**Leveling the playing field: Teaching and learning science for aesthetic understanding**

Mark Girod[1], David Wong[2], Kevin Pugh[3], Joseph Martineau[4], Michael Pardales[5], &
Shane Cavanaugh[6]

We'll have to figure out author order later!

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Contact:

Mark Girod, Ph.D.
Western Oregon University

[1] Western Oregon University. Monmouth, Oregon.
[2] Michigan State University. East Lansing, Michigan.
[3] University of Toledo. Toledo, Ohio.
[4] Michigan State University. East Lansing, Michigan.
[5] University of Michigan, Flint. Flint, Michigan.
[6] Michigan State University. East Lansing, Michigan.

345 N. Monmouth Ave.
Monmouth, OR  97361
Phone: (503) 838-8518
Email: girodm@wou.edu

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**Abstract**

From the aesthetic framework of Dewey (1934), learning theory and related pedagogy are developed and identified as teaching for aesthetic understanding. In a quasi-experiment, three units of instruction were taught in a 5th grade classroom contrasted against learning in an adjacent 5th grade classroom. Detailed comparisons of teaching are given and pre and post measures of interest in learning science, science identity affiliation, and efficacy beliefs are investigated. Tests of conceptual understanding before, after, and one month after instruction reveal teaching for understanding fosters more, and more enduring, learning of science concepts. Several interactions related to girls and low efficacy learners suggest that refocusing learning goals on goals of aesthetic understanding may "level the playing field" for poorly served students and enrich their resultant conceptual understanding. Also, correlation analyses between pre and post-tests of conceptual understanding and pre and post-measures of aesthetic understanding suggest that prior conceptual knowledge is not predictive of aesthetic understanding.

What is science? Why do scientists do science?

These two questions – one about the definition of science, the other about the motivation of scientists – has guided much of the psychological and pedagogical theorizing about science. Most of this theorizing has taken place within the broader philosophical paradigm that some have called the cognitive-rational perspective (Greeno et al., 1997) where science is seen as a rational search for warranted claims and useful representations. In this view, the essence of science is its logic, careful coordination of theory and evidence, careful testing of hypotheses, openness to critique, and willingness to change. In addition, scientists themselves, who typically do not concern themselves with either the philosophy or psychology of their work, will also frequently portray their work in this way.

In the current cognitive-rational paradigm in education, logical coherence and useful representations about the world are the endpoint and motivation for human activity. In this paradigm, the mind is naturally prompted to solve problems, to reduce discrepancy, and to seek integration and regularity. Certainly, rationality is an important part of human capacity in general, and of science, in particular. However, in raising reason to its elevated status, other important qualities of human capacity and human experience are overshadowed.

Wong (2002) suggests that the question "what is the nature of science" can be productively rephrased to "what is it that gives science its vitality?"

> "In studying the nature of science, students should not simply understand epistemological beliefs and methodological procedures, but also appreciate what makes science vibrant, exciting, and fulfilling. That is, students should gain a sense of what brings life to the discipline, the community, and, most of all, individual scientists. The "nature" of science should capture that which makes it a creative, motivating, and deeply personal enterprise. In short, to study the nature of science is to appreciate its vitality. By focusing on vitality, I make a direct link to some of the central problems of K-12 science education: vitality is precisely the quality that students least experience when learning science." (p. 2).

Rephrasing the nature of science as a question of vitality opens up the possibility that science is more than just a cognitive-rational activity. The question implicitly recognizes that humans are motivated by more than just the need to solve problems, make accurate predictions, or develop a logically coherent picture of the world. If we were to we ask what about science makes scientists feel more alive, more fully human, here is what we might learn about the "nature of science."

> Dirac: "It is more important to have beauty in one's equations than to have them fit experiment" (1963, p. 47).
>
> Dirac, for example, had this to say about the general theory of relativity, "It is the essential beauty of the theory which I feel is the real reason for believing in it" (1980, p. 10).
>
> Simone Weil: "The true subject of science is the beauty of the world" (as quoted in Fischer, 1999, p. 91)
>
> Herman Weyl: "My work always tried to unite the true with the beautiful; but when I had to choose one or the other, I usually chose the beautiful" (as quoted in Chandrasekhar, 1990, p. 53).

Science, beauty, aesthetics

In these observations, we are reminded of the primacy of the aesthetic experience in scientific work. In the common vernacular, aesthetics refers to a sensitivity of the beautiful and an appreciation for what makes something beautiful. In the more formal theoretical language, aesthetic experiences are ascribed special qualities. Dewey's (1934) aesthetic theory undergirds much of our conceptualization of aesthetics and so we elaborate on his ideas.

*Intrinsic Meaning*

One distinguishing quality of an aesthetic experience is its intrinsic meaning. Deweyan scholar, Phillip Jackson (1998) writes,

> Extrinsic meaning (likewise, significance or value) refers to what an object or event signifies. It has to do with the subservient and instrumental role that the object or event plays in the attainment of some end. Intrinsic meaning (likewise, significance or value) inheres within the object or event itself. It intrinsically characterizes the thing experienced. Intrinsic meaning is also instrumental, but in a different way than extrinsic meaning is. It is not put to use directly. Instead, it serves to enrich the immediacy of subsequent experience. That enrichment

> Dewey looks on as being so wonderful and yet so fortuitous as to be called a gift of the gods…

A gift of the gods may indeed be of instrumental importance, but, without question Dewey and Jackson refer here to intrinsic worth. Just as art and art-making are valued as intrinsically meaningful, so do scientists value their science and science-making.

*Imaginative Quality*

A second important quality of the aesthetic is its imaginative quality. Great art gives us pause; pause of wonderment and awe. Similarly, powerful science ideas afford a similar experience. Jackson, on Dewey,

> "Esthetic experience is imaginative," but he quickly points out that "all conscious experience has of necessity some degree of imaginative quality" (LWIo, z76), a fact that sometimes gets obscured in discussions of how the arts work. The difference between aesthetic experience and ordinary experience lies in the relative predominance of the imaginative element. It predominates in aesthetic experience, Dewey explains, "because meanings and values that are wider and deeper than the particular here and now in which they are anchored are realized by way of expressions although not by way of an object that is physically efficacious in relation to other objects" (LWI0, p77).

Dewey and Jackson suggest that art (and science) are somehow less fulfilling or less vital without an imaginative quality; without wonderment.

*Dissolution*

Third, and perhaps the most difficult notion of aesthetic experience to grasp, is the idea of dissolution – or the elimination of self as a distinct referent in the experience. The experiencer (self) and the experienced (world) move together and transact in ways that pervade both. Each are changed and neither exist wholly independent of the other. Dewey explains,

> "The uniquely distinguishing feature of esthetic experience is exactly the fact that no such distinction of self and object exists in it, since it is esthetic in the degree in which organism and environment cooperate to institute an experience in which the two are so fully integrated that each disappears" (LWI0, z•q)

We've each experienced this unique quality of an aesthetic experience at some point. Recall a situation in which you related the experience of a romantic moment, a spectacular meal, or a fabulously funny story and made the statement, "You had to be there." This is suggestive of the dissolution that has occurred between you and the moment (or object, or joke, or experience). It is indescribable because you have moved beyond it in time and cannot reconnect with it – or with you in that experience. The moment, and you, have become inextricably linked. This is dissolution and is a key component of the aesthetic experience.

Intrinsic value, imagination, and dissolution of the self-object distinction – these qualities describe the aesthetic experience and give insight to what scientists find compelling about their work. The cognitive-rational paradigm concerns itself in some ways with these qualities, most notably intrinsic value, but for the most part, the realm of aesthetic experience is overlooked. The cognitive-rational perspective has historically struggled to account for flights of imagination and creativity. It is difficult, if not impossible, to explain how new ideas emerge from a logical, analytic process (although many have tried – see Csikszentmihalyi, 1990; Root-Bernstein, 1999). In addition, the dissolution of the self –object distinction in aesthetic experiences is practically incommensurable with conventional cognitive views of the scientific inquiry. Objectivity and skepticism, two central qualities of scientific activity, are most often conceived upon the assumption that the observer can "stand back from" the object. Scrutiny, unbiased observation, and clear thinking require "distance" between the person and object.

Dewey was well aware this age-old chasm between "scientific" and "artistic" activity. His project as a philosopher was to redefine the nature of science and art and highlight more similarities than were typically acknowledged. In doing so, he attempted to unify cognitive and aesthetic activities into a single coherent account of how we are transformed by experience. It is not the goal of this paper to explicate these ideas and we point interested readers read to excellent treatments of this subject by Dewey (1934), Jackson (1998, 2002), Prawat (1998), and Garrison (1997).

And, what is the aesthetic experience of science? Again, scientists speak for themselves.

