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TEACHING 5TH GRADE SCIENCE FOR AESTHETIC UNDERSTANDING

By

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ABSTRACT

TEACHING 5TH GRADE SCIENCE FOR AESTHETIC UNDERSTANDING

By

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Many scientists speak with great zeal about the role of aesthetics and beauty in their science and inquiry. Few systematic efforts have been made to teach science in ways that appeal directly to aesthetics and this research is designed to do just that. Drawing from the aesthetic theory of Dewey, I describe an analytic lens called learning for aesthetic understanding that finds power in the degree to which our perceptions of the world are transformed, our interests and enthusiasm piqued, and our actions changed as we seek further experiences in the world. This learning theory is contrasted against two other current and popular theories of science learning, that of learning for conceptual understanding via conceptual change theory and learning for a language-oriented or discourse-based understanding. After a lengthy articulation of the pedagogical strategies used to teach for aesthetic understanding the research is described in which comparisons are drawn between students in two 5th grade classrooms

– one taught for the goal of conceptual understanding and the other taught for the goal of aesthetic understanding. Results of this comparison show that more students in the treatment classroom had aesthetic experiences with science ideas and came to an aesthetic understanding when studying weather, erosion, and structure of matter than students in the control group. Also statistically significant effects are shown on measures of interest, affect, and efficacy for students in the treatment class. On measures of conceptual understanding it appears that treatment class students learned more and forgot less over time than control class students. The effect of the treatment does not generally depend on gender, ethnicity, or prior achievement except in students' identity beliefs about themselves as science learners. In this case, a significant interaction for treatment class females on science identity beliefs did occur. A discussion of these results as well as elaboration and extension of the pedagogical model used in teaching for aesthetic understanding is discussed.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Science and aesthetics

Introduction

It may seem odd to pair beauty and the arts with science. Much has been written on the fundamental differences between the two as well as the cultures in which they are practiced. C.P. Snow's, *The two cultures and the scientific revolution* (1959), provides a detailed account of fundamentally perceived differences between science and the social sciences (in which he includes the arts) in epistemology, ontology, and cultural values and norms of practice. Recently, however, we have seen a resurgence of attempts to connect the arts and sciences. To name just a few: Root-Bernstein (1997) has argued that science and art share a common underlying aesthetic motive and aesthetic theory; Holton (1978) argues for the role of imagination and artistic creativity in science; Chandrasekhar (1987), suggests scientists find motivation and desire to participate in science through aesthetics; McAllister (1996) appeals to aesthetics as a critical factor in a highly rational account of scientific progress and revolution; while Fisher (1999) seeks to blur the boundaries between science and art almost completely. We can also find calls to wed science and art in the writing of John Dewey and recent philosophers, aestheticians, and theorists who draw from Dewey's theories and ideas

(Fesmire, 1995; Garrison, 1995; Greene, 1981, 1995; Jackson, 1995, 1998; Prawat, 1993; Pugh, 1999b; Shusterman, 1992; Wong et al., 2000). My point is that the notion of a connection between art and science is not new. More importantly, however, is that conversations on the connection of art and science have not found significant voice in the science education community. A small number of position papers have appeared in major science education research journals suggesting attention to the role of aesthetics in science learning (Flannery, 1991) but I have found no empirical research which calls for strict attention to aesthetics in pursuit of student learning. In response, my dissertation research is designed to a) develop a theory of the role of aesthetics in science learning, and b) investigate the adequacy of the theory and the efficacy of the theoretical strategies designed to foster learning of this type.

An investigation of aesthetics in science faces a problem. Scientists are rarely inclined to discuss their insights, inspirations, and creative passion as they seem less than objective and anti-intellectual in the existing, highly rational, culture of science. Often, in the retelling of a scientific discovery, the 'human,' 'creative,' 'inspired,' and 'passionate' sides of scientists and their stories get left out. These are often deemed unimportant or anti-intellectual, pulling readers away from the important details of theory development, research results, and answers to equations. Holton (1978) has attributed this 'code of silence' among the scientific community to an unwillingness to disclose secrets of creativity, or diminish the discipline with tails of insights from dreams and inspiration from myth and music. This is the problem that Snow addresses in his book and an analysis of these things must overcome or sidestep this problem to find evidence for the importance of art and beauty in the lives of scientists. One solution is to find evidence in autobiographical accounts, notebooks from the lab benches of scientists themselves, and even third-party stories and re-tellings of events and discoveries in science. Luckily, there exists a wealth of each. Using these sources, the remainder of this chapter serves to more thoroughly recognize the existing aesthetic space within science.

Beauty and art in the lives of scientists

Root-Bernstein, in arguing for the importance of the arts and creative expression in the lives of scientists, lists nearly 400 19th and 20th century scientists that actively participate in non-scientific forms of creativity; including 65 Nobel Prize winners (1989, pgs. 318-327). The list includes such notables as Thomas Huxley, who painted; Lord Rayleigh, who experimented in photography; Louis Pasteur, who was a wood and metal sculptor; Einstein and Heisenberg, who were musicians; and Marie Curie and Ludwig Boltzmann, who wrote poetry. Root-Bernstein also recognizes that many famous scientists simply do not have an artistic side, or at least choose not to exercise it, but the extraordinary list and the lesson taken from it, cannot be ignored. Many scientists gravitate toward artistic expression and Root-Bernstein suggests the reason lay in the similarities between arts and science.

However, one could argue that scientists are simply a subset of the general population and, like anybody else, a certain percentage of them engage in artistic expression. This is certainly true, however, following Root-Bernstein, I wish to extend the connection and argue that many scientists find their work beautiful and the science they do aesthetically pleasing. Recall Dirac's famous line, "It is more important to have beauty in one's equations than to have them fit the experiment" (1963, pg. 47). Similarly, Simone Weil writes, "The true subject of science is the beauty of the world" (as quoted in Fischer, 1999, pg. 91) and Herman Weyl follows with "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, pg. 53). Comments like these beg two questions, 'What is beauty, and, more importantly for this conversation, 'What is beauty in science?' The first question lies in the realm of philosophy and conversations in aesthetics and aesthetic theory. I will not attempt a full treatment of aesthetics as a) my intent is not to contribute to philosophy and aesthetics literature, and b) other, more complete discussions of aesthetics can be found elsewhere. I will, however, attempt to articulate a few possible answers to the second question on the notion of beauty in science. As with this introduction, I will draw extensively from biographical accounts of scientists in the process of doing and analyzing science as well as from philosophers of science commenting on the process of science and scientific progress.

What is art, beauty, and aesthetics? What is beautiful in science?

Scholarly writing begs operational definition. An attempt to define art and aesthetics is doomed to fail before the first word is uttered. Philosophers have been mulling this question for thousands of years. Realizing that no definition will suffice for everyone, Root-Bernstein gives us this,

> To begin with, I will define what I mean by aesthetic...Having read dozens of definitions, I find that the single element that is common to all aesthetics, as diverse as their particular details may be, is an evaluation of some aspect of nature or of human creation in terms

> of whether or not it is *acceptable* and *satisfying* within a given cultural and historical context. In using this definition, I reject absolutely the traditional notion, embodied in most dictionary definitions of aesthetics, that an aesthetic evaluation must concern one or more of the five senses. Such definitions assume that it is possible to feel without engaging one's emotions and intellect simultaneously. Sensory impressions are not equivalent to feelings, and I refuse to accept that feelings are divorced from thinking. To think is to feel. I maintain that it is this integration of thinking and feeling that characterizes the highest forms of aesthetic experience in both the sciences and the arts (Root-Bernstein, 1997, pg. 55).

Similarly, I have read many definitions of art and a great deal of classical aesthetic theory (Beardsley, 1967; Burke, 1990; Santayana, 1955; Shusterman, 1996) and conclude, like Root-Bernstein, that the task of coming to a definition is fruitless. However, like Root-Bernstein, I wish to extend conversations on aesthetics beyond pure sensory perception, in the process avoiding drawing boundaries between thought, action, emotion, and even language. Rather than review four thousand years of philosophic conversations about aesthetics I'd like to begin with a brief overview of the aesthetic theory referred to as naturalized aesthetics. It is this brand of aesthetic theory that resonates most significantly with me and lends itself well to the analysis of scientists' experiences that follows.

Dewey and naturalized aesthetics

In response to analytic philosophy and analytic aesthetics, a group of predominantly American philosophers began to formulate a 'naturalized' aesthetic. These philosophers believed that to remove conversations of beauty from the contexts of ordinary life, contemporary values, and experience is wrong-headed. Philosophers of this ilk argue for continuity between aesthetics and the rest of life and culture. Nelson Goodman, for example, writes of continuity between art and science arguing that both serve human interests through "their common cognitive function." Goodman, along with Dewey, insists that "what matters aesthetically is not what the object is but how it functions in dynamic experience, urging that we replace the question 'What is art?' with that of 'When is art?' (Goodman cited in Shusterman, 1996, pg. 11). This abandoning of the analytic project proves to be particularly important in an analysis of aesthetics in science for the experiences of scientists engaged in scientific work are most commonly described in the language of the event rather than in the language of the objects of science.

The most complete account of naturalized aesthetics, or what has come to be called pragmatic aesthetics, comes in Dewey's *Art as experience* (1934). Echoed later by Goodman (1978), Shusterman

(1992), Garrison (1995, 1997), and others, Dewey argues to move the central focus of conversations about aesthetics to daily living. Dewey argues against the tradition of removing art from daily lives and cloistering it away in museums and galleries only to be viewed by the elite. Dewey suggests that art be not in objects but in the experiences to be found between person and world. Living a life more artfully would include living in ways that allow more aesthetic experiences. Dewey's contribution to the argument I am currently building is crucial as aesthetics moves from objects to events and interactions, and experiences. Dewey provides several qualities of aesthetic experiences, which I draw from extensively in chapter 2.

From these brief paragraphs on aesthetics we move to the question of beauty in science. Again, these conversations are wide ranging. I'll focus the conversation on three themes that seem to be common in writing from scientists and philosophers of science.

Conversations on beauty in science are as diverse and wide-ranging as conversations in aesthetics and philosophy. Various authors writing from modern, foundational stances discuss traits or qualities within objects of science as beautiful or artistic. In this regard, commonly cited qualities of beauty are simplicity of form, symmetry, pattern, and unity of structure. Similarly, Roald Hoffman, in a series of articles in *American Scientist*, discussed various molecular structures and in what ways he found these forms to have a quality of beauty (1987; 1988a; 1988b; 1989). Rather than engage in a discussion of the artifacts of science and the aesthetic qualities of the artifacts, I wish to focus the discussion on beauty in scientific ideas and experiences.

The first theme within this “scientific aesthetic space” is related to beauty in scientific ideas. Many scientists have expounded on the exquisite beauty of powerful scientific ideas. 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" (Dirac, 1980, pg. 10). The second theme can be found in conversations related to cosmology, the divine structure of the universe, and, in even more extreme language, the beauty in knowing God’s design. Scientists and philosophers writing from this perspective often speak of tapping into some fundamental structure found in primitive archetypal universals. A third theme describes beauty in the experiences that scientists articulate as they participate in scientific research, creativity, and experimentation. For these authors, beauty is what’s found in the act of knowing and experiencing science in intimate quality. What follows is further articulation of each of these three themes in an attempt to illuminate existing conversations on beauty in science. I hope to persuade readers that beauty and aesthetics do play an important role in science and the lives of scientists in anticipation of my own contribution.

