. Students' interest and willingness to engage in science ideas, regardless of prior achievement or demographic characteristics, shows that, in overemphasizing the linguistic/conceptual aspects of science learning, we might be missing a vital access point that teaching for aesthetic understanding can provide for all students. This research also suggests that a pedagogy too focused on discourse-based learning ends in an instrumentalism that does not offer students a long term path to

engagement in science, changed action, and inquiry. In this way, teaching for aesthetic understanding levels the playing field, and has great promise as a future, vital element in the teaching of science.



## **Appendix A: Generalized aesthetic understanding interview protocol**

1. Did you learn anything during the course of this unit that made you think differently or see things differently? If so, tell me what you thought about or saw differently? If so, tell me why you think these ideas made you see the world differently? If not, why didn't learning make you think or see the world differently?
2. Was learning about the ideas in this unit interesting or exciting? In what ways? Was it more interesting or exciting than other things you learn in science? If so, what was so different about it? If not, why not?
3. Did you do anything as a result of this new learning? Did you tell anybody else what you learned about during the unit? Did you try to learn more about any of these ideas on your own? Did you look for examples of what you learned out in the world? Tell me why or why not.
4. Do you think differently about the ideas you studied in this unit? If so, how? In what ways? If not, why not?

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