Burke (1990): “The passion caused by the great and sublime in nature, when those causes operate most powerfully, is Astonishment; and astonishment is that state of the soul, in which all its motions are suspended, with some degree of horror” (p. 53).

Kant (1790) describes the sublime as: “a feeling of grandeur of reason itself and of man’s moral destiny, which arises in two ways: (1) When we are confronted in nature with the extremely vast (the mathematical sublime), our imagination falters in the task of comprehending it….” (citation??) .

Heisenberg in a discussion with Einstein: “You must have felt this too: the almost frightening simplicity and wholeness of the relationships which nature suddenly spreads out before us and for which none of us was in the least prepared” (as quoted in Chandrasekhar, 1990, pg. 53).

Whewell, in commenting on Newton’s *Principia* suggest an admiration and trepidation at the mathematics within: “As we read the *Principia*, we feel as when we are in an ancient armoury where the weapons are of gigantic size; and as we look at them, we marvel what manner of men they were who could use as weapons what we can scarcely lift as a burden…” (as quoted in Chandrasekhar, 1990, pg. 45).

In these examples, the aesthetic seems to be associated with the intense experience of revelation about the nature of the world and one’s part in it. This experience is hardly captured by constructs of the rational, cognitive paradigm – constructs such as disequilibrium, dissonance, problem-solving, objectivity, and so on. Instead, the aesthetic is awe, astonishment, admiration, fear, and trepidation. Our argument is grounded in the belief that science education should foster these kinds of experiences for its students.

Summary

We propose a new organizing framework for science learning to stand in contrast to learning oriented toward the cognitive-rational paradigm. We refer to this framework as learning for aesthetic understanding and, at its core, is the notion of the aesthetic experience. Students learn through a process of changed perception, a virtual transformation of their world and themselves as they seek to verify or explore the power and wonderment of science ideas. Aesthetic understanding brings unification or coherence to students' understanding and necessarily moves them out into the world as a result of the intensely compelling nature of experience. What exits aesthetic experience is a more rich, multifaceted understanding that incorporates conceptual knowledge, skills, dispositions, feelings, attitudes, actions, and emotions and value. To value is to see the relative worth, utility, or importance. Value can be placed on an object, skill, or idea in ways that are not necessarily connected to instrumental outcomes. In fact, we argue that instrumental value too often guides teaching and learning. Worth, utility, and importance should be guided instead by aesthetic outcomes - those outcomes that lead to more pleasing or beautiful results.

Given these dimensions of the aesthetic framework and associated learning for the goal of aesthetic understanding, the following research study was conducted.

## The Research

A quasi-experimental study was conducted in a large, urban elementary school in a Midwestern city. The student population was a heterogeneous mix of Caucasian and African American students from mostly middle class families. Two 5$^{th}$ grade classrooms, and the teaching and learning that occurred there, 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 three times a week for 60 minutes at a time. Because of imminent state testing and rigid curricula and pacing, both classes were taught on almost the exact same schedule. Each used many of the same activities, assignments, and lab activities. All students in both classes took the exact same tests of canonical scientific understanding. The only significant differences between the two classrooms were the instructional strategies employed by the two teachers. The treatment class (27 students) was taught using strategies to facilitate aesthetic understanding while the control class (27 students) was taught using strategies to facilitate a more generic conceptual 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

| Research Phase | Data gathering procedures |
|---|---|
| $Time_1$ – Before any science instruction | Student interviews investigating prior aesthetic experiences and aesthetic understanding in science |
| $Time_2$ – $Time_4$ (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) |
| | Student interviews investigating emerging aesthetic understanding |
| $Time_5$ – After all science instruction | Student interviews of aesthetic understanding |

$Time_1$ 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 $time_2$, $time_3$, and $time_4$, 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. 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 experience and resultant aesthetic understanding including changed perception, increased value for science ideas, and increased interest in learning science. A generalized interview protocol is appended as A.

$Time_5$ 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. The length of the interviews varied from 15 minutes to 40 minutes each.

Treatment class pedagogy

Extending the conversation on the role of aesthetics in science and aesthetic experience in particular, we now offer an associated pedagogy. This pedagogy serves as the treatment for the research study. Central elements of the treatment pedagogy are emphasis on perception via metaphor, creation of wonderment (imaginative quality), and investigation of personalization of content and experience with content (to explore dissolution and build intrinsic value).

Rather than most heavily valuing ways of talking about science or ways of representing science ideas through conceptual models or schemas, the teacher teaching for aesthetic understanding most heavily values new ways of seeing the world – ways that are made possible by metaphors that illuminate powerful science ideas. All three groups of teachers - those that value linguistic or discursive ways of knowing, those that value conceptual or empirical ways of knowing, and those that value aesthetic or metaphoric ways of knowing – want the same thing: for students to believe in accepted, canonical, scientific ideas about the world. However, the important difference between the third and the first two groups is that teachers teaching for aesthetic understanding hold firmly to the belief we must teach students how to see the world through science ideas before their ways of thinking and speaking will conform to canonical understandings. This is a subtle but fundamental change over discursive or cognitive-rational learning frameworks. Once a teacher makes this transition to valuing “perceptual change,” the task becomes how to teach in ways that move students toward this goal. We offer three steps in this regard.

Step 1: Offer the metaphor (lens)

The most important steps in teaching for aesthetic understanding is choosing a lens or metaphor to guide student perception. This initial lens or metaphor is used to organize a body of content (a single science idea, a set of related science ideas, a lesson, a series of lessons, a whole unit) in engaging ways. Whether this initial organizer is a metaphor, an analogy, a simile or whatever, isn’t important. What is important is that this initial organizer is used to shape student perception – providing a lens through which to view the world anew. For simplicity sake, we refer to this initial organizer, this lens if you will, as a metaphor. We do believe, however, that it is probably pedagogically more effective if this initial organizer is a metaphor. A sizeable literature exists which supports the claim that metaphors are powerfully useful in fostering learning (see Ortony, 1979 for a good overview).

Once the teacher identifies an appropriate metaphor she must share it with her class in such a way that produces a sense of wonderment in students. Wonderment, we suggest, is different from engagement, interest, or motivation to learn as it captures an imaginative quality useful in student learning. Teaching for aesthetic understanding necessitates engagement in ways that encourage wonder, imagination, and consideration of the possible. An adequate metaphor engenders wonderment, providing a sense of engagement and interest with particularly forward looking qualities. Wonderment creates anticipation, a quality vital to engagement, inquiry, and deep learning.

A skillful teacher shares the metaphor in ways that contribute to this sense of wonderment utilizing poetic and even dramatic language. As students come to understand how the metaphor is being used and relish in the wonderment it fosters, the teacher must consciously model the power of the metaphor. The metaphor must be shown to transform the teacher’s own perception allowing access and understandings of new and interesting aspects of the world. There are many ways that a teacher could model this value. We’ve found telling stories to be the most effective. Teachers must make a point of telling stories or sharing experiences in which the metaphor was usefully transformative. This modeling of the power of the metaphor gradually leads into scaffolding students' attempts to personalize the metaphor – to employ it as a perceptual lens on their own terms, in their own world.

Step 2: Unpack the metaphor

Step two of the pedagogical model might be described broadly as "playing with the metaphor." The main task here is to investigate where the metaphor works and where it falls short as an adequate and empowering descriptor of the world. Teachers might ask questions such as: What does our metaphor help us to see? What kinds of things are more clearly illuminated because of the metaphor? What kinds of things does our metaphor not help us to see or explain? What could we add to the metaphor to make it more effective or more illuminating? Although this step of the model ought to be guided by the teacher it is important to allow students to do most of the "work" in "unpacking" or "playing" with the metaphor.

What seems to naturally follow from unpacking the metaphor is some effort on the part of the student to personalize the metaphor – as alluded to above. If this does not follow naturally then the teacher must encourage it. The act of personalization is crucial because it connects the more formal world of science to the life of the individual student. As with the teacher, student storytelling is useful in personalizing science ideas. Storytelling allows students to describe how they are coming to make sense, find examples of, and extend their understanding about science content. As a check on effectiveness, the teacher should listen for signs of dissolution as a result of the aesthetic experience. This may suggest effective pedagogical delivery. Also, it needs to be noted here that we are not radical constructivists. We do not believe that any student personalization is adequate. Perceptual change and personalization of science are powerful because they are grounded in powerful science ideas. The development of canonical science ideas is important. For this reason we found that during student sharing of experience, it is often necessary and a good opportunity to refine and, if necessary, re-teach content ideas.