Beauty in ideas

> I once heard Dirac say in a lecture, to an audience which largely consisted of students, that students of physics shouldn't worry too much about what the equations of physics mean, but only about the beauty of the equations. The faculty members present groaned at the prospect of all our students setting out to imitate Dirac (pg. 90: cited in Weinberg, 1987, pg. XX).

Initially it may seem strange to talk of beauty in ideas. However, if we first examine extreme examples, perhaps this strangeness can be chased away. In this effort I first recognize discussions of beauty that relate to the notion of the sublime. Aestheticians are quick to remind us those theories of ugliness, perversity, and sublime lie within the realm of aesthetics as well. Burke (1990) recognizes a common characteristic in all such theories as their ability to astonish. “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” (pg. 53). Similarly, 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...." For example, in teaching concepts in astronomy, geology, and biology, it becomes helpful for students to appreciate the vastness (or minuteness) of extremely large and extremely small numbers to develop an adequate conceptual understanding. In response, I've taught a lesson in which students construct a 'tapestry' of one million dots (66 2/3 pages of 15,000 dots taped together). Most students, when visually confronted with a million dots find the experience to be a bit mind-boggling as well as a bit mind-bending. A million is a number that scientists use frequently but, arguably, the average student (and adult) fails to grasp its enormity. Coming to understand the notion of 'a million' is a task that could qualify as experiencing Kant's first category of the sublime – the mathematically sublime. Kant's second category of sublime is similar, (2) "When we are confronted with the overwhelmingly powerful (the dynamical sublime), the weakness of our empirical selves makes us aware (again by contrast) of our worth as moral beings" (Kant as cited in Beardsley, 1967, pg. 28). For me, my experience standing at the edge of Niagara Falls for the first time comes to mind as an excellent example of this second brand of Kant's sublime. The enormous power and thundering energy so evident at the falls almost forces one to be aware of his own frailty and insignificance. In fact, some of the earliest common use of the word sublime came as authors found themselves floundering to adequately describe the experience of viewing Niagara Falls. The word sublime connotes a mixture of awe, inspiration, and a bit of fear. Interestingly, we find many examples of scientists who employ sublime in descriptions of their work. For example, Heisenberg in a discussion with Einstein writes, "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" (Heisenberg as quoted in Chandrasekhar, 1990, pg. 53). Similarly, Whewell, in commenting on Newton's *Principia* suggest an awesome 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).

Comments such as these are certainly not new to the rhetoric of science as we can even find reference to the notion of the sublime in Plato as quoted in the *Phaedrus*: "The soul is awestricken and shudders at the sight of the beautiful."

Conversations on the sublime may only peripherally relate to the notion of beautiful ideas. Ideas do not necessarily lie at experiences of the sublime so we turn now to more direct, and often neglected, conversations on intellectual beauty.

> Nowadays the concept of intellectual beauty is not, I believe, commonly repudiated so much as neglected; few of the standard works on aesthetics pay more than lip-service to it and I know of none which has either attempted a deep analysis or given to it equal weight with sensory beauties in the framing of general aesthetic concepts (Osborne, 1964, pg. 160).

"However, the study of intellectual beauty has fallen into disregard only relatively recently: in eighteenth-century aesthetic theory, for instance, it held an important place" (McAllister, 1996, pg. 18). McAllister continues with a description of Francis Hutcheson's 18th century aesthetic theory...

> ...Hutcheson endorses an epistemological tenet that was popular in his time, that the qualities of objects are distinct from, and in fact the causes, of "ideas," which are the only immediate materials of sensory awareness. Beauty is such an idea, occasioned in the mind by particular qualities of external objects" (pg. 18).

We turn to Hutcheson himself for further elaboration, "...the word *beauty* is taken for the *idea raised in us*, and a *sense* of beauty for *our power of receiving this idea*" (1973, pg. 34). Beauty, then, for Hutcheson, is at the intersection of object and observer. Beauty does not lie alone in objects but in the observer's aesthetic perception (and cogitation) of those qualities. What qualities more commonly stimulate aesthetic perception and perception of beauty? Hutcheson continues, "The figures which excite in us the ideas of beauty seem to be those in which there is uniformity amidst variety" (1973, pg. 40). Hutcheson suggests that 'uniformity amidst variety' can be found in objects, the natural world, and in intellectual ideas. Hutcheson argues that scientists perceive this uniformity amidst variety at three levels of increasing abstraction: (1) the lowest level of abstraction are the things that make of the subject matter of science - the beauty of stars layed out across the night sky or the beauty in the elegant curves of the double helix model of DNA - requires no expertise to recognize; (2) natural regularities not directly seen but illuminated by scientific theory or models - one must have some command of scientific theory - like the astronomer who sees beauty in the regularities of celestial motion once he puts his model into action, or how plate tectonic theory helps us to appreciate the dramatic form and elegance of the landscape; (3) finally the most abstract level is in the actual theory and mathematical formulae themselves. Recall Dirac's quote on the general theory of relativity that begins this section. Add to it, Ernst Rutherford speaking in 1932...

> A well-constructed theory is in some respects undoubtebly an artistic production. A fine example is the famous Kinetic Theory of

> Maxwell. The theory of relativity by Einstein, quite apart from any question of its validity, cannot but be regarded as a magnificent work of art (pg. 14: cited in Badash, 1987).

Who can deny the elegance and beautiful parsimony in Einstein's $E=mc^2$? Certainly no more an elegant equation could exist with such explanatory power. These examples are in the realm of beauty in scientific ideas. We now turn to the next theme.

Beauty and cosmology

> We know on excellent authority that beauty is truth, that it is the expression of the ideal, the symbol of divine perfection, and the sensible manifestation of the good (Santayana, 1955, pg. 11).

Another strand of the conversation on aesthetics in science equates beauty with truth; fundamental God's eye truth. The notion of a connection between truth and beauty has been around for centuries as indicated by the ancient Latin phrase, *pulchritudo splendor veritatis* (beauty is the splendor of truth). It is little surprise that scientists find theories and equations with an unwavering verisimilitude more beautiful or aesthetically pleasing than those with less of it. In the autobiography of Emily Heisenberg, she describes her husband's reflections on his career as contemplations on the beauty of the universe and quotes him as stating, "I was lucky enough to look over the good Lord's shoulder while He was at work" (E. Heisenberg, 1984, pg. 143). Knowing the divine plan, or, more commonly, having the divine plan revealed, is common language in scientific discovery. Again, from Heisenberg,

> ...one evening I reached the point where I was ready to determine the individual terms in the energy table, or, as we put it today, in the energy matrix, by what would now be considered an extremely clumsy series of calculations. When the first terms seemed to accord with the energy principle, I became rather excited, and I began to make countless arithmetical errors. As a result, it was almost three o'clock in the morning before the final result of my computations lay before me. The energy principle had held for all terms, and I could no longer doubt the mathematical consistency and coherence of the kind of quantum mechanics to which my calculations pointed. At first, I was deeply alarmed. I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy at the thought that I now had to probe this wealth of mathematical structure nature had so generously spread out before me. I was far too excited to sleep, and so, as a new day dawned, I made for the southern tip of the island, where I had been longing to climb a rock jutting out into the sea. I now did so without too much trouble, and waited for the sun to rise (Heisenberg, 1971, pg. 61).

It is difficult to ignore the vehemence by which many scientists describe their discoveries and creative insights as being almost beyond their control – perhaps as if their discoveries were simply revealed to them or uncovered, previously there but simply unobserved. To borrow from the psychologist Carl Jung, his notion of an archetype is useful here in understanding descriptions of discovery in science.

> Archetypes are like riverbeds, which dry up when the water deserts them, but which it can find again at any time. An archetype is like an old watercourse along which the water of life has flowed for centuries, digging a deep channel for itself (Jung, 1968, pg. 395).

Kepler foreshadowed Jung's archetypes as he described geometry as underlying the structures of the universe writing, "Traces of geometry are expressed in the world, as if geometry were the archetype of the cosmos" (Fischer, 1995, pg. 52). Although Jung's psychological archetypes evade thorough description, Kepler's archetypes reveal themselves through mathematics.

Einstein, following Kepler, sought to understand God's plan of the universe and because he did not believe God allowed for chance, Einstein believed he could describe God's plan at some basic level. This led Einstein to pursue a unifying theory of physics – a blueprint for the universe. In this pursuit, Einstein too appealed to archetypal images and elements.

> Indeed, there is overwhelming evidence that Einstein wasn't too amused by the idea of the big bang, but this didn't change the fact that his vision of the world clung to something archetypal, because there are still, as in the classical age, four elements. Instead of fire, earth, water, and air we now have space, time, matter, and energy. Additionally, whereas Aristotle postulated a *prima materia*, an original material from which the archaic group of four could originate and become influential, Einstein went on the hunt for a unified field theory which took on the same task of the *prima materia* (Fischer, 1999, pg. 89).

Einstein's search pushed him into unusual territory – territory bounding on spirituality, metaphysics, religion, and myth as much as physics.

> Einstein himself had continuously emphasized the psychological-spiritual – components of scientific research and in response to psychologists spoke about many of the images preceding his thinking. It was difficult for him most of all to convey his thoughts to others on things he had long understood only visually, first in formulas and then in words (Fischer, 1999, pg. 84).

Today we may imagine Einstein as simply a richly divergent thinker but this is not Einstein's explanation. It was his belief that the fundamental structure of the universe, of God's plan, if you will, would occasionally reveal itself to him in these archetypal kinds of images. Similarly, August Kekulé described his discovery of the molecular structure of benzene in richly archetypal language.

> I turned the chair towards the fireplace and sank into a half sleep. Once again the atoms danced before my eyes. My inner eye distinguished larger images of multiple shapes, winding and turning like snakes. And then what did I see? One of the snakes took hold of its tail, and the image swirled threateningly before my eyes. As if by a stroke of lightning I woke up and spent the rest of the night working on the consequences of the hypothesis (Friedrich August Kekulé as quoted in Fischer, 1999, pg. 76).

Although Kekulé example seems a bit overly dramatic and perhaps fanciful, the notion of divine truth revealed is maintained. Truth and beauty can be found in knowing God's design for the universe. God's design lies in archetypal kinds of images and divine patterns of organization that can be discovered, known to already exist, simply waiting to be discovered. We turn now to the final theme in description of beauty in science.

Beauty in experience

> For some people the contemplation of scientific theories is an experience hardly less golden than the experience of being in love or looking at a sunset (Haldane quoted in Huxley, 1991, pg. 53).

Science educators frequently look to the science discipline for guidance as to the important subject matter ideas, behaviors, and dispositions to guide teaching and learning. Often, science within the discipline is characterized as highly analytic, logical, objective, and methodical. Pedagogy that draws from this characterization of science frequently asks students to step back, to be critical and observant of objects, events, and the world. However, some scientists portray science with quite an opposing personality - one that draws us in, begs our creativity, passions, and emotions. This portrayal of science can be described using Dewey's epistemology in ways that break down false binaries such as objective vs. subjective, logic vs. intuition, thought vs. feeling, mind vs. heart, and think vs. feel. Dewey's epistemology refuses to separate these into discrete, distinguishable acts. Similarly, Cherryholmes writes, "When we give up the text/context distinction [or any other binary in his argument], we deny ourselves the luxury of looking at the world in fragments (pg. 42, 1999). To think is to feel, and vice versa. A large literature exists to support this claim in science and science learning (see Root-Bernstein, 1989 for a good start). I believe the heart of a critique of most current and popular perspectives in science education lay in their portrayal of science as something to be analyzed, stood back from, and acquired. From the perspective I'll develop in chapter 2, that of aesthetic understanding, science learning is something to swept-up in, yielded to, and experienced. Learning in this way joins cognition, affect, and action in productive and powerful ways. It is a more holistic in its substance and consequence. I draw from the work of scientists and philosophers of science to further support our claims and critique.