Step 3: Formalize the language

The final step in teaching for aesthetic understanding is to formalize the metaphor and metaphoric language into canonical science language. Without formalizing the language, science ideas remain in a metaphoric state. Teachers must help students to make sense of their metaphoric understandings against the more formal language of science as found in textbooks, curriculum guides, and standardized tests.

What's most useful about the model is that activities can be employed at any step in the model with equal pedagogical value. Activities could be designed to help develop student perception, to engage students in "unpacking" of the metaphor, and to formalize science language. Activities could involve formative assessment activities designed to expose emerging student understanding and to ensure high quality aesthetic understanding at the end of the instructional cycle. Activities could also employ technology resources – again for the purpose of expanding perception, unpacking, or formalizing. The model is a flexible framework in which other pedagogical moves are easily incorporated. Table 2 shows a summary of the pedagogical model followed by an example from this research that illustrates the model.

**Table 2: Summary of pedagogical model useful in teaching for aesthetic understanding**

| Step | Step description |
|---|---|
| Step 1: Offer the metaphor (lens) | • provide the lens, when possible rooted in metaphor<br>• use the lens to generate wonderment of the phenomena<br>• model the power of the lens to inspire, provoke, and explain |
| Step 2: Unpack the metaphor | • "work the lens/metaphor" to investigate what it illuminates, hides, explains, and does not explain<br>• test or verify the power of the lens/metaphor in student world<br>• provide time and space for students to personalize the science content |
| Step 3: Formalize the language | • formalize the lens/metaphor through scientific language |

An example: Teaching erosion

In the course of this research a unit on erosion and weathering was taught for the goal of aesthetic understanding. The unit was framed using the metaphor of a war or battle between forces that try to destroy or break down the earth's features and those features that resist this destruction. The following is a transcripted passage from the first day of the unit on erosion in the treatment class. The first author served as the teacher – accounting for the first person narrative.

> *Boys and girls I want to tell you about a war. There's a horrible, violent war being waged – right now – outside our classroom window in fact. The two sides of the war battle endlessly – tirelessly – without rest. The participants on one side try to stand strong – to be firm in the face of their enemy – to resist certain destruction. But the other side is too strong – too persistent – ruthlessly aggressive and amazingly strong. This side will prevail, in fact, they always prevail. The casualties of this war are all around us – horribly disfigured, in some cases, beyond repair. Do you want to see some of the casualties of this war? I caution you, the images are powerfully disturbing.*

Here, full color posters of the Grand Canyon, a coastal seascape, and an alpine/glacial scene were shown to students. The point is, of course, that erosion is all around us and can be imagined as a battle between the forces that cause erosion and those objects and landforms that try (without agency, of course), in vain, to resist erosion. The metaphoric lens of "the battle" framed the instructional unit and the presentation was crafted using richly descriptive and highly imaginative language. Students were drawn into the engagement with the metaphor in a way that created drama and wonderment.

Next, students were asked to "work the metaphor" of "battle." They identified the players in the battle (forces of erosion and objects that resist erosion), the "weapons" used (wind, waves, rain, glaciers, rivers and so on) and the "casualties" of the war (canyons, beaches, valleys, sediments and so on). After an extended analysis of the metaphor the class took a short fieldtrip around the outside of the school building looking for evidence of the battle. At the conclusion of the instructional day students were challenged to search out evidence of the battle, describe the battle to someone else, and try to help another see the world through the lens of the metaphor. Upon returning to class the following day students reported their experiences "personalizing" the metaphor and verifying its utility in their own world. The stories told were amazing and extent to which students sought out connection to science ideas was amazing. However, up until this point, not a single "science word" had been used! Students had been learning science for two days without the language found in textbooks or on standardized tests. This was necessary to build a framework of perception, engagement but led to the need to adopt more canonical and parsimonious language.

Students were ready to develop a more formal language because their metaphoric descriptions were limited in the detail that they were able to provide. Several other activities across the course of the erosion unit to support the formalization process. Students exited the unit with an understanding of the following three central scientific ideas: a) erosion is a naturally occurring process that never stops and affects all objects, b) we can do things to slow erosion or to minimize its detrimental effects, and c) erosion can, at times, play a positive role as in soil production. These are, word for word, the science curriculum goals for studying erosion in this elementary school.

<u>Pedagogical details in both treatment and control classrooms</u>

Because this research purports to make claims of difference between two classroom experiences and attribute these differences to pedagogical treatment, it is necessary to, as completely as possible, establish the pre-existing differences between the two classrooms. This section serves this analysis.

Science instruction occurred in both classrooms an average of 2 days per week for a total of 20 days in the treatment class and 18 days in the control class. On the average, science lessons lasted 60 minutes, ranging from 40 minutes to 80 minutes in length. On each instructional day, a researcher observed the teaching and learning as it occurred taking extensive fieldnotes focusing in on the content of the science lesson and the interactions of students trying to learn science. All lessons were tape recorded and further analyzed for content, while student assignments, artifacts, and testing materials were also gathered. Across the course of this research, both classes were preparing for an upcoming statewide assessment of science understanding and so both followed very closely the state and local curriculum goals for 5th grade science. These curriculum goals are listed in Table 3.

**Table 3. Curriculum goals for three units**

| Goals for conceptual understanding used in both classrooms |
|---|
| Goals for weather unit:<br><br>• The student will (TSW) use weather data and weather maps to predict up-coming weather.<br>• TSW also teach their family about severe weather and the necessary precautions for severe weather.<br>• TSW describe the atmosphere.<br>• TSW describe weather conditions and climates.<br>• TSW describe seasonal changes in weather.<br>• TSW explain appropriate safety precautions during severe weather.<br><br>Goals for erosion unit:<br><br>• TSW describe land features such as mountains, plains, hills, and valleys<br>• TSW describe common sedimentary products such as gravel, sand, silt, and clay<br>• TSW describe common processes of weathering and erosion<br>• TSW describe soil as a product of weathering<br>• TSW describe ways to control erosion such as planting vegetation and slowing runoff<br><br>Goals for structure of matter unit:<br><br>• TSW understand the relationship between the three states of matter and the energy of the molecules found in each (solid = low energy, liquid = more energy, gas = most energy)<br>• TSW understand how solids are organized into repeating patterns or structures and what happens to those structures as energy is added<br>• TSW describe molecular motion in various states of matter<br>• TSW describe phase changes using appropriate terminology such as evaporation, condensation, melting, freezing |

More than simply subscribing to the same curricular goals, daily classroom instruction appeared quite similar as well from the duration of the three units to the amount of time spent on each content idea with each unit. Table 4 outlines the three units in terms of their daily content. Dissimilar elements appear italicized.

**Table 4. Duration and content analysis of all units in both classrooms**

<table>
<tr><th>Treatment classroom – aesthetic understanding</th><th>Control classroom – conceptual understanding</th></tr>
<tr><td><u>Weather unit:</u><br><br>Day 1: atmosphere and air pressure<br>Day 2: air pressure and local winds<br>Day 3: weather instruments<br>Day 4: predicting weather from weather data<br>Day 5: landscape portraiture and use of the sky in art<br>Day 6: global winds, seasons and seasonal change<br>Day 7: severe weather<br>Day 8: severe weather precautions and preparedness<br>Day 9: review and post-test</td><td><u>Weather unit:</u><br><br>Day 1: atmosphere and weather instruments<br>Day 2: weather prediction from data<br>Day 3: global winds and climate<br>Day 4: seasons and seasonal change<br>Day 5: air pressure and local winds<br>Day 6: severe weather<br>Day 7: severe weather precautions and preparedness<br>Day 8: review and post-test</td></tr>
<tr><td colspan="2">Notable differences between the two weather units:<br><br>Although both units appear very similar, the treatment classroom used air pressure as the focusing concept while the control classroom, having just completed an extensive unit on astronomy, used the heating of the earth's surface as a focusing idea to discuss weather. The extra day in the treatment classroom can be attributed almost solely to the addition of an art activity designed to investigate how artists use the sky (in its variety of appearance) to contribute to the story or mood of a scene. Actually very little science content was covered on that day.</td></tr>
<tr><td><u>Erosion unit:</u><br><br>Day 1: mechanics of erosion (both physical and chemical)<br>Day 2: sedimentation lab exercise<br>Day 3: completion of lab exercise<br>Day 4: erosion overview with Bill Nye<br>Day 5: soil formation and erosion control<br>Day 6: review and post-test</td><td><u>Erosion unit:</u><br><br>Day 1: mechanics of erosion (mostly physical)<br>Day 2: sedimentation lab exercise<br>Day 3: erosion overview with Bill Nye<br>Day 4: erosion control<br>Day 5: review and post-test</td></tr>
</table>

Table 4 (cont'd)

Notable differences between the two weather units:

For this unit and the next, the two classrooms followed almost identical lesson plans. In this case, the extra day in the treatment classroom is attributed to shorter science periods. In other words, the control classroom completed the sedimentation lab exercise in one long day rather than two. Also, the control classroom did not cover soil formation as an explicit topic of erosion or chemical reactions as agents of erosion.

| <u>Structure of matter unit:</u> | <u>Structure of matter unit:</u> |
|---|---|
| Day 1: *molecular modeling* | Day 1: *properties of matter* |
| Day 2: molecular arrangement and states of matter | Day 2: molecular arrangement and states of matter |
| Day 3: changes in states of matter | Day 3: changes in states of matter |
| Day 4: review and reinforce key concepts | Day 4: review and reinforce key concepts |
| Day 5: post-test | Day 5: review and post-test |

Notable differences between the two weather units:

Here the big differences are in the inclusion of molecular modeling activities in the treatment class and their substitution for a long instructional conversation about various properties of matter in the control classroom. Although properties of matter are not included in the curriculum goals it was time well spent as much terminology and many naïve understandings were addressed. Again, although the units appear very similar at the surface, they are guided by very different goals, as we shall see next.

Before describing the precise differences in pedagogical practices between the treatment and control classrooms, we offer short vignettes describing each classroom, its students, routine science instruction, and norms and values held by each teacher. The first vignette describes Ms. Parker's classroom – the control class, followed by the treatment classroom.

<u>Control class vignette</u>

The control classroom is heavily adorned with science related objects – huge strips of birch bark hang from the ceiling alongside sea sponges, tumbleweeds, and cattails. An empty turtle shell sits on the countertop alongside broken eggshells from some gigantic reptile, a fish tank teeming with tiny goldfish, and a row of miniature greenhouses growing in the windowsill. The bookshelves have many science related books for children and the walls have several science related posters describing things such as the sun, our solar system, the life cycle of a frog, and rainforest ecosystems. The room appears to be filled with anticipation of great scientific inquiry.

Science class almost always began the same way in Ms. Parker's room. With her at the head of the class, students commonly read from their science textbook, a handout, or some other science related materials. Ms. Parker stated, "I like to get something in their hands – something they can read and follow along with." Individual and group reading and discussion of science topics usually takes about 45 minutes. During this time the day's topic is presented (almost exclusively through the reading), Ms. Parker further elaborates and personalizes the content often telling stories of her personal experience or trying to relate common experiences or events to the topic at hand. For example, during the erosion unit, Ms. Parker told an elaborate story about canoeing down a river and examining the riverbanks for erosion. Students seem to enjoy her attempts to familiarize science concepts. After initial presentation of content is made students are encouraged to ask questions relating to their own emerging understandings of content. However, Ms. Parker discourages student storytelling. In fact one day she stated flatly, "Is your hand raised for a question or do you want to tell a story? I don't want to hear any stories!" This is an important difference between the two pedagogical programs. After this period of instructional conversation, students are typically given some type of activity to complete – most commonly a worksheet related to the daily topic. Science period last for 60 minutes. This is 25% longer per lesson than the treatment class so although the treatment class spent consistently more days per unit, the number of science minutes is actually higher in the control classroom.

In an interview, Ms. Parker expressed her goals for science instruction, "I want my students to develop a conceptual understanding of the topics we are studying. This means they would understand the appropriate terminology and how those words and ideas fit together – like moons are smaller than planets and asteroids are smaller than moons." It was common for Ms. Parker to request that students "use the science words" in asking questions or making comments. Although learning a large vocabulary of science may seem unappealing to adults, Ms. Parker employs creative methods, has a pleasant disposition, and gives lots of encouragement that makes her students feel good and seem to enjoy learning in her classroom. Although science is probably not her strong suit, Ms. Parker really does appear to be an outstanding teacher – as her runner-up Teacher-of-the-Year status reflects.

<u>Treatment class vignette</u>

As with Ms. Parker's room, the treatment classroom had science posters on the wall and a row of miniature greenhouses sitting on the window ledge. A wide variety of science-related children's books were available for leisure reading. While Ms. Parker's children's desks were arranged in small groups of 4 or 5, the desks in this room were arranged in long horizontal rows so perhaps 10 children sat side-by-side. The feeling in the treatment classroom is a bit more formal but not less exciting or interesting.

Instruction in the treatment classroom also followed a fairly specific routine in classroom instruction. Upon beginning a science lesson, the treatment classroom teacher would often write an organizing question, idea, or word on the board around which the daily lesson would be organized. For example, one day, instruction was led by a discussion stimulated by the question, "What makes the wind blow?" Students rarely had any materials to read but discussions moved rapidly and unpredictably as they followed students' lines of inquiry and entertained students' hypotheses. Unlike Ms. Parker, the treatment classroom teacher felt it was important for students to tell stories related to their personal experiences and emerging understandings of science ideas so a great deal of time of each lesson was spent telling stories and listening to the stories of others – both children and adults.

Rather than focus on science terminology, the treatment classroom teacher focused on the act of transforming student perceptions of the world. The goal for students was to begin to see scientific phenomenon in the world around them. This goal was specific for each unit and explicit in intent – meaning all students knew the goal was to see the world differently. In fact many lessons began with this question from me, "So, yesterday we talked about X. What did you see yesterday as you walked home from school or played outside afterwards?" Long conversations about previous ideas often ensued until eventually the conversation turned to the next topic at hand.

Also similar to Ms. Parker's classroom, most lessons ended with an activity - however the activities in the treatment classroom were of a different quality than the activities in the control classroom. Rather than individual seatwork type activities designed to reinforce concepts, terminology, and application, the activities employed in the treatment class were often whole group, experiential, and perceptually driven. For example, the treatment class took several short "fieldtrips" outside, around the school grounds, looking for evidence of erosion and to observe the weather or weather phenomenon like wind, cloud formation, and precipitation.

It is clear from these two vignettes describing typical pedagogy and lesson organization that, although the subject matter taught in the two classrooms was very similar, the differences in values (valuing of conceptual understanding in the control class and valuing of aesthetic experience and changed perception in the treatment class) had profound implications for the way instruction proceeded. What follows is a more detailed explanation of the important pedagogical differences between the two classrooms in table 5.

**Table 5. Differences in pedagogical treatment**

| Control classroom | Treatment classroom |
|---|---|
| Content: Framed as science concepts and terminology<br><br>Content analysis of weather unit revealed 62 weather related science words that students were introduced to including the labels for 14 different kinds of clouds. Common phrases such as these indicate the value of concepts and terminology in developing a successful conceptual understanding:<br><br>"Come on class, use your science words!"<br><br>"Who can list the three different forms of precipitation?"<br><br>"What are the names of the two different temperature scales?"<br><br>"Good question, now ask it again using science words." | Content: Framed as metaphoric ideas and perceptual lenses<br><br>Content analysis of the same weather unit revealed 20 weather related science words 3 organizing metaphors and several minor metaphoric descriptions of various phenomenon. For example:<br><br>Organizing metaphor:<br><br>Atmosphere as an ocean of air<br>Weather as unbalanced energy<br><br>Minor metaphoric description:<br><br>Air pressure is greater closer to the surface of the earth just as the leaves in a bag are packed closer together the further down you go into the bag.<br><br>Also, a conscious effort was made to employ wonderment in treatment class lessons. This wonderment may or may not be related to a metaphor. For example:<br><br>During a lesson on the atmosphere students learned that there is approximately 17 miles of air above them – pressing down on them.<br><br>During a unit on the structure of matter students learned that most matter is actually composed of a great deal of empty space – spaces between molecules.<br><br>No efforts to generate wonderment in the control classroom were documented. |

Focus of power: Teacher oriented

As revealed in the vignettes, Ms. Parker consistently told her own stories trying to personalize science content or relate it to real-world phenomenon and experience but denied students the opportunity to do the same. Also, choral reading and choral responding was used frequently as a means to cover content and allow for student participation but within the confines of a very well defined task. Exchanges such as this were frequent:

T: Class, all together, water freezes at?
Ss: 32 degrees.
T: A barometer measures?
Ss: air pressure.
T: A weather satellite does?
Ss: Gathers weather data.

Also, well-defined response-type activities were also used frequently. For example, having distributed a handout on cloud types, this exchange occurred:

T: At what height would you find an altostratus cloud?
S: 30,000 feet.
T: Read and search to find out what nimbus means. Anybody?
S: Rain.

Focus of power: Learner oriented

Treatment class pedagogy constantly tried to empower students to see and act with science ideas in ways that fit for students individually. As a result, 8 student-generated science related stories were told per day. Several days were consumed almost entirely with these stories. Class often began with these questions:

Who thought about wind yesterday? Tell us what you thought about?

Who saw some erosion over the weekend? Tell us about what you saw and what you thought about?