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

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

In light of this, I see that Einstein was implying a merger, a joining of Root-Bernstein's I and It in an effort to understand. We are all little pieces of nature and we must work to recognize and draw on that connection in ways that assist our understanding. Knowing in this way has been described as a synthetic process in which cognition, emotions, and actions merge; perception illuminated by multiple senses and sensations. Another example from Boltzmann commenting on the music and artistry of the mathematics of Maxwell...

> Even as a musician can recognize his Mozart, Beethoven, or Schubert after hearing the first few bars, so can a mathematician recognize his Cauchy, Gauss, Jacobi, Helmholtz, or Kirchhoff after the first few pages. The French writers reveal themselves by their extreme formal elegance, while the English, especially Maxwell, by their dramatic sense. Who, for example, is not familiar with Maxwell's memoirs on his dynamical theory of gases?...The variations of the velocities are, at first, developed majestically; then from one side enter the equations of state; and from the other side, the equations of motion in a central field. Even higher soars the chaos of formulae. Suddenly, we hear, as from kettle drums, the four beats "put $n = 5$" The evil spirit V (the relative velocity of the two molecules) vanishes; and, even as in music, a hitherto dominating figure in the bass is suddenly silenced, that which had seemed insuperable has been overcome as if by a stroke of magic. ... This is not the time to ask why this or that substitution. If you are not swept along with the development lay aside the paper. Maxwell does not write programme music with explanatory notes...

> One result after another follows in quick succession till at last, as the unexpected climax, we arrive at the conditions for thermal equilibrium together with the expressions for the transport coefficients. The curtain then falls (Boltzmann as quoted in Chandrasekhar, 1990, pg. 53)!

This perceptual fusion described by both Boltzmann and Einstein is called *synaesthesis* by Richards et al. (1925) and is described as "the simultaneous, harmonious experience of diverse sensory impressions from complex works of art resulting in a fusion of apparent opposites or unification of differences" (pg. 7). Synaesthetes, people who experience this quality of perception, often describe numbers as particular colors, temperatures as particular tastes, and sounds as particular images (see Lemley, 1999, for a more recent discussion). Odin (1962) elaborates,

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

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

> Synscientia means literally, knowing in a synthetic way, being able to conceive of objects or ideas interchangeably or concurrently in visual, verbal, mathematical, kinesthetic, or musical ways. Very simply stated, I have found no eminent scientist who simply solves

> mathematical equations or pours chemicals into test tubes and analyzes the results or catalogues chromosomal abnormalities. Scientists, or at least scientists who are worth their salt, feel what the system they are studying does. They transform the equations into images; they sense the interactions of the individual atoms; they even claim to know the desires and propensities of the genes (1996, pg. 66).

Root-Bernstein proceeds with multiple examples of synscientia from scientists such as Jane Goodall, Dian Fossey, Ernst Mach, and Barbara McClintock. Similarly, we recall Temple Grandin, autistic animal scientist at Colorado State University. As described by Oliver Sacks in *An Anthropologist on Mars* (1995), Grandin has a unique ability to put herself in the position of her animals, "I visualize the animal entering the chute, from different angles, different distances, zooming in or wide angle, even from a helicopter view - or I turn myself into an animal, and feel what it would feel entering the chute." So impressed with Grandin, Sacks continues, "...her sense of animals' moods and feelings is so strong that these almost take possession of her, overwhelm her at times. She feels she can have sympathy for what is physical or physiological - for an animal's pain or terror..." (pg. 267). Grandin's ability to think and feel in multiple ways, her synscientific abilities, helped her to become one of the world's most highly regarded animal scientists, despite adult autism.

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

Summary

I wish to end this chapter with some thoughts on what can be gleaned from this conversation for science education. In my mind, the lessons are twofold: (1) Linking science and art makes sense in developing both analytic lenses and pedagogy to support student learning. Many scientists write of this marriage and the two fields share the common tools of keen observation and compelling representation. (2) We ought to formulate theories of learning science that incorporate an appeal to the aesthetics in science. It is on this note that the next chapter proceeds. Drawing largely from the aesthetic theory of John Dewey (one of the theoreticians of naturalized aesthetics discussed earlier) I articulate my learning theory identified as aesthetic understanding. I compare and contrast my theory of aesthetic understanding against two current and popular competing theories of understanding – conceptual understanding via conceptual change theory and a discourse based understanding via linguistic oriented views of understanding. My theory places aesthetics and aesthetic experience at the center of learning and aesthetic understanding is offered as a powerful alternative to these more common views.

In prelude to articulation of aesthetic understanding, I close with these lines from Root-Bernstein, "A person who cannot appreciate the beauty in a piece of art, or in a piece of science, does not understand it any more than if they cannot appreciate its intellectual content." And, similarly, "Students rarely, if ever, are given any notion whatever of the aesthetic dimension or multiplicity of imaginative possibilities of the sciences, and therefore, no matter how technically adept, can never truly understand or appreciate them" (1997, pgs. 63-64). With Root-Bernstein, I believe that understanding must incorporate elements of aesthetics and aesthetic appreciation through aesthetic experience or truly powerful learning simply does not occur.

Chapter 2: Development of a theory of aesthetic understanding

> Understanding is a lot like sex. It's got a practical purpose, but that's not why people do it normally (Oppenheimer as cited in Cole, 1997, pg. 5).

> The world looks so different after learning science. For example, trees are made of air, primarily. When they are burned, they go back to air, and in the flaming heat is released the flaming heat of the sun which was bound in to convert the air into tree. [A]nd in the ash is the small remnant of the part which did not come from air, that came from the solid earth, instead. These are beautiful things, and the content of science is wonderfully full of them. They are very inspiring, and they can be used to inspire others (Feynman as cited in National Academy of Science, 1995).

Introduction

Like Oppenheimer, I believe that understanding is not most often driven by practical or instrumental purposes. The desire for understanding is driven by something more human. It is our nature to seek connections - connections to others, to the earth, and to ideas. This sense of connectedness is not only at the level of individual cognition, it comes from a desire to know with one's heart and mind, emotions and cognitions, imagination and reason. Understanding is a lot like sex. We do it to feel connected in ways that tell us we are human. As Feynman suggests, we strive to understand for aesthetic reasons.

Many conceptions of learning science are driven by the goal of conceptual understanding. Teachers want their students to have accurate mental models of the way the world operates - to "get it" if you will. Recently, another goal for science education has become to help children learn to "talk science." Such discourse-based perspectives argue that science educators should strive to teach students how to inquire, formulate, and argue in ways true to the nature of science. Both of these are worthy goals. However, I will argue that both fall short of another important criterion of success in science learning. Ultimately, education should influence not only how students understand and talk about the world, but how they experience (i.e. think, feel, act) it. The arts can educate us in ways few other disciplines can. I believe we can teach science in ways that borrow from aesthetic and artistic pedagogy to tap the power of aesthetic experience. These experiences can be the basis for a powerful, different kind of understanding - aesthetic understanding. For some readers, using the arts as inspiration for science education may seem misguided. Jackson, referring to Dewey's "Art as Experience" explains what we can learn from our experiences with art:

> The arts, above all, teach us something about what it means to undergo an experience. Successful encounters with art objects and performances offer a set of standards by which to judge ordinary experiences. (Jackson, 1998, p. 124).

I articulate one possible solution to the following question: How can we construe learning in ways that appeal to aesthetic ways of knowing while fostering value in important and powerful curricular ideas? My perspective, learning as developing aesthetic understanding, will be compared and contrasted to two other popular views of understanding in science education research: learning as change in conceptual understanding (as exemplified in conceptual change theory) and learning as change in discourse and participation with others. Because my theoretical framework is relatively new and, in some ways, radically different from other current science education frameworks, I take the time to develop its framework more completely than perhaps most research studies.

Three conceptions of understanding in science learning

Two common and popular views of understanding in science education are conceptual change learning made popular by Posner et al.'s (1982) widely-cited paper "Accommodation of a scientific conception: Toward a theory of conceptual change" and a discourse-based view of understanding as characterized in Jay Lemke's (1990) influential book *Talking science.* Each of these views has garnered much support in the science education research community and have large bodies of research based on their ideas. However, I am dissatisfied with both and offer my own version instead. I intend to articulate each view focusing my critique around six main questions.

- To what epistemological tenets does the theory subscribe?
- What's the role of the learner?
- What motivates learning?
- What gets learned?
- What would be the central curricular organizer in the theory?
- What's the role of the teacher?

I believe these questions address the most substantive issues in a theory of understanding and will allow us to highlight the similarities and differences between them.

Conceptual understanding and conceptual change theory

Conceptual understanding and conceptual change theory, at least as I've characterized them here, are rooted in Cartesian rationalism and individual cognitive psychology. Research on the power of misconceptions has been taking place for 60 years originating in the early work of Piaget but only in the 1980's did misconceptions and conceptual change research get appropriated by the science education community. Posner et al. (1982) gives the best description of the underlying philosophy and intentions of conceptual change theory:

> Our central commitment in this study is that learning is a rational activity. That is learning is fundamentally coming to comprehend and accept ideas because they are seen as intelligible and rational. Learning is thus a kind of inquiry. The student must make judgments on the basis of available evidence. It does not, of course, follow that motivational or affective variables are unimportant to the learning process. The claim that learning is a rational activity is meant to focus attention on what learning is, not what learning depends on. Learning is concerned with ideas, their structure and the evidence for them. It is not simply the acquisition of a set of correct responses, a verbal repertoire or a set of behaviors (pg. 212).

Posner's emphasis on the rational means that science is a matter of developing concepts that correspond to the reality of the world. School science is, similarly, a matter of helping students build accurate mental representations of the world based on available evidence.

Conceptual change researchers popularized misconceptions research (McCloskey, 1983; McCloskey, Caramazza, and Green, 1980; Clement, 1982; Clement, 1983; Brown and Clement, 1989; Rosnick, 1981) and recognized that students often hold powerfully robust yet incorrect ideas about the world. To relinquish these ideas in an attempt to gain more accurate ones is the process of conceptual change and, when successful, yields conceptual understanding. Conceptual change is an arduous process that depends mainly on four factors. First, the individual must be dissatisfied or somehow convinced that her current ideas or ways of thinking are incorrect or incomplete. Without this impetus to change or adopt new conceptions, no new learning will occur. Second, the new, or more canonical thinking, must be intelligible to the individual. Often new knowledge is either at a higher level of sophistication or even developmentally inappropriate to learners and so conceptual change cannot proceed. Third, a new conception must suggest answers to questions unanswered by previous conceptions. Fourth, the new conception must suggest "the possibility of a fruitful research program" (Posner, Strike, Hewson, and Gertzog, 1982, pg. 214). It's interesting that Posner et al. write from the perspective of disciplinary science. Their metaphors and criteria seem to suggest conceptual change at the disciplinary level rather than at the individual level. In their analysis, this fact is treated as unproblematic. I disagree but will withhold critique for a later section.