Did anybody do any re-seeing that they want to tell us about?

As a result of the less well-structured nature of the pedagogy employed in the treatment classroom, lessons were occasionally jumpy as students moved between seemingly unrelated concepts. However, it is believed that allowing frequent opportunities to personalize science ideas and new perceptual lenses, and scaffolding attempts to do so with encouraging feedback, is critical in learning science for aesthetic understanding.

Although the treatment class teacher told numerous stories related to his own experiences with relevant science ideas and ways of experiencing the world, he did this in an effort to model the power of new perceptual lenses. On the average, he told 3 stories related to science ideas and how they helped him to see, understand, and appreciate detail and beauty. His language during these stories purposefully included these kinds of words to demonstrate that a connection between science and art or beauty was possible and even desirable.

| | |
|---|---|
| | Ms. Parker told no stories throughout in which she expressed affinity for new ideas and perception. |

Table 5 (cont'd)

| Activities: Individual, content driven | Activities: Group, experientially and aesthetically driven |
|---|---|
| As suggested in the vignettes, activities in the control classroom were designed to reinforce conceptual understanding, comprehension of terminology, and individual student cognition. For example, across the 18 instructional days of the three science units, 11 activities were used: 9 worksheets in which students completed definitions, responded to short questions regarding content, and read short passages and answered comprehension-style questions related to science concepts; 1 laboratory exercise was used (designed by the treatment class teacher) in which students worked in groups to separate sediments of various sizes and graph data generated – a skilled needed on the upcoming statewide science test; and 1 whole group activity in which students modeled the organization of molecules in solids, liquids, and gases. This activity was also designed by the treatment classroom teacher. | By contrast, across the 20 instructional days in the treatment classroom 12 activities were used. The nature of these activities was qualitatively different, however, than the activities used in the control classroom. Activities here were designed specifically to provide experiences useful in facilitating emerging aesthetic understanding and new ways of seeing the world. For example, 3 activities were designed to integrate traditional art and science (one was an activity in which students learned about how artists use the sky to convey emotion and contribute to the story line in art while another was designed to observe and create artwork that detailed intensely eroded landscapes – imagine much southwestern art and you'll probably picture some desolate, heavily eroded landscape portrait); 3 activities were short "fieldtrips" in which students walked around the school observing science ideas learned in class such as different types of erosion and to view the sky as an ocean of air; 1 activity involved building molecular models out of toothpicks and gumdrops; 1 activity involved students in make-believe scenarios in which they had to predict upcoming weather events; 1 activity was the identical lab activity used in Ms. Parker's room in which students manipulated various sediments; and 3 activities involved traditional worksheet type assignments in which students were asked to respond to short questions regarding their emerging conceptual understanding. However, each of these worksheets were designed to include at least one question that allowed students |

| | |
|---|---|
| | to comment on their personal experiences with science content. |

In review, major differences existed between the two instructional programs in terms of how the content was crafted (although students took identical tests of conceptual understanding), the relations of power in the classroom including how the teacher shared personal experiences with science and whether or not students were encouraged to share their own experiences, and how activities were designed to either support conceptual understanding, in the case of the control classroom, or to support aesthetic understanding, in the case of the treatment classroom. The differences are subtle yet important and powerful. We wish to share one final example of an important but subtle difference in pedagogical programs. It exists in the context of learning about the atmosphere at the beginning of the weather unit.

On the first day of the weather unit in Ms. Parker's class the students learned about the atmosphere – it was, of course, the first topic covered in their $5^{th}$ grade science book in the unit on meteorology. The book defined the atmosphere as the layer of gases that surround the earth. It stated that the atmosphere is something like 80,000 feet thick and is divided into 4 major layers: the troposphere, mesosphere, ionosphere, and exosphere. Students recited the names of the four layers, wrote down the thickness of the atmosphere on concept maps they had just begun and moved on. The atmosphere is a central element of weather as it is the weight of the atmosphere that causes air pressure and air pressure is an important element of weather.

On the first day of the weather unit in the treatment class, students and teacher went outside, laid on their backs in a circle, and peered up into the sky. The treatment class teacher asked, "Can you see those treetops over there? Can you see those birds flying above the trees? Can you see those low puffy clouds? Can you see above those clouds to the thin wispy ones beyond? There's depth to the sky – some things in the sky are higher than others. That's because the sky is actually like an ocean of air. Right now you're lying at the bottom of an ocean of air looking back up toward the top through miles of air. There's actually 17 miles of air pressing down on you and your face right now and that air has weight. Air matters." After this little speech, 15 minute long question and answer period followed as students asked questions such as "Why don't we feel the air? What would happen if our atmosphere was twice as deep? And What kind of gases are in our atmosphere?" Students were particularly struck by the metaphor of atmosphere as ocean as five days later (this lesson took place on a Wednesday and the next science day was the following Monday) 11 different students mentioned that they had either thought about the ocean of air as they enjoyed their weekend, mentioned the idea to somebody else, and in the case of 2 students, tried to recreate for them the experience of lying on their back and "seeing" up into the ocean of air. Both classes learned about the atmosphere. The control class also learned about the layers of the atmosphere (material beyond the scope of the science curriculum goals) but the treatment class learned in such a way that students were drawn to wonder, tell others, and see the world through new eyes. We believe this brief anecdote captures the essence of the difference between the two instructional programs.

Summary of research design

Comparisons are made between these two groups of 5th grade students (treatment group learning for aesthetic understanding and the control group learning for the goal of conceptual understanding) for the outcome variables: interest in learning science, science identity affiliation, science efficacy beliefs, conceptual understanding (at pre, post, and 1-month post instruction), and total levels of attained aesthetic understanding. This data and data gathering mechanisms are described more fully below.

Data –descriptive statistics

*Identity, efficacy, and interest*

Both before, and at the conclusion of science instruction, all students completed a science identity, efficacy, and interest scale. We hypothesized that learning for aesthetic understanding would have an effect on these dimensions because it is a unique portrayal of science and science learning. The efficacy scale was taken from a scale widely used with children this age (Pintrich & DeGroot, 1990) and achieved adequate reliability scores ($\alpha = .75$) in pilot tests with over 100 5th graders in a cross-town elementary school. The identity items were constructed for use in this research but also performed with an acceptable reliability in pilot testing ($\alpha$ = .82). Science interest was measured by having students rank their 8 common elementary school subjects from most to least favorite in which to learn. At administration, the phrase “in which to learn” was emphasized stressing the importance of learning that subject matter over getting to interact with friends or some other confounding variable. In this way, science rank is really a proxy for science interest. Descriptive statistics for the attitude, efficacy, and identity factors are included in Table 6.

**Table 6: Descriptive statistics for outcome variables by condition and time of administration**

| Outcome | | Treatment class | | Control class | | Total sample | | |
|---|---|---|---|---|---|---|---|---|
| | | Pre | Post | Pre | Post | Pre | Post | Change |
| Interest* | Mean | 4.27 | 3.37 | 4.73 | 5.19 | 4.50 | 4.28 | -0.22[1] |
| | SD | 1.93 | 1.41 | 1.99 | 2.04 | 1.96 | 1.72 | -0.24 |
| Efficacy | Mean | 24.89 | 30.11 | 24.08 | 27.15 | 24.49 | 28.66 | 4.17[2] |
| | SD | 6.46 | 2.90 | 7.69 | 5.50 | 7.03 | 4.58 | -2.45 |
| Identity | Mean | 10.93 | 14.52 | 10.73 | 13.04 | 10.83 | 13.79 | 2.96[3] |
| | SD | 3.98 | 3.52 | 4.44 | 3.41 | 4.17 | 3.52 | -0.66 |

*As approximated by ranking the 8 elementary subjects from “most like to learn” to “least like to learn” so a lower score suggests stronger interest.

[1] $F=3.69$ (2, 52), NS

[2] $F=10.36$ (2, 52), $p > .01$

[3] $F=1.86$ (2, 52), NS

Table 6 shows the means and standard deviations for each factor on both pretest and post test as well as treatment and control group. Interestingly, the change column shows that mean factor scores increased (became more positive) on all factors for both classes.

*Measures of conceptual understanding*

In addition to measures of efficacy, identity, and interest, students also completed tests of conceptual understanding before and after each of the instructional units. Three achievement outcomes (conceptual understanding of weather, erosion, and matter) were analyzed, as a pretest, as a posttest immediately following the completion of instruction, and as an extended posttest approximately one month after the completion of instruction. Tests of conceptual understanding were identical in both classes and at all three administrations. Tests consisted of short answer and multiple choice items scored by two, independent researchers (blind to student name) achieving an inter-rater reliability of .90. Table 7 gives descriptive data for each of the three unit tests, across each of the three administrations, for both treatment and control classrooms.