Finally, beyond the criteria above, conceptual change depends on students' current conceptual ecology. Two features of this conceptual ecology matter most: a) how anomalies in observation or experience get recognized and perceived as the individual operates in the world; and, b) the individual's epistemological beliefs or underlying views of science and the world. For example,

> ...if a change to special relativity requires a commitment to the parsimony and symmetry of physical theories (as it did for

> Einstein), then students without these commitments will have no rational basis for such a change. Faced with such a situation students, if they are to accept the theory, will be forced to do so on nonrational bases. For example, because the book or the instructor says it is "true" (Posner, Strike, Hewson, and Gertzog, 1982, pg. 224).

In successful conceptual change teaching, students' new conceptions will be "more fruitful" and will be more closely resemble the accepted concepts of the discipline. Conceptual change learning is sometimes characterized as replacing students' wrong ways of thinking with right or correct ways of thinking (Smith, DiSessa, and Rochelle, 1993). The teacher's job is to provide opportunities for students to see the weaknesses or the inaccuracies in their current conceptions through demonstrations or activities designed to instill cognitive dissonance. These dissonance-creating demonstrations have been called discrepant events - discrepant because what students think will happen does not as their beliefs are based on incorrect ways of knowing (Liem, 1992). The students' role is to scrutinize and modify their science knowledge. Once criteria for conceptual change have been met, students then work to accommodate this new or discrepant knowledge with their current conceptions producing, if all has gone well, more canonical conceptual understanding.

Discourse-based understanding

Discourse-based perspectives, as represented by socio-cultural theory, typically view science as culturally, socially, and contextually situated activity. With an appreciation of the 'situatedness' of knowledge comes a concomitant concern about issues of power and equity. Rather than extend the myth that science is for the elite, Gallas (1994) argues discourse-based pedagogy allows "teachers and children to move purposely together toward an inclusive kind of talk about science where everyone is admitted" (pg. 3). Gallas and Lemke (1990) both suggest learning to talk science is an accurate representation of what the discipline of science is most like; a particular discourse or way of talking. Gallas describes her book in this way, "taken metaphorically, it is about acquiring a discourse" (pg. 4), the discourse of science.

Learning in a discourse-based science classroom occurs through joint questioning, re-phrasing, defending, hypothesizing, critiquing, theorizing, and imagining about science. Student ideas are taken as central to the class conversation. The direction of conversation is often dictated entirely by students, perhaps only occasionally guided by the teacher. Gradually, students learn how to more easily and appropriately talk about science in ways that use science words and skills accurately.

Simultaneously, students begin to feel less alienated by science as their own ideas are taken as having worth. An occasional problem in discourse-based classrooms is that ways of talking often take precedence over the acquisition of canonical science knowledge. However, in the hands of a skilled teacher, canonical understandings do develop.

The teacher in such a classroom must be highly skilled in both pedagogy and subject matter. Beyond establishing a supportive and nurturing discourse community, the teacher must have the skills and knowledge to recognize and subtly guide student talk toward more fruitful paths of inquiry. The student role is to share, defend, and critique science ideas along with her teacher and classmates. Learning in a discourse-based classroom takes a great deal of time and practice. Lemke (1990) offers an entire chapter on changing teaching strategies to more effectively learn through discourse. Students feel motivated to learn as their identity and efficacy beliefs about science develop as their ideas are validated and taken seriously. Also, the fundamentally social qualities of learning are attractive to students.

Without a doubt, successful learning in a discourse-based classroom is challenging. These words from Bakhtin (1990) eloquently describe the difficulties of learning a new discourse.

> [The word] becomes "one's own" only when the speaker populates it with his own intention, his own accent, when he appropriates the word, adapting it to his own semantic and expressive intention. Prior to this moment of appropriation the word...exists in other people's mouths, in other people's contexts, serving other people's intentions: it is from there that one must take the word, and make it one's own. And not all words for just anyone submit equally easily to this appropriation, to this seizure and transformation into private property: many words stubbornly resist, others remain alien, sound foreign in the mouth of the one who appropriated them and who now speaks them; they cannot be assimilated into his context and fall out of it; it is as if they put themselves in quotation marks against the will of the speaker. Language is not a neutral medium that passes freely and easily into the private property of the speaker's intentions; it is populated - overpopulated - with the intentions of others. Expropriating it, forcing it to submit to one's own intentions and accents, is a difficult and complicated process (1990, pg. 293-294).

Discourse-based understanding includes two main components: 1) acquisition of thematic patterns and 2) appropriation of elements of identity as associated with science, science ideas, and scientific community. Thematic patterns can be further divided into two processes. First, learning the organizational patterns appropriate to particular science discourses, meaning, the kinds of questions to consider, the evidence that will be persuasive, and something of the logic necessary to make compelling claims from existing warrants. Second, learning the particular semantic patterns necessary to string together science words in ways that make sense.

Identity acquisition includes imagining possible "future-selves" (Markus and Nurius, 1986) and appropriation of a "science-self" into ones "identity-kit" (Gee, 1991). Students who learn science for a discourse-based understanding develop positive conceptions of themselves as science learners, do-ers, and inquirers. Students take on the identity of participants in a particular science discourse community.

Analysis of conceptual change and discourse perspectives

I now turn to an analysis and critique of these two influential perspectives in science education. Dewey's theory of knowledge and learning, particularly his more mature views developed in *Experience and nature* (1929) and *Art as experience* (1934), are the foundation for this analysis and the development of my perspective on aesthetic understanding.

Dewey would probably acknowledge that learning science's concepts and appropriating its discourse are important features of effective science education. However, he would go on to emphasize that these elements are subsumed in the broader goal of education - to help students lead lives rich in worthwhile experiences. The task of school is to provide students with transformative experiences: experiences that are valuable in themselves and valuable in their potential to lead to other worthwhile experiences.

Dewey's emphasis on experience needs elaboration for he gives the term important, but easily overlooked, nuance. What does Dewey mean by experience, particularly educative experience? The potential for educative experience often arises in the course of living. However, the experience frequently ends without ever developing. The "inchoate" experience remains embryonic and never comes to mean anything because we are distracted, tired, or lazy. Thus, while there is activity – that is, things happening over time, there is no coherence, development, or flow to these things. Such is the nature of ordinary experience. Dewey contrasts ordinary experience with what he alternately calls educative experience, aesthetic experience, or simply, an experience:

> "In contrast with such experience, we have an experience when the material experienced runs its course to fulfillment. Then and then only is it integrated within and demarcated in the general stream of experience from other experiences. A piece of work is finished in a way that is satisfactory; a problem receives its solution; a game is played through; a situation, whether that of eating a meal, playing a game of chess, carrying on a conversation, writing a book, or taking part in a political campaign, is so rounded out that its close is a consummation and not a cessation. Such an experience is a whole and carries with it its own individualizing quality and self-sufficiency. It is an experience." (Dewey, 1934, p. 35).

When material experienced "runs its course to fulfillment," Dewey emphasizes that educative experiences become more than events that merely happen. Instead, the forward movement of an experience has a unity among its constituent elements: "every successive part flows freely, without seam and without unfilled blanks, into what ensues" (Dewey, 1934, p. 36). Furthermore, in these experiences there is a sense of what could be, an anticipation of how things might come together. As an experience becomes imbued with qualities such as anticipation, development, and unity, it also becomes an act of thinking and meaning. Dewey describes educative experiences as having a plot or history, and pervading dramatic quality. Given how Dewey has characterized the structure, flow, and energy of an experience, I propose that educative experiences can be thought of, indeed they are, dramatic events.

Dramatic and compelling experiences with world

An important issue to consider when comparing different perspectives on learning is the question of what motivates learning. In the discourse-based perspective, the construct of participation is crucial as both the product and motivation for learning. The product of learning, the goal of instruction, is the development of new forms of participation and acquiring the language of a new community. Motivation for learning is characterized by how students respond to their evolving participation – the degree that they feel able or willing to take on new roles and identities. Dewey would likely applaud the discourse perspective's attention to identity and participation because it pushes understanding out from inside the head and reconnects it more directly with action and activity. He would likely remark, however, that the discourse perspective's emphasis on language is an overly narrow interpretation of activity. Language is principally a social phenomenon, an activity between people. While the study of language is a wonderfully effective strategy to appreciate the socially contextualized nature of meaning, it underestimates the importance of interaction with the world of objects and nature. This is a critical shortcoming when the domain of interest is science. For Dewey, an account about what motivates student learning must take into account the interaction of person and world. Indeed science learning is often a discourse between learner and idea, objects, and experiences in science.

In mainstream cognitive perspectives, such as conceptual change theory, learning is motivated by a desire to reduce perturbations in one's various representations of the world. Thinking is prompted by disequillibrium or problems. To think is to solve problems (Posner et al., 1982). Dewey's response to this image of the learner is interesting. Many educators, particularly in the science education community, associate Dewey with inquiry learning, i.e. problem driven learning. Although his earlier work tends to support this view, he modifies his position in his later writing. [The two versions (1910 & 1933) of his *How we think* illustrate this development]. Dewey maintains while some learning is a response to a particular problem, other learning is an exploration of the possible (Prawat, 1993). In other words, learners get a sense of what might be and are inspired to move forward. Thus, learning not only results in understanding, it is also compelled by it. Here Dewey clearly describes how ideas precede, rather than follow, inquiry:

> There is no mistake more common in schools than ignoring the self-propelling power of an idea. Once it is aroused, an alert mind fairly races along with it. Of itself it carries the student into new fields; it branches out into new ideas as a plant sends forth new shoots (Dewey, 1933, pg. 335).

The drama of anticipation and revelation of the possible animate learning differently than in the problem --- solution view.

The accounts of student motivation provided by conceptual change and discourse perspectives, therefore, are insufficient. What is gained from a Deweyan perspective, from seeing educative experiences as dramatic events? To appreciate Dewey's view of motivation, one must first understand the role of anticipation in dramatic experiences (Dewey, 1934; Jackson, 1998; Prawat, 1993; Wong, et al., in press). Consider this example: a person walks down a hallway, approaches a door, and opens the door. This is a mundane description of an ordinary occurrence. It means nothing. By contrast, consider: a person walks to open one of two doors, to encounter immediate pain or pleasure, to make an irreversible choice that will forever change the course of his life. This example (a loosely borrowed version of Stockton's short story, "The Lady or the Tiger") is a dramatic event, rather than a simple occurrence. What transforms the experience of this event for either the person opening the door or the person reading the story from an ordinary experience to a dramatic, aesthetic experience is the powerful feeling of anticipation it evokes. The various elements of the event develop and cohere as the individual pushes forward and as the event pulls the individual with it. Similarly, consider science students for whom science lab is little more than a series of activities to complete. Granted, they are active and there is experience. However, one would be hard pressed to characterize the lab as an unfolding drama of inquiry where one part leads to the next, where the activity is compelled by the anticipation of what might be. In both examples, the event not only happens, but has an energy that connects its parts and moves it forward.

Anticipation is an inherent quality in all-powerful learning experiences. In effective conceptual change or discourse based science lessons, anticipation is a salient element of the students' experience, even though it may not be emphasized in the theory that inspired the instruction. Students look forward to the solution of a vexing problem (given that it is meaningful to them) just as they look forward to becoming members of a group.