**Table 7: Means and standard deviations for tests of conceptual understanding by condition and test administration**

| | Pre-test | | Post-test$_1$ | | Post-test$_2$ | |
|---|---|---|---|---|---|---|
| | Control | Treatment | Control | Treatment | Control | Treatment |
| Weather unit | | | | | | |
| Class mean (%) | 18.25 | 17.07 | 80.50 | 84.13 | 66.50 | 75.72 |
| SD (%) | 19.90 | 17.46 | 22.05 | 17.16 | 19.51 | 19.71 |
| | | t=-.23 | | t=2.14* | | t=4.07*** |
| Erosion unit | | | | | | |
| Class mean (%) | 17.00 | 10.90 | 69.33 | 84.29 | 55.00 | 76.92 |
| SD (%) | 13.92 | 10.48 | 30.12 | 18.76 | 25.91 | 25.75 |
| | | t=-1.76 | | t=2.12* | | t=3.03** |
| Matter unit | | | | | | |
| Class mean (%) | 12.00 | 9.94 | 72.67 | 82.37 | 42.33 | 66.99 |
| SD (%) | 8.36 | 14.53 | 18.09 | 14.01 | 19.08 | 23.98 |
| | | t=-.62 | | t=2.14* | | t=4.07*** |

*p > = .05

**p > = .01

*** p > = .001

Descriptive data for the tests of conceptual understanding show that, on the average, students in the treatment classroom performed better on the post-test of conceptual understanding, on each of the three unit tests, to a statistically significant degree. More importantly, students in the treatment class scored much better after one-month on a second post-test of conceptual understanding. Modeling the effects of gender, ethnicity, treatment, and pre-test, using Hierarchical Linear Modeling[7] revealed that treatment was the only main effect and no significant interaction terms were found.

*Measures of Aesthetic Understanding*

Students in both classes were interviewed regarding their experiences learning science, investigating, in particular, learning that corresponded to our definition for aesthetic understanding, including renewed perception, increased value, and increased interest and wonderment. Student responses were coded depending on the number of examples students gave in response to each interview question and totaled to yield a degree of aesthetic understanding achieved by students in each class at four times – prior to all science instruction, and at the end of each of the three instructional units. The interview protocol is appended as A. Differences in categorizing and coding student responses were minimal and inter-rater reliability of .92 was achieved. Table 8 provides mean scores of conceptual understanding for both groups at each of the interviews (before instruction = $interview_1$; after the first unit = $interview_2$; after the erosion unit = $interview_3$, and; after the matter unit and at the end of all instruction = $interview_4$).

**Table 8: Average scores of aesthetic understanding by treatment for each of the interviews**

| | $Interview_1$ | $Interview_2$ | $Interview_3$ | $Interview_4$ |
|---|---|---|---|---|
| Control | | | | |
| Class mean | 7.11 | 3.08 | 2.93 | 3.35 |
| SD | 1.63 | 1.75 | 1.76 | 2.10 |

[7] In the analyses of these three outcomes, multiple administrations are nested within students. Each student is expected to have a unique effect on both performance and rate of growth in performance on these three outcomes. Thus, if we use ordinary estimation methods (ANCOVA) and ignore individual student effects, the errors across timepoints will not be independent since a student's score at the second administration is not independent of that same student's score on the first administration (Bryk & Raudenbush, 1992). For this reason, hierarchical linear modeling was used to explore the effect of the treatment on conceptual understanding both immediately after the unit ended and again, approximately one month after instruction had ended as a measure of enduring understanding (or, by reverse logic, student forgetting).

| | | | | |
|---|---|---|---|---|
| | t=-0.87 | | | |
| Treatment | | | | |
| Class mean | 6.63 | 7.38 | 8.38 | 7.29 |
| SD | 2.34 | 2.29 | 1.76 | 1.48 |
| | | t=5.38*** | t=7.93*** | t=7.29*** |

*** p > = .001

Examination of Table 8 shows that students in the treatment class scored higher on a measure of aesthetic understanding after each of the three instructional units. In addition, class standard deviation goes up in the treatment class suggesting a homogenizing effect for students learning together in this unique way. Just the opposite effect is seen in the control class as standard deviation increases across time. None of this is particularly interesting as we would expect that students learning for a particular goal would respond in ways reflective of this goal after instruction. It does suggest the pedagogy of teaching for aesthetic understanding was effective.

The following sections discuss results of several inferential tests designed to investigate suspected interaction effects. It is these results that suggest aesthetic understanding may "level the playing field" for several important groups of students.

Data - Inferential modeling

Modeling of the outcome variables after learning for aesthetic understanding was done using analysis of covariates (ANCOVA) controlling for the effect of the pretest. Because we had no sound theoretical basis to suggest that only particular variables would effect student feelings toward science, models were constructed both forwards (adding parameters one at a time to check for collinearity) and backwards (starting with all possible parameters and removing them one at a time toward the most parsimonious model). Final models for all factors were identical using either procedure. In all modeling the following parameters were used:

- dtreatment The effect of being in the treatment class
- dfemale The effect of being female
- dminority The effect of being minority (African American or Hispanic

The following models describe the effect of teaching for aesthetic understanding on each of the three outcome variables. As a rule of thumb, main effects that also appear in interactions will not be interpreted. Interpretation of interactions is challenging and because they can sometimes account for significance of main effects, we will only interpret interactions and main effects that stand alone.

*Modeling of efficacy factor*

Table 9 gives parameter estimates for main effects and interactions within the final B.efficacy model (meaning efficacy after all instruction).

**Table 9: Final model parameter estimates for model of B.efficacy**

| Parameter | B | Std. error | t | p-value |
|---|---|---|---|---|
| Intercept | 19.631 | 2.604 | 7.538 | .001 |
| dtreatment | 12.171 | 3.782 | 3.218 | .002 |
| dminority | -2.474 | 1.055 | -2.345 | .023 |
| A.efficacy | .360 | 0.098 | 3.667 | .001 |
| dtreatment*A.efficacy | -.387 | 0.148 | -2.612 | .012 |

An examination of table 9 showing parameter estimates for the B.efficacy ANCOVA model shows that the effect of dminority is significant ($t = -2.345$, p-value = .023) meaning, for some reason, minority students in both treatment and control classrooms reported lower levels of efficacy in science learning. The interaction of dtreatment*A.efficacy ($t = -2.612$, p-value = .012) indicates that students reporting an initially lower efficacy in the treatment class experience more growth in their efficacy beliefs. In other words, students in the treatment class with less confidence in their ability to be successful in science class report a greater increase in this confidence than lower efficacy students in the control class. The treatment seems to be more effective for students typically less successful in science class. Figure 1 represents these result graphically including ethnicity, pretest, posttest, and treatment effects.

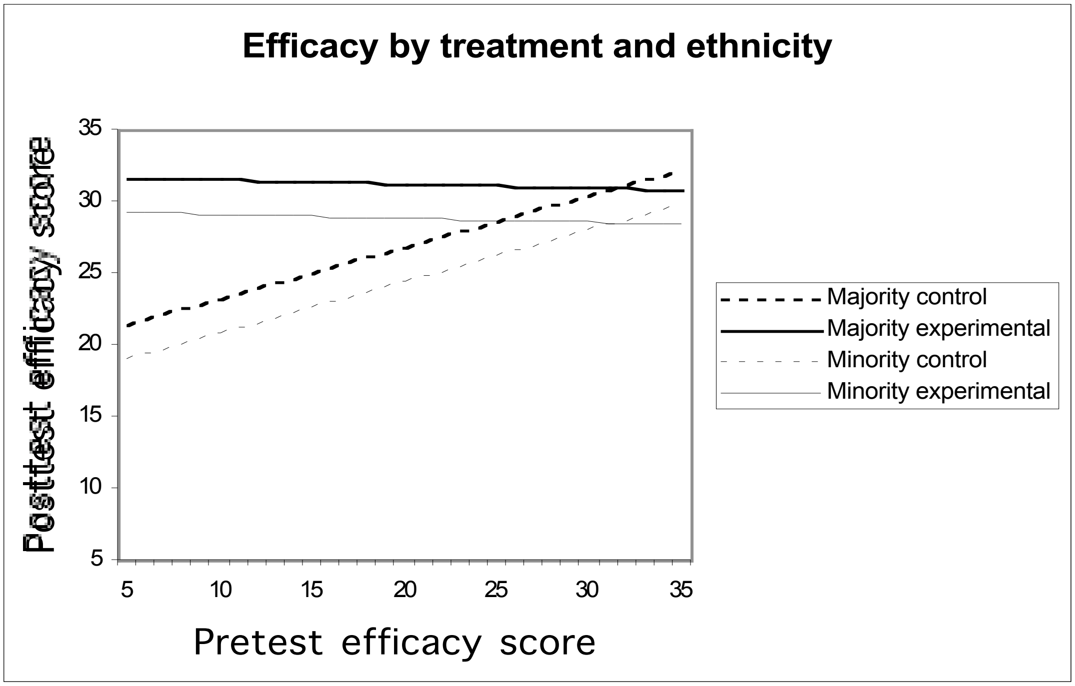


**Figure 1: Efficacy by treatment and ethnicity**

It is clear from Figure 1 that treatment group students have higher overall levels of efficacy than control class students but the effect of ethnicity does not depend on the treatment. Figure 1 also suggests that perhaps a ceiling effect can account for the slight, but obvious, regression effect across time for the treatment class. Recall from Table 6 showing descriptive statistics for efficacy indicates a fairly sharp decrease in standard deviation from pre to post-test, particularly as compared to the control class, who's mean scores was much lower.