However, in my view, it is not sufficient to claim that some form of anticipation can be found in students' experiences in these situations. The conceptual change and discourse perspectives might agree, with indifference, with this observation. Thus, I take the point further by making anticipation itself the heart and substance of worthwhile learning. In other words, when Dewey's position that education should lead to worthwhile experiences means that schooling should fill students' lives with anticipation. Now, the difference between Dewey's views and others becomes more distinct and consequential. Not only should students learn concepts and how to talk science, they should look forward to the experience of using and developing concepts and discourse in the real world. They should desire to see where those concepts take them, to see how it might transform their existence in the world. Similarly, students should have some sense of where their newly acquired language might take them, feel an urgency to move in that direction, and to further develop their language. For Dewey, good teaching initiates and sustains the drama of learning initiated by anticipation.

Anticipation is aesthetic

Anticipation both organizes and develops the educative experience and is, therefore, fundamentally intrinsic to this dramatic event. Unlike concepts or language, anticipation does not exist, in any meaningful sense, separate from specific experiences. In this way, it is quintessentially aesthetic in nature. Similarly, the value of concepts and language is typically associated with what is achieved through their use. Conceptual understanding facilitates problem solving, language enables participation with others. Although Dewey agrees that all educative experiences should be instrumental in this way, he would maintain that the aesthetic nature of intense experiences also infuses them with intrinsic value. Educative, aesthetic experiences are worthwhile in themselves and their yield.

To repeat a point made earlier, instruction generated or analyzed from conceptual change or discourse perspectives can have aesthetic qualities. The point I are making is that these important qualities of learning are either less likely to occur or less likely to be noticed when instruction or analysis, respectively, is grounded in these perspectives. To bring out the aesthetic qualities in learning, I propose that science education should be organized around a fundamentally different curricular unit. Rather than understanding concepts or appropriating language, learning science should be about having ideas-based experiences (Pugh, 1999b).

Ideas, anticipation, and epistemology

Ideas and concepts. What is an idea? I begin by contrasting ideas with concepts. In essence, the difference between an idea and a concept is the difference between an aesthetic and non-aesthetic conceptual understanding. Put another way, the difference between an idea and a concept is anticipation.

In the conceptual change paradigm, good teaching is directed toward the learning of concepts. Often contrasted with facts, concepts are more integrative and, therefore, more powerful for remembering, understanding, and using science knowledge. As an alternative, I propose that science teaching should be organized around ideas rather than concepts. Since ideas and concepts are typically synonymous in the common language of science education, some definitions and distinctions are in order.

What is the difference and relationship between ideas and concepts? To begin, concepts are typically associated with ways of representing or thinking about the world. In the cognitive tradition, sense-making is a core activity: individuals make sense of the world, and act according to the sense they make. The mind is the office and cognitive activity is the business of sense-making. In this portrait of human activity, concepts (or its relatives: schema, mental models, representations, etc.), are the "sense" that is constructed and then acted upon (c.f. Greeno et al., 1996). In the cognitive tradition, the mind and its constructions mediate between person and the world.

By contrast, Dewey's emphasis on experience focuses our attention not only on what is occurring in the head, but also on the active, temporal connection between the individual and the world. Jackson notes,

> One of [Dewey's] main points is that experience is not a psychological phenomenon. It is not something that happens exclusively "within" us, though it may certainly have components that we commonly describe in psychological terms. Rather, experience takes place in the world itself. It is made up of our continuous interaction and participation with objects, situations,

and events that constitute our environment (Jackson, p.194, 1995).

This "continuous participation" connotes not only the transaction between person and world, but also an amalgamation of action, feeling, and thought. That is, to participate fully in an experience means not only to think, but to engage all of one's faculties. Thus, while cognitive perspectives on learning emphasize thinking, Dewey emphasizes something else – something I call "being." In contrast to a static state of a mental representation, being is an activity. As an activity, being highlights the organic connection between person and world – a central characteristic of Dewey's philosophical project. Because participating in an experience is engaging with the world in a particular way, an experience describes a particular way of being. The distinction between ordinary experience and an experience discussed earlier is Dewey's way of highlighting the important qualities of intelligent, educated ways of being.

Just as concepts are the core object of thinking in the cognitive perspective, ideas are the core construct in a Deweyan perspective on learning. Whereas concepts are representations and are the basis for thinking, ideas are anticipations and are the basis for being. To some readers, ideas and concepts may seem synonymous and I admit that Dewey's use of the term "idea" (along with other terms) while precise, is often confusing. To clarify, consider a hypothetical, yet familiar example: in the midst of a rather uninspired high school science lesson on photosynthesis, a student suddenly sits bolt upright and exclaims, "I have an idea. What if... " In this example, the having of an idea is an event that moves forward with dramatic energy: it is an experience. The student is filled with thought, has feelings associated with where the idea may lead, and is energized to act either physically or in imagination. Thus, in an experience, thought, feeling, and action are unified and the individual experiences what it is like to be fully alive.

The goal of effective teaching is not merely to foster new understanding, but to foster new ways of being. Education is transformation and inspiration (the word "inspiration" has the Latin root "inspirare" which means "to breathe life into"). The degree to which teaching facilitates inspiration rather than just conceptual understanding, is the degree it is organized around Deweyan ideas rather than just concepts.

Ideas and language. What can be said about the difference between language and ideas? Often portrayed as a tool or as a system of symbols, language and words, like concepts, do not adequately capture the unity of thought, action, and, in particular, feeling. Again, the reason for this is revealed when I examine the underlying epistemology of discourse perspectives.

With roots in critical theory, literary criticism, anthropology, and post-modern epistemology, discourse perspectives and even very current conceptual change theory (Sinatra and Dole, 1998) have educated our sensitivity to the contextualized qualities of learning and knowledge. A foundational mission shared by these perspectives has been to debunk conceptions of meaning as: something "in the object," something that can be rationally derived from a general system of rules, or something "in the individual mind." Instead, discourse perspectives recognize meaning as something situated in a social (i.e. gendered, cultural, historical, political) context. (note: "Situated" can imply that meaning is embedded in either physical (Brown et al., 1989; Gibson, 1966) or the social setting. Most perspectives are hybrids of these assumptions).

With the development of theories about the socially situated nature of meaning, language plays an increasingly important role as both the process and product of meaning-construction. Two reasons may be cited: first, as an entity, language is neither in the head nor in the object – it is between people. Thus, the Rortian "linguistic turn" presents a solution to the age-old problem about the "location" of knowledge and the mind (cf. Cobb, 1994). Thus, meaning resides neither in the head nor in the world, but in the language we develop. In this view, to learn science is to learn its language (e.g. Gregory, 1990; Lemke, 1990; Roseberry et al., 1992). Second, because language and communication are inherently social phenomena, they are well-suited to reflect how meaning is shaped by gendered, cultural, historical, and political forces.

As we become more focused on language and the socially contextualized nature of knowledge, Dewey would warn against the tendency to diminish the role of the “real” world. Knowledge is not a purely social (or individual) construction. Meaning is not solely a product of social negotiation. For Dewey, legitimate knowledge and meaning always has a basis in our interaction with the world. Put differently, experience is not a purely psychological phenomenon. Dewey writes,

> "Instead of signifying being shut up within one's own private feelings and sensations, ... experience signifies active and alert commerce with the world; at its height it signifies complete interpenetration of self and the world of objects and events" (Dewey, 1934, p. 25).

Jackson elaborates this idea,

> “Experience, in other words, is transactional. It is not just what registers on our consciousness as we make our way through the world but includes the objects and events that compose that world. The objects and events are as much a part of experience as we are ourselves.” (Jackson, 1998, p. 3)

Although Dewey and Jackson warn against construing experience as an internalized individual phenomenon, an analogous point can be made that knowledge should not be portrayed as something completely internal to the social processes of group activity.

Thus, Dewey's epistemology contributes to discourse and conceptual change perspectives by bringing greater balance among influences of the social-contextual, the individual psychological, and the natural world. All three entities function as both generators and arbiters of knowledge. The notion that meaning is negotiated is expanded to include negotiation not only in interaction with others, but also in interaction with the world. Similarly, the value of an idea lies not simply its rational basis, nor the sway of the social influences associated with it, but also in what it yields for individuals as they act in the world.

Aesthetic understanding

In my view, learning is the having of aesthetic experiences ending in aesthetic understanding. I find the term "aesthetic" appropriate for its emphasis on the qualitative unity and coherence among parts and because realizing this unity creates an experience which is compelling in its own right and, not simply in its instrumental value. In addition, aesthetic captures the involvement of the whole person, not just rational faculties or interaction with others. The intent of my analysis of the conceptual change and discourse perspectives is to make a case for aesthetic qualities of understanding. I take time here to further develop three central qualities.

Aesthetic understanding is dramatic and compelling

Transformative experience is "active and alert commerce" with the world – "commerce" being the forward moving transaction between testing ideas and undergoing the consequences. The drama of powerful learning comes from the anticipation internal to this process. Dewey's emphasis on ideas and anticipation supercedes the problem solving mechanism of conceptual change in that learning can be both driven by problems and inspired by possibilities. In addition, Dewey's account gives a prominent place for emotion, the varied feelings of anticipation, in the experience of learning. In contrast to the discourse perspective, subject matter has greater prominence in Dewey's account of what motivates students. In educative experiences, anticipation about testing ideas in the world, rather than social participation, compels students' engagement.

For Dewey, experience is a negotiated process between action and undergoing ending in expanded perception. The goal of an experience is to resolve these perceptions into some meaningful, unified experience. Dewey calls "dynamic organization" the process by which we negotiate action and undergoing; the process by which we organize our perceptions and rectify our structures into a coherent whole. "That which distinguishes an experience as esthetic is conversion of resistance and tensions, of excitations that in themselves are temptations to diversion, into a movement toward an inclusive fulfilling close" (1934, pg. 56). We work hard to make our conceptions or experiences "fit", and when they do, understanding becomes aesthetic. "The doing may be energetic, and the undergoing may be acute and intense. But unless they are related to each other to form a whole in perception, the thing done is not fully esthetic" (pg. 50).

Because of this flux, an experience is an emotional state that fuses actions, events, and emotion into a unified whole. This drama and affective unification also provide an aesthetic quality to experience.

> It is not possible to divide in a vital experience the practical, emotional, and intellectual from one another and to set the properties of one over against the characteristics of the others. The emotional phase binds parts together into a single whole; "intellectual" simply names the fact that the experience has meaning; "practical" indicates that the organism is interacting with events and objects which surround it. The most elaborate philosophic or scientific inquiry and the most ambitious industrial or political enterprise has, when its different ingredients constitute an integral experience, esthetic quality (pg. 55).

Dewey believed aesthetic experiences are recursive, not circular, but perhaps spiraling. Rather then coming to a final conclusion, we are compelled to seek other experiences. To "get it" is not to come to rest as can be connoted by other perspectives. For Dewey, understanding often generates more thinking and more action – even more than the logical problems associated with problem solving perspectives - as we ask ourselves which route to pursue or where and how else might these ideas be useful. I believe aesthetic understanding is not an endstate but only a jumping off point that compels us to learn more.

Students may make statements like the ones below, which would qualify as evidence of the compelling power of experience:

In reference to the compelling power:

"I can't wait to tell others about this!"

"I've really been thinking a lot about this."

"Learning about this has made me want to learn about other things."

The compelling nature of experiences can be thought of as facilitating "ideas-on-the-brain." Students who think about ideas want to talk about them, pursue them in other ways and in other settings have ideas-on-the-brain, which is an indicator of the compelling, forward-looking nature of experience.

Aesthetic understanding is transforming

Dewey's epistemology highlights how a new entity is created in the dramatic experience of learning. This "event" or "situation" exists only in the transaction of the individual, world, and idea. Dewey's concept of transaction highlights two key features of aesthetic experience. First, it describes how learning can truly have intrinsic value. Other perspectives tend to portray concepts and language as tools or means to an end and, in my opinion, struggle to explain how learning can occur for "its own sake."

Second, Deweyan transaction illuminates how dramatic experiences are transformative. As the individual acts on the world, the world necessarily acts on the individual. Each is influenced and changed by the other. The unfolding of an experience is the mutual development of the individual and world. This mutual transformation as individual and world transact is a key element in Dewey's epistemology. Dewey writes,

> Experience does not go on simply inside a person. It does go on there, for it influences the formation of attitudes of desire and purpose. But that is not the whole story. Every genuine experience has an active side which changes in some degree the objective conditions under which experiences are had (1938, p. 39).

As an example, a friend tells a story about his childhood in which he came to be aware of the idea of adaptation. Suddenly, everywhere he looked he saw evidence of why and how living things survived. He literally "saw" adaptation all around him and was changed by the revealing power of this idea. Neither he nor his world exited this transaction the same. This is the potential of aesthetic experience. Through action, or more specifically, the transaction between individual and world, experience is transformative.

In short, the new relationship between person and world is the "product" of learning. This view contrasts with conceptual change perspectives where individuals' conceptions or representations alter to fit the world. In addition, individuals are changed only to the extent that their understandings change. Dewey's describes a change in being – a change in thinking, acting, and feeling.

The discourse perspective describes transformation of identity and participation and, in this regard, resonates with Dewey's emphasis on the whole person. However, discourse perspectives, especially those influenced by the work of Lave and her colleagues, tend to see transformation as a progression toward an established practice. Individuals move from peripheral to more central, more legitimate tasks as they become part of a community of activity. Similarly, learning can be described by the degree that individuals have appropriated the language of a community such as science. This view of transformation contrasts with Dewey's in two ways. First, as in the conceptual change perspective, there is little discussion of how the learners' worlds are transformed as they develop. Second, instead of convergence toward the conventions of an established group, Deweyan transformation allows for more individuality of experience often spawning creative leaps and more divergent thought. It seems to us that some account for variation from norms is essential to account for how new ideas and new practices can emerge from established groups.

To operationalize this quality of aesthetic understanding, some examples of statements students may make after a transformative experience are helpful:

In reference to transformed world:

"I see the world in a whole new way."

"I can't help but see the idea everywhere now."

In reference to transformed person:

"I feel differently about myself."

"I can see myself continuing to study this."

Another indicator of transformative experience would be if a student articulated new opinions, beliefs, or goals for him or herself. For example, Brieana, a student in this research stated, "I'm thinking about becoming a geologist." This was not previously an idea she had entertained. Through her engagement with substantive ideas, she was transformed into someone who may become a geologist.

Aesthetic understanding is unifying

In aesthetic experience, learners are drawn forward in anticipation of consummation.

> In contrast with such (ordinary) experience, we have an experience when the material experienced runs its course to fulfillment. (The experience) is so rounded out that its close is a consummation and not a cessation (Dewey, 1934, p. 35).

Consummation – the coming together of the various parts and incidents, the completion of development – not only marks the endpoint of an experience, but is anticipated through the entire event. To consummate an experience is to see how formerly disparate elements fit together. The coming together of parts is the drama inherent in great art, riveting stories, and engaging scientific inquiry.

For example, in learning about the periodic table of the elements one comes to understand it as an organized representation of the building blocks of molecules and matter. We begin to view relationships between elements and molecules differently. This relationship begins to make more sense and we can make predictions based on our knowledge. The periodic table resolves into a more unified representation rather than disconnected facts to be understood separately. Concurrently, individual elements come into relief. One can speak more accurately and more comprehensibly about sodium and chlorine as individuals because their atomic relationships are better understood.

This quality of emerging unity is not easily detected in discourse perspectives' accounts of learning outside of group or community unity. Again, however, this is unity associated with participation not subject matter knowledge. In the conceptual change perspective, on the other hand, sense making and connection are intimately related. In the cognitive paradigm, to understand is to make connections. Although both Deweyan and conceptual change perspectives seem to both emphasize how learning is unifying, Dewey pushes the idea to the next level. What makes powerful learning fundamentally aesthetic is that it takes on a profoundly moving, spiritual character. Jackson explains:

> I think what Dewey means is that it is during those moments of full perception, when we are totally absorbed in what this object or event or ideas is like, that the various components of our psychological being – our ability to think, to feel, to appreciate, to experience through all of our senses- come into play at once. At such moments our various capacities not only are realized (i.e., become real) but are also momentarily fused and unified. Only then do we experience what it is like to be fully human (1998, p. 149).

When ideas engage all our faculties, when we realize greater coherence in our world, when we expand our capacity to think, feel, and act, we experience a kind of transformation of ourselves that is deeply and innately compelling. This is the intrinsic, aesthetic value of educative experience.

If students made statements like the ones below, it may be evidence of the unifying potential of experience:

In reference to unifying potential:

"This is all starting to fall into place for me."

"The world is beginning to make more sense."

"I get it and it's so cool!"

Summary

Let us review and summarize the main features of aesthetic understanding. Central to aesthetic understanding is the idea of aesthetic experience. Students learn through a process of changed perception, a virtual transformation of their world and themselves as they seek to verify content 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 quality of 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 ideas in ways that are not necessarily connected to instrumental outcomes. In fact, I 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. Recall Oppenheimer's quote that leads this paper, "Understanding is a lot like sex. It's got a practical purpose but that's not why people do it normally." Similarly, we should not always learn for what knowledge can do for us, or what it may buy us in the future. The goal of learning should be the having of aesthetic experiences, coming to aesthetic understanding, and developing value for ideas beyond the purely instrumental.

Table 2.1 provides a summary of the three perspectives on science learning.

Table 2.1 Summary of three perspectives in science learning

	Conceptual understanding via conceptual change theory	Discourse-based understanding	Aesthetic understanding
Exemplar	Posner et al.'s "Toward a theory of conceptual change"	Lemke's *Talking science*	Dewey's *Art as experience*
Knowledge is	In the head Representations and concepts	In the group In language and participation with others	In action in the world (physical and social)
Central curricular unit	Concepts Disciplinary knowledge	Language, participation	Ideas, experiences
What motivates learning?	Problems Logical inconsistencies Cognitive dissonance	Desire to participate in a group Anticipated identity or role in the group	Anticipation of possibilities Desire to try out ideas
How does learning occur?	Accommodation of new knowledge with prior knowledge Stimulated by cognitive disequillibrium or dissonance	Appropriating language Moving from peripheral to central participation in a group	Having aesthetic experiences with subject matter ideas
Role of teacher?	Help students identify, confront and replace misconceptions with accepted canonical ways of knowing Emphasis on individual cognitive structures	Help students adopt socially accepted norms or ways of talking about science Scaffold identity development and emphasize community of shared meaning-making	Help students to see possibilities and potentials for science ideas to re-shape and re-vitalize the world Emphasis on truth and beauty as ideas are verified in world

Table 2.1 (cont'd)

Role of learner?	Learner must recognize misconceptions then accommodate or replace them with "correct" ideas	Learner active in constructing and co-constructing knowledge with other students, teacher, and society or culture at-large	Learner active in verifying potential of ideas Process of verification is both individual as well as socially and culturally situated

In the next chapter I describe a research study designed to test the efficacy of both the analytic lens of aesthetic understanding and the means by which to facilitate it in a classroom of 5th grade students. I believe teaching designed specifically to foster aesthetic understanding through powerful aesthetic experiences with science ideas has the potential to be deeply meaningful and powerfully important learning. I believe learning for aesthetic understanding may have positive effects on student interest and attitude toward science as well as positively effect student efficacy and identity beliefs as science learners. Additionally, I hypothesize that learning for aesthetic understanding does not mean a compromise in learning for more typical conceptual understanding, or even, perhaps discourse-based understanding. In fact, I hypothesize that learning for aesthetic understanding, because it is so perceptually oriented, literally changing the way students perceive the world, may help to foster more enduring levels of conceptual understanding. Chapter 3 describes a research study designed to test these hypotheses.

Chapter 3: The Research

Introduction

The theoretical argument in the previous chapter, and pedagogical moves designed to foster aesthetic understanding, have been under continuous formulation and revision across the last three years. Simultaneously, I've worked out methodological issues related to investigating the efficacy of both the theory and instructional program. What has emerged from this preceding work is a clear set of research questions, data gathering procedures, and measures useful in this research. Before describing these, however, I will describe the setting in which this research occurred.

Setting

This research was conducted in an urban elementary school in a fairly large, Midwestern city. In an effort to test the theory of aesthetic understanding and the efficacy of the instructional program designed to foster aesthetic understanding, I served as the science teacher for one 5th grade classroom and drew comparisons between pedagogy and student outcomes with the other 5th grade classroom. In this way, the study is of quasi-experimental design in which students were drawn into the two classes randomly at the beginning of the year although I knew which class

I'd be working with beforehand due to a pre-existing relationship with one teacher and not the other. The two classes each progressed through three similar units (weather, erosion, and structure of matter) but the instructional goals in my classroom (treatment class) were that of teaching for aesthetic understanding while the goal in the other class (control class) was for a conceptual understanding. Although the pedagogical practices witnessed in the control classroom and described later do not appear to be exactly similar to the pedagogy outlined in chapter 2 for conceptual understanding, this was the goal articulated by the teacher that teacher. I will discuss the details shortly. For now, the participants are 53 5th grade children in two classes – one experimental and one control. Student characteristics appear in Table 3.1.

Table 3.1 Student characteristics

Class	Female		Male		Totals
Ethnicity	African American	Caucasian	African American	Caucasian	
Treatment class	6	9	5	7	27
Control class	4	10	7	5	26

Design

Given this setting, the research questions were:

- Can I teach in ways that facilitate aesthetic understanding?
- How similar or different will students' aesthetic experiences be to those predicted by the theory in chapter 2?
- Will teaching for aesthetic understanding foster more positive attitudes, science efficacy beliefs, science identity beliefs, and interest in science than teaching that is not for the goal of aesthetic understanding?
- Will teaching for aesthetic understanding yield a comparable level of conceptual understanding than teaching that is not for aesthetic understanding? Will teaching for aesthetic understanding perhaps yield a more enduring conceptual understanding?

In an effort to investigate these questions, I have developed a 5-stage design involving gathering various pre-instructional data, teaching 3 instructional units while gathering data across each, and gathering post-instructional data. The overall scope of this research appears as Table 3.2 below followed by further explanation of each stage.