*Modeling of identity factor*

Table 10 gives parameter estimates for main effects and interactions within the final B.identity model (meaning identity after all instruction).

**Table 10: Final model parameter estimates for model of B.identity**

| Parameter | B | Std. error | t | p-value |
|---|---|---|---|---|
| Intercept | 14.167 | .938 | 15.097 | .001 |
| dtreatment | -1.417 | 1.327 | -1.068 | .291 |
| dfemale | -2.095 | 1.279 | -1.638 | .108 |
| dtreatment*dfemale | 5.279 | 1.795 | 2.941 | .005 |

An examination of table 10 showing parameter estimates for the B.identiy ANCOVA model shows that the interaction between dtreatment*dfemale is significant (t = 2.941, p-value = .005) indicating that treatment class females reported significantly higher levels of identity affiliation with science than control class females and treatment class males. Again, this is encouraging because it is commonly assumed that boys, and in particular, middle-class white boys, are more likely to identify themselves as science-type people. The treatment of teaching for the goal of aesthetic understanding seems to reverse this trend and has the effect of increasing female students' science identity affiliations. Figure 2 shows a graphical representation of the estimated marginal means for B.identity.

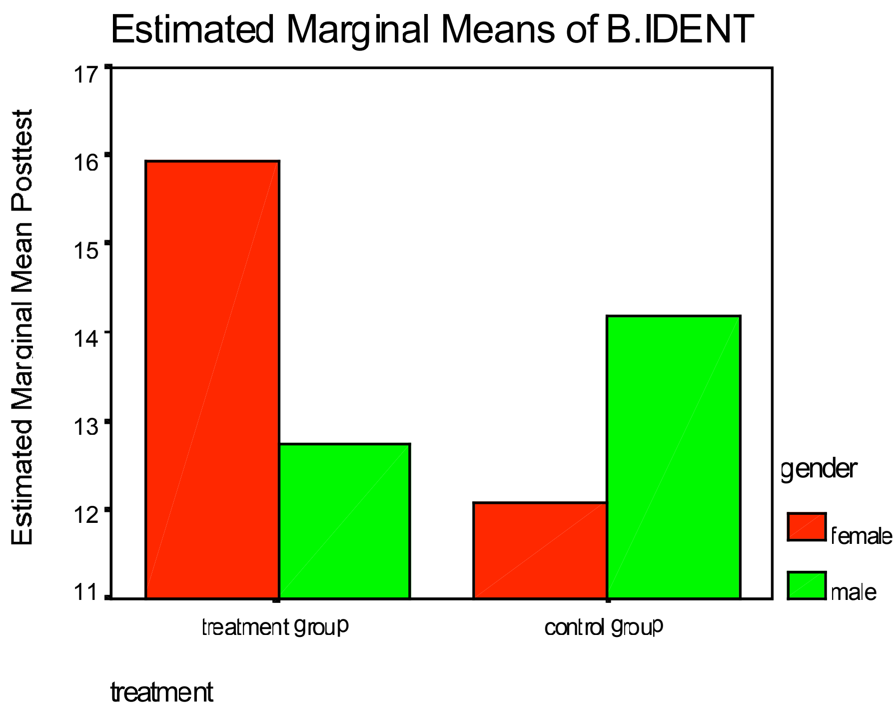


**Figure 2: Estimated marginal means of B.identity**

To assist in interpretation of Figure 2 we need to understand the changes in reported identity affiliation from pre to post, for both males and females, for both treatment and control class students. Table 11 gives us this information.

**Table 11: Identity by treatment and gender**

| Student | A.identity | B.identity | Growth |
|---|---|---|---|
| Control males | 12.42 | 14.17 | 1.75 |
| Control females | 9.29 | 12.07 | 2.78 |
| Treatment males | 10.42 | 12.75 | 2.33 |
| Treatment females | 11.33 | 15.93 | 4.6* |

*p > .05

Although all four groups of students reported gains in the degree to which they identified themselves as "science-type people" the largest effect is for treatment class females. Post-hoc comparisons using the Bonferroni method indicate the difference between treatment group females and control group females is the only significant difference (t – values??). The difference between treatment group males and control group males, the next largest difference according to Figure 2, is not significant (p-value = .711) and neither is the difference between male and female students in the treatment class (p-value = .088) or the difference between male and female students in the control class (p-value = .646).

*Modeling of science interest factor*

Students were asked to rank the following 8 elementary school subjects (mathematics, science, social studies, art, physical education, music, reading, and spelling) from most to least favorite subjects to learn – 1 being most favorite and 8 being least favorite subject to learn. Table 12 gives parameter estimates for main effect and interactions within the final B.science rank model (meaning science rank after all instruction). We realize that this data is discrete and does not lend itself perfectly to ANCOVA modeling but, because it is standard in the field to do so when using ordered data consisting of this many points, we analyzed this data with ANCOVA.

**Table 12: Final model parameter estimates for model of B.science rank**

| Parameter | B | Std. error | t | p-value |
|---|---|---|---|---|
| Intercept | 1.937 | .880 | 2.202 | .033 |
| dtreatment | .07305 | 0.619 | 0.118 | .907 |
| dfemale | 1.828 | 0.61 | 2.99 | .004 |
| dminority | 3.054 | 0.951 | 3.21 | .002 |
| dtreatment*dfemale | -1.732 | 0.839 | -2.063 | .045 |

An examination of table 12 showing parameter estimates for the B.science rank ANCOVA model shows the main effects of treatment, gender, and ethnicity as significant. However, each of these are including in interactions so we only interpret these. The interaction of dtreatment*dfemale is significant (t = 2.063, p-value = .05) meaning treatment class females reported science as a more favorable class at the end of instruction than control class females or treatment class males. Once again, the effect of teaching for understanding seems to be differentially effective for female students. Figure 3 shows estimated marginal means for B.science rank for male and female students in treatment and control classes. The graph shows that the effect of the treatment essentially brings female treatment groups students ranking of science in line with male students in both the treatment and control classes. Female students in the control class continue to rank science as significantly less favorable a class than their peers. Recall that a lower rank (shorter bar) is a more favorable rank.

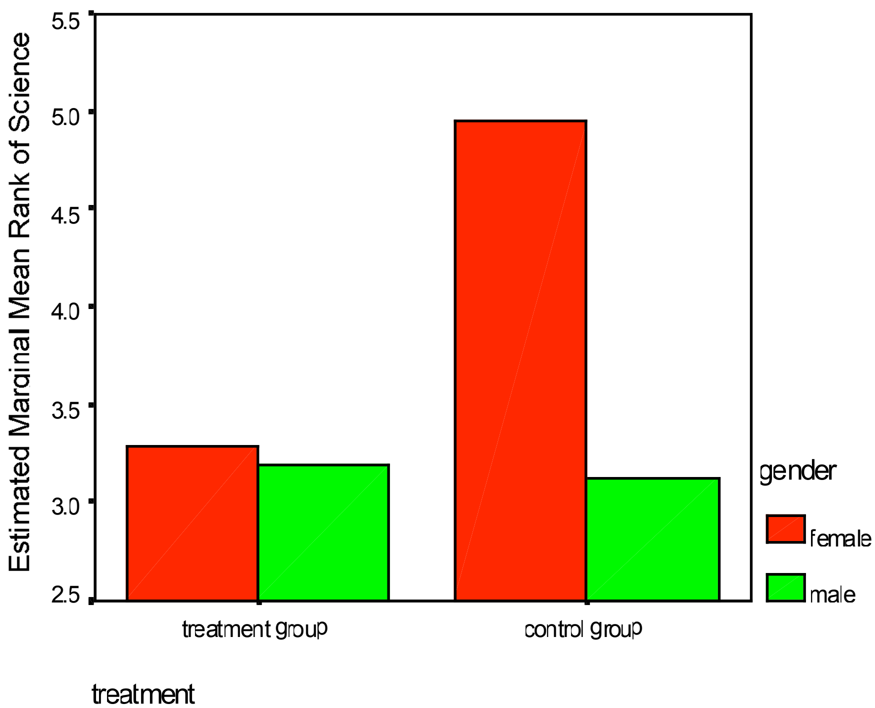


**Figure 3: Estimated marginal means for B.science rank**

<u>Summary</u>

The effect of the treatment on students' interest in learning science, identity affiliation regarding science, and efficacy beliefs seems powerful. The interactions found support low pretest and female students. We might attribute these interaction terms to a ceiling effect of the measure as most treatment class students' scores approached the upper limit of the measure, thereby, allowing students with more room to grow (low pretest scores and sometimes female students), to do so. However, we might also conceive of a different explanation for these interactions related to differences in feminine experience and informed by feminist epistemology.