Table 3.2: Research design and timing schedule

$Time_1$ – Before any science instruction	• Whole class interviews investigating prior aesthetic experiences and aesthetic understanding in science • Pre-Feelings Toward Science Inventory
$Time_2$ – $Time_4$ (instructional cycles)	• Pre-test of conceptual understanding • Post-test of conceptual understanding • Enduring post-test of conceptual understanding (administered one month after end of instruction) • Interviews investigating emerging aesthetic understanding with half the class

Table 3.2 (cont'd)

$Time_5$ – After all science instruction	• Whole class interviews of aesthetic understanding • Post-Feelings Toward Science Inventory

$Time_1$ was used to establish positive prior relationships with the children in an effort to reduce any novelty effect my presence in the classroom may have. I also interviewed all students in each class regarding their previous aesthetic experiences with science (protocol appended as A), and administered the Feelings Toward Science Inventory (appended as B) exploring notions of affect, interest, identity, and efficacy beliefs around science learning. Additionally, I established that the classes are not unusually dissimilar by making sure no students were "tracked" into the classes based on some extenuating circumstances (like perhaps ability, participation or interest in certain kinds of activities, gender, behavioral record...). It is my belief that students in these two classes are not unusually dissimilar, however, I gathered baseline data on all constructs of interest to confirm this. Results of baseline data, which will be further discussed in chapter 4, revealed no statistically significant differences between the two groups of students. In fact, the classes were remarkably similar in student composition and scored similarly on all pre-tests.

During $time_2$, $time_3$, and $time_4$, I studied my own teaching and student learning across three instructional cycles. During each of these cycles I administered a pre-test of conceptual understanding, taught for aesthetic understanding, and administered a post-test of conceptual understanding. One month after the post-test I administered the same post-test to investigate enduring conceptual understanding. It is my conjecture that because the pedagogy is designed to foster changed perceptions of the world and increased student interest and affect toward science, that conceptual understanding may be more likely to endure over time. In an effort to explore the effect of interviewing, and thereby reinforcing values related to aesthetic understanding, only half the students in each class were interviewed after each instructional cycle. The effect of these interviews will be explored statistically. These interviews are semi-structured but 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. I conducted the interviews for students in the control classroom and an assistant conducted all interviews with treatment students. I felt as though, having been their teacher, acting as the interviewer for the treatment class students may have compromised the validity of student responses as students could have possibly given answers in an effort to please (or displease) me.

$Time_5$ was used to re-administer the Feelings Toward Science Inventory and conduct whole class interviews regarding student aesthetic understanding of each of the three units. I chose to interview students after each instructional cycle because I believe it may take some practice to become able to or grow proficient at experiencing aesthetic understanding. Throughout the study all interviews were conducted in pairs of students. Students were paired in ways that match students of approximately equal science achievement. Because several questions in the interview related to subject matter, I tried to reduce situations in which students of dramatically different abilities were paired as this may cause discomfort in telling their experiences or discussing their emerging ideas of subject matter ideas.

As alluded to in the opening paragraph of this chapter, I have explored these ideas previously and have chosen a battery of measures that I believe effectively investigate my research questions. Those measures are described more completely below.

Data came from three main sources. First, all students in both classes completed the Feelings Toward Science Inventory both at $time_1$

and $time_5$. Second, all students in both classes were interviewed at $time_1$ and $time_5$ to investigate the efficacy of the treatment as well as half the students in each class at the end of each instructional cycle ($time_2$, $time_3$, and $time_4$). Third, all students responded to three sets of measures of conceptual understanding (pre, post, and enduring conceptual understanding). The next section examines the development of these measures and the interview protocol, the confidence in each instrument, and what each instrument will provide in light of the research questions.

Measures

All measures have been either developed and refined by me or adapted from other sources and further refined to better suit my research context and interests. Table 3.3 shows a summary of measured constructs, measures, and item analyses of each measure. A brief discussion of the development of each instrument follows the table.

Table 3.3: Measures

Measure	Research Question	Item analysis by factor
Feelings Toward Science Instrument	RQ #3: Will teaching for aesthetic understanding foster more interest, positive attitudes, science efficacy beliefs, and science identity beliefs in learners than teaching that is not for the goal of aesthetic understanding?	Affect: #1, #5, #8^{-}, #9, #15, #19^{-}, #20^{-}, #21 Interest: 3-, #12, #14, #18, #23, #25 Efficacy: #2, #4, #7, #11, #13^{-}, #17^{-}, and #24^{-} Identity: #6^{-}, #10, #16, and #22^{-}
Conceptual understanding	RQ #4: Will teaching for aesthetic understanding yield comparable levels of conceptual understanding as teaching that is not for aesthetic understanding? Will teaching for aesthetic understanding yield a more enduring level of conceptual understanding?	All curriculum goals and tests of conceptual understanding were written from curriculum guides produced by the local school district that map directly on to state curriculum guidelines for 5th graders. Curriculum goals can be found in the description of the instructional units in table 5. All tests of conceptual understanding are appended as D-F.

Table 3.3 (cont'd)

Aesthetic understanding and aesthetic experience interview protocol	RQ #1: Can I teach in ways that facilitate aesthetic understanding? RQ#2: How similar will student experiences of aesthetic understanding be to hypothesized ones outlined in chapter 2?	The protocol consists of 3 main questions with several probes. The first question asked students to describe any learning during the unit that had the effect of changing student perceptions of the world. The second question asked if this new perception added interest and excitement while the third question investigated the degree to which students' new-found understandings moved them to action in the world. The protocol is appended as B.

Feelings Toward Science Instrument

The Feelings Toward Science Inventory is a mixed-bag of items and factors taken from many other sources. All items appearing on this inventory have been pilot tested on 3rd, 4th, and 5th graders and I have some degree of confidence in the instrument to perform as I expect. Below is a description of each factor measured by the instrument and something on the origin of the items that compose that factor.

Attitude. Attitude is a complex and slippery conceptual term. Few researchers seem to be talking about exactly the same thing when they discuss attitude and even less agreement exists among researchers as to how to best measure it. I've spent many, many hours exploring attitude, it's constituent parts, and how to measure it only to become convinced that no definitive sources exist and that I should choose or create a measure that does precisely what I want it to do. After much deliberation I decided that for me, the most significant facet of attitude was an affective quality. "I like science" or "I think science is great!" is more telling, in my opinion, than some more ambiguous kinds of questions that could be asked. Yes, I want children to have positive affective responses to science class and science ideas. For this reason, I've chose to measure science attitude with a modified version of the *Attitude toward Science in School Assessment* (ATSSA) (Germann, 1988). The ATSSA defines attitude as the affect for or against science at the exclusion of a great many other factors and forces. Germann explains,

> The objective in the development of the Attitude toward Science in School Assessment (ATSSA) was to measure a single dimension of a general attitude toward science, specifically, how students feel toward science as a subject in school. Attitude, here, does not include such scientific attitudes that might motivate a person to become a scientist; that affect performance, competence, and success in science as a profession; that affect contributions to and acceptance of new knowledge; that deal with the foundations, interactions, and dynamics of science; or that apply to philosophy, ethics, or politics. Nor does it include other attitudes toward science, such as toward scientists, toward methods of teaching science, toward scientific interests, or toward particular science courses. Another domain avoided was that of judgments of personal ability in science, the value of science to the individual, or

> the value of science to society. **The interest was in the degree to which students like or enjoyed science** (pg. 694) (emphasis added).

Like Germann, what I'm most interested in is students "like" or "enjoyment" of science. For this reason I've chosen to use the ATSSA. The ATSSA was developed and piloted on 492 students in grades 7-12. Germann reports Cronbach alpha estimates of reliability to be .95. However, in factor analysis of my pilot test results I found that items in the ATSSA loaded best on two factors - one related to pure affect and another related to affect and cognition or intellectual engagement. I refer to this additional factor as interest and will discuss this factor next.

Interest. Again, having originally appeared in the ATSSA instrument, 6 items seemed to load separately on a separate factor combining elements of both cognition and affect – interest. These 6 items performed with the following reliability coefficients on pilot tests involving 80 3rd, 4th, and 5th graders in the same school in which this research was conducted.

Efficacy. I piloted a short measure of perceived student efficacy in science. These items were taken from an instrument designed to measure motivational beliefs and self-regulated learning strategies (Pintrich and DeGroot, 1990). The original nine item scale (original α =

.89) was reduced to 7 items and modified slightly for a lower reading level. My pilot results yielded a reliability of α = .82

Identity. These items were taken from a variety of sources reported to measure science efficacy beliefs. Their origin is less important than how they performed during pilot testing and in this research study. The four items achieved a reliability of α = .75 in pilot tests.

All factors are measured together on a single instrument called the Feelings Toward Science Instrument included as Appendix A.

Various tests of conceptual understanding

Again, all measures of conceptual understanding were written from curriculum guidelines provided by the local school district that reflect statewide curriculum goals for 5^{th} grade science. Pre-tests and tests of enduring conceptual understanding were reduced to either 3 or 4 open-ended questions in which students had to construct short answers requiring anywhere from a sentence to a short paragraph of response. The test of conceptual understanding administered immediately after instruction was consistently longer than the other two but contained the identical open-ended questions as the other two tests. Final scores of conceptual understanding (pre, post, or enduring) were computed using only these common items. Again, these are appended as C-E. All items on tests of conceptual understanding were scored using the following 5-point rubric taken from Marzano (2000):

Table 3.4: Conceptual understanding scoring rubric

Score	Description of proficiency
4	The student has a complete and detailed understanding of the information important to the topic.
3	The student has a complete understanding of the information important to the topic but not in great detail.
2	The student has an incomplete understanding of the topic and/or misconceptions about some of the information. However, the students maintain a basic understanding of the topic.
1	The student's understanding of the topic is so incomplete or has so many misconceptions that the student cannot be said to understand the topic.
0	No judgement can be made.

Two researchers scored all items and inter-rater reliability measured .76. Differences in assigned scores were discussed and a final score was mutually agreed upon.

Aesthetic understanding interview protocol

The interview protocol is a semi-structured instrument that follows a reasonably set sequence of questions designed to investigate the quality of aesthetic experiences had by students. I've indicated a certain number of possibly fruitful follow-up questions but did not try to anticipate every twist and turn of dialogue. Potentially fruitful leads were followed and students were allowed to largely shape the dialogue of the interview. This protocol was developed for my practicum research and has been modified through numerous trials including a pilot study only a year ago. Although I have never used the protocol in it's current form, I have used most of the questions in one form or another in previous inquiry projects investigated similar ideas. My prior experiences with similar investigations and protocols lead me to expect the instrument to perform its function adequately. The protocol is included as appendix B.

All 76 student interviews were transcribed. As with tests of conceptual understanding all student interviews were coded twice by 2 different researchers using a coding scheme appended as H. The two raters achieved inter-rater reliability of .71. Scoring differences were discussed and a final score was settled on for each sub item in the interview.

Summary

Before describing the pedagogical differences between the two classrooms I'll elaborate on the values, goals, and focusing issues behind the pedagogy designed to foster aesthetic understanding. The preliminary conversation will help make more clear why the pedagogical moves were made as they were in the treatment class.

Chapter 4: The pedagogical treatment

Introduction: Expanding the capacity for perception through 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).

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 and Robinson, 1990; Jackson, 1998). Recall the way many scientists in chapter 1 described with vivid imagery their perception and appreciation of science ideas. For this reason treatment class pedagogy also has the goal of expanding student perception through an act I've called re-seeing. It is described next.

Our brains are amazing. With just a quick opening and closing of our eyes, one can gather a great deal of information about our surroundings - color of the room, approximate number of people in it, something of the objects in the room. This ability to rapidly recognize and interpret our surroundings is vital to our existence – it certainly kept our species alive on the African savanna. However, it also serves to blur perception. Too much of what we see in the world is generalized and simplified. We often fail to look closely and carefully at our world. 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 wrote that ordinary living, routine, un-observed interaction with the world cause 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” (1934, pg. 109). Art, however, “throws off the covers that hide the expressiveness of experienced things.” Dewey 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” (1934, pg. 110). As we’ve read previously, science ideas, like art, have the potential to reveal and renew as well. We, however, must become proficient in the act of seeing the world through artful eyes.