<u>Discussion</u>

We suggest what may account for the gender effects found in teaching for aesthetic understanding is its emphasis on re-seeing the world, personalization of knowledge and experience, and consciously addressing affect and changed action in learning. Science has been criticized for its over-reliance on logic, analysis, and objectivity (Barton, 1998; Harding, 1991; Keller, 1985) and learning for aesthetic understanding broadens the field to include other tools and dispositions like metaphor, creativity, mindplay, personalization, and storytelling. Perhaps, in this way, learning for aesthetic understanding appeals to a different kind of learner (Belenky, Clinchy, Goldberger, & Tarule, 1986) opening up success in science to a more broad range of student. As discussed in the opening of this paper, science is often perceived as the ultimate in logical endeavors. The scientific method, rigorous methodological control, objectivity, and micro-analysis are all cornerstones of the discipline. Until recently, in fact, scientists were often less than forthcoming when describing the exact methods of their discoveries as their descriptions of dream-time inspiration may perhaps seem less science-like and may jeopardize the trustworthiness of their conclusions. A classic example comes from Darwin who felt it necessary to carefully manufacture a description of the process by which he came to conclude that natural selection and evolution were viable and credible scientific ideas. In fact, it is documented that he originally conceived of the idea of natural selection in making a metaphoric leap from the processes of dog breeding, a common activity in his part of the world at the time. The leap came in Darwin considering the possibility that, like the dog breeder, Mother Nature could similarly select particular characteristics to design particular species. Darwin's theory of natural selection came not from careful observation and deductive logic but from blind insight borrowed from local dog breeders and facilitated by metaphoric insight (see Prawat, 1999 for a more elaborate discussion). It seems that as scientific progress continued with quite impressive results that the objective, methodologically rigorous image of science was perpetuated.

Recently, we've seen renewed interest in accounts of science that portray it as other than objective. Science historians and cognitive scientists together have combined to attempt a de-bunking of the objective model of science. Root-Bernstein and Root-Bernstein (1999), describe the critical tools of science to be methods of imagination, analogizing, and playing with scientific ideas. In an earlier work, Root-Bernstein (1989), described the act of scientific discovery as largely facilitated through artistic interpretation and expression. The connection between art (and aesthetic experience) and cognition comes through the imaginative process of metaphor use. A large literature already exists describing the power and utility of metaphoric thinking. When we combine this with accounts from scientists related the primacy of the aesthetic experience, we find that body metaphor, those that describe pushing, pulling, touching, feeling, and coming into contact with scientific ideas and phenomenon, we begin to understand science as a much different, highly subjective endeavor.

Cognitive scientist Mark Johnson (1990) argues that all human understanding is based in metaphor and imagination taken directly from bodily experiences in the world. He argues that we each have some notion of right and left of center that can be applied to right and left of zero on a number line in learning about magnitude. Interestingly, his discussion of body metaphor (my term) fits well with descriptions that scientists employ in talking about their experiences with science. Plant geneticist Barbara McClintock describes her work with plant chromosomes, "I found the more I worked with them, the bigger and bigger they got and when I was really working with them I wasn't outside, I was down there. I was part of the system" (in Keller, 1985, pg. 165). McClintock's account of her science sounds far from something objective, an experience to be stood-back-from in cool analysis. It sounds similar to the description of <u>an</u> experience as described by Dewey and similar to those accounts from other scientists articulated previously. This leads us to a potential explanation for the gender effects the research data suggest. Keller (1985, 1992) has argued that science, and its positivistic paradigm and associated distancing strategies like, remaining objective, do not match the epistemology and preferred ways-of-knowing of women. The more perceptually based, imaginative and metaphorically rich pedagogy employed in teaching for aesthetic understanding perhaps stands in direct contrast to science as it is traditionally portrayed. Again, as female scientists describe, and Keller suggests, this different portrayal of science in teaching for aesthetic understanding is enough to promote increased feelings of identity toward science and interest in learning science. Even the stereotypically masculine metaphor for erosion, that of a battle, was not enough to overpower the embodying aspect of the metaphor.

Additionally, this research makes important and practical contributions to literature in three important areas. Each are discussed below.

*Science education*

Literature in science education consistently has science educators looking to the practice of scientists to help guide science education (see Harding and Hare, 2000 for one recent discussion). Although a large literature exists in which scientists discuss the role of aesthetics and beauty in their science and inquiry (Dirac, 1963; Fischer, 1999; Gleick, 1992; Hoffman, 1988; Poincaré, 1946; Root-Bernstein, 1989; Tauber, 1997; Tinbergen, 1958/1969), little empirical research, in our investigation, has been conducted with the goal of drawing on aesthetics to foster children's science learning. In fact, only recently have references to aesthetics and beauty begun to appear in national standards (AAAS?? And others??) and literature related to learning the nature of science (NOS lit. with beauty). This research does exactly that. Teaching for aesthetic understanding brings students to high levels of conceptual understanding while simultaneously bolstering more positive feelings toward science and fostering changed action and renewed interest in exploring and engaging with the world. Further, this research identifies a reasonably clear system of pedagogy designed to foster aesthetic understanding. And perhaps most importantly, teaching for aesthetic understanding seems to "level the playing field" for female, low achieving, and minority students in ways that few instructional programs have done in the past. Much literature documents the gender and ethnicity gaps in science (achievement gap??) and aesthetic understanding could be offered as one pragmatic solution to closing this gap.

*Learning theory*

Unlike many versions of constructivism in which knowledge is viewed as something that exists inside students heads, meaning the act of learning is that of effectively labeling or naming experiences in the world that then correspond to canonical language, or; knowledge viewed as something found in language, situated within communities of practice and social and cultural spaces; to knowledge as something co-constructed not only between participants, within discourse communities, but co-constructed with the regularity that exists in the natural world. This is a heavy statement that may lead one to ask, "Do you mean to say that I have some transaction with a forest as I walk through it?" This is exactly what we are implying. Constructivism of this nature, as demonstrated by teaching for aesthetic understanding, views the regularity found in the natural world as a viable participant in the co-construction of knowledge. It is our strong opinion that few scientists would disagree. In fact, a growing conversation exists in science studies known as "reality studies" that hold the regularities that exist in the nature world as centrally important for learning and the development of new knowledge (give some references here…).

Additionally, the epistemological stance assumed in this work is also more true to Deweyan epistemology as taken from Peirce as taken from Scotus over 800 years ago (see Prawat, 2001 for a more elaborate discussion). Deweyan epistemology gets appropriated frequently in the name of activities-based learning, inquiry learning, hands-on learning, and a number of other modern variations. However, teaching for aesthetic understanding, is, in my read, the most faithful instantiation of Deweyan epistemology – corresponding to ideas from Dewey's most well developed works written late in his career (1929; 1933; 1934).

*Aesthetics*

In the previous paragraph, we downplay the connection between this work and conversations in the field of aesthetics but we do believe our ideas contribute in a small but important way. Although our intent was never to contribute to aesthetic theory, our work can be viewed as an extension of Dewey's aesthetic theory. Dewey was clear in his mission to connect lived experience to the power and potential of art to transform our lives and our interactions with the world. Dewey, however, was careful not to draw a connection to subject matter ideas such as we have done in the field of science. Like art, we believe powerful science ideas have the same potential to facilitate powerfully transformative experiences. As this work demonstrates, not only is this possible, but the results are important and dramatic. Teaching for aesthetic understanding can be viewed as a slight elaboration on Dewey's naturalized aesthetics arguing for a clear and compelling connection to the disciplines (in this case, science).

Conclusion

Teaching for aesthetic understanding levels the playing field and has great promise as a future, vital element in the teaching of science. If we truly value "science for all" then we need to consider different paths to learning. Teaching for aesthetic understanding represents one powerful alternative.

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