"Re-seeing" is an attempt to focus our perception on the nuance and detail of the world. Re-seeing requires that we look carefully when we might be tempted to assume we see everything. Re-seeing is also a disposition that causes us to ask questions of what we perceive such as, "What's really going on here? Why do things look the way they do?" And "What kinds of things do I need to know more about to really re-see this?" I've used re-seeing with powerful results in my teaching. During the course of an astronomy unit, a student of mine named Edie exclaimed excitedly, "I did some re-seeing last night!" While getting into her mother's car, she noticed the moon and it's features. "I could actually see different shapes and things on the moon and you could tell that it was just a shadow that made it look like a fingernail." For probably the first time in her life, Edie looked carefully at the moon and wondered why it looked like it did - she "re-saw" the moon. Gertrude Stein made similar comments regarding her 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, Stein gained an understanding of art that she previously lacked.

Re-seeing, with its emphasis on Dewey-like perceptual metaphors, can be used as a central activity in classrooms. Variations on the act of re-seeing can be to 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 that I believe most scientists and artists engage in daily. 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).

Recall the closing argument in chapter 1, taken from Root-Bernstein (1997), that students simply cannot come to fully understand and appreciate science if they cannot understand and appreciate its aesthetic qualities. I imagine most science teachers, particularly teachers of older students, would spend very little 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)?

Although this ends my formal discussion of re-seeing in an attempt to train the capacity for expanded student perception, I will return to this idea later in the section describing the treatment in this research – the instructional program used in my classroom.

Re-seeing and other strategies employed in teaching for aesthetic understanding?

I believe I have established that science and art have an underlying set of related skills, attitudes, and experiences that can be drawn on in important ways. This section addresses the question of how to teach in ways that help illustrate this connection, drawing on the shared qualities of art and science, all in the pursuit of science learning. Root-Bernstein (1997) has written similarly and offers three suggestions for doing so.

First, in suggesting how science education should draw from the arts, he suggests that too much of what teach in science is "communicating objective results." He continues, "as Wittgenstein pointed out, 'The limits of my language mean the limits of my world.' What cannot be said or written as numbers must have other means of expression or they will not exist for students" (pg. 71). The "tools of the imagination," pattern forming, analogizing, abstracting... these things cannot as easily be taught. Root-Bernstein suggests we look to artists and their craft as alternative formats for communication is stock in their trade. If we could prepare students who were eager and adept at communicating and experiencing through modes beyond purely logical, mathematical, and linguistic, we would be that much closer to experiencing science in it's wholly human element.

Second, "The second lesson inherent in recognizing the aesthetic component of science is that an aesthetic experience always involves interpretation, and some people will be better interpreters than others" (pg. 72). Here, Root-Bernstein suggests that science cannot be presented for public consumption (like in school curriculum) in it's most rigorous and definitive form, such as the way scientists may interact with it. Science needs good interpreters to shape and present it in ways palatable and powerful to the consumer. We need to reverse the opinion that there is nothing to be gained in reformulating and reinterpreting existing science and alter "the low esteem in which clear and understandable presentation is held" within the scientific community. Together with the first point, both ideas suggest that science teachers must re-vitalize curriculum and content in ways that are a) "clear and understandable" as well as b) tap alternative formats or unique representations to communicate unique insight about the world. I believe the notion of idea as opposed to concept, as articulated in chapter 2, is a perfect illustration of this. Allowing ideas (often metaphoric) to focus curriculum is a path to clarity while providing a unique representation – different from the scientific models, simplifications, and illustrations more commonly used.

Finally, Root-Bernstein gives his third recommendation: "The third lesson inherent in the recognition that scientific creativity relies upon the same aesthetic tools of thinking as the arts is that the arts can be the source of skills and insights that science needs to progress" (pg. 73). Again, as illustrated above by numerous scientists, perception and deep-seeing is critical to both artists and scientists. We must educate perception if we are to educate scientists. Drawing from the recommendations from Root-Bernstein as well as from my own insights from experience and intuition, I will now describe the details of the pedagogical intervention employed in this research.

Across the last three years I've worked to articulate this conceptual framework and have been conducting experimental teaching in a local elementary school trying to develop and refine the pedagogical strategies used to facilitate aesthetic understanding. What follows is a description of this pedagogy that I will apply in the experimental classroom. In a sense, this pedagogy will be the 'treatment' used in my research. Each of these pedagogical moves was designed to foster aesthetic understanding, specifically the three qualities described previously as transformation of person and world, compelling and dramatic affect, and having unifying effects, as well as aesthetic value. I will not attempt to articulate exactly the relationships between individual pedagogical moves and specific qualities of aesthetic understanding such as "doing X will foster transformed self." I believe the pedagogy, in its entirety, fosters aesthetic experiences and leads to aesthetic understanding and aesthetic value.

The teacher plays a unique role in teaching for aesthetic understanding. A useful metaphor for describing her job is to imagine her as an artist in her studio trying to shape curricular ideas and experiences for children in artistically pleasing and aesthetic ways. She does this in several ways that I will describe. Basically, her job is to position students in the path of potentially unfolding aesthetic experiences. She does this first by structuring the curriculum in ways that assist or support transformative experiences. Pugh (1999b) describes this process as "artistically crafting" concepts into Deweyan ideas. Below, I've briefly described a few guidelines or "things to try" when crafting curricular ideas.

Curriculum

Children come to experience science first through the eyes of their teacher. Organizing content into ideas (as opposed to concepts) is a central and difficult task in teaching for aesthetic understanding. Typically, I use the following strategies to recover the power of science ideas. I ask myself why I love my area of specialization, what ideas really ignite my interests and passion, and what ideas get me most excited about teaching. Then I let these ideas serve as top-level organizers for my instruction. For example, I'm fascinated by the idea of adaptation. It is what drew me to study biology and I find power and beauty in its implications. In teaching an ecology course, I chose to highlight adaptation as my class moved through the more traditionally organized textbook. While studying biomes, my students imagined what adaptations organisms might need to survive in different regions. While studying ecosystems, my students studied how particular organisms were uniquely adapted to inhabit particular niches within that ecosystem. Highlighting the idea of adaptation allowed us to move through relatively traditional looking curriculum while carrying a powerful and important scientific idea. Adaptation allowed my students to find coherence in nature, literally see their world and its organisms differently, and were necessarily drawn into the world as they looked for their own examples of adaptation as it related to ecology. How is this different? Rather than simply leave the concept of adaptation as something to be understood, I let adaptation, and my enthusiasm for it, guide our entire unit. Adaptation became an idea to be relished, explored, and valued. This simple re-focus put a powerful and revealing idea at the center of learning. Teachers' passions ignite students' passions and teachers' passions are typically guided by ideas. What lesson can be taken away from this example? I believe to qualify as an idea, a focusing topic must be: a) recognized by and perceived as faithful to the discipline of science and its methods of perceiving, inquiring, and communicating science knowledge, organizing a broad enough range of knowledge into a graspable conceptual "handle"; b) powerful and inspiring to the person who plans to teach it, and finally; c) powerful and inspiring, useful and accessible to learners.

Activities

While teaching for aesthetic understanding a teacher should ask students to be more imaginative and creative as they wonder about the potential of ideas. Students should ask more, "what if..." style questions such as, "What if this rock could talk? What story could it tell of us its travels?" Students should be pushed to imaginatively explore the power of ideas. Investigating the potential of ideas to transform takes time and opportunities. A teacher should provide both, individually and in groups. A student activity that helps children to expand their abilities to perceive the world differently is "re-seeing" described previously.

Teacher behaviors

Teachers must always be aware of the attitudes and dispositions they convey to their students - knowingly and unknowingly. Teaching for aesthetic understanding forces teachers to be acutely aware of this as we try to invite more students into engagement with science ideas. Shaping curriculum in ways I've described previously is a good first step but, inevitably, teachers find themselves faced with teaching something that they do not personally enjoy or value. In these cases, like the artist, one must develop skills at continuing to portray the kind of science (or art) that students want to engage with. As students work to develop their own aesthetic understandings of science ideas, they may find value and beauty in ideas that you (the teacher) do not value. When this occurs, it is imperative that the teacher effectively scaffolds students' attempts to see the world in different, artistic ways. This isn't as trivial as it may sound. Seeing the connection between art and science often forces learners to think and talk in ways that may make them seem awkward or even foolish. Leo, a recent student of mine found it useful to imagine himself as molecule swimming in molten lava, trying to form crystals. I thought he was just being silly as he 'swam' around the room with his eyes shut claiming, "It's hard to swim in molten lava. If it cools to soon, I won't form crystals!" But Leo needed to express his emerging understanding in this artistic way. After stifling a chuckle, I commended Leo for attempting to find value in his own understanding of the crystallization process. Teaching for aesthetic understanding forces teachers to see the world through the eyes of children, and vice versa.

Specifically, teachers must work to help students find value in science ideas through modeling and scaffolding.

Model aesthetic understanding. Recall the Feynman quote that begins this proposal in which he artfully describes the process of combustion. Feynman exemplifies what it means to have a well-developed sense of aesthetic understanding of the process of combustion and, likewise, teachers must model ways-of-knowing that incorporate high degrees of many kinds of learning or ways-of-knowing, specifically 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 and 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.

Model positive attitude, interest, and affect. Allowing ideas to guide content and curriculum decisions almost guarantees a certain degree of personal interest, positive affect, and positive attitude toward the idea. Teachers must be willing to express these affective qualities as these teach. I maintain there's no more effective pedagogical move than to teach with intense passion and personal interest in subject matter. Learners "soak" this energy up and tend to transfer it to them own developing understanding.

Scaffold efficacy and identity beliefs. As students engage with science through this unique portrayal, they will inevitably experience a wide range of emotions and dispositions. Teachers must capitalize on and scaffold the development of dispositions that indicate an emerging sense of science identity and efficacy beliefs.

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 excited and interested 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 what guided pedagogy in the treatment class.

Pedagogical differences between the treatment and control classrooms

I was present on all but 2 of the 18 instructional days taught in the control classroom. My role was as observer with the goal of documenting the pedagogical practices used across the three science lessons. I took extensive field notes, wrote after class about my observations and emerging hypotheses, and collected class materials and a great deal of student work. Information about the control classroom pedagogy comes from an analysis of these data sources.

Instructional units and subject matter content for both treatment and control classrooms was quite similar. In fact, both classes would be taking a statewide assessment of science understanding in the spring and so both followed very closely the state and local curriculum goals for 5th grade science. Therefore the curriculum goals for both classes are identical and listed in table 4.1.

Table 4.1 Curriculum goals for three units

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

In fact, more than just 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 4.2 outlines the three units in terms of their daily content. Dissimilar elements appear italicized.

Table 4.2 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>Weather unit:

Day 1: atmosphere and air pressure
Day 2: air pressure and local winds
Day 3: weather instruments
Day 4: predicting weather from weather data
Day 5: landscape portraiture and use of the sky in art
Day 6: global winds, seasons and seasonal change
Day 7: severe weather
Day 8: severe weather precautions and preparedness
Day 9: review and post-test</td><td>Weather unit:

Day 1: atmosphere and weather instruments
Day 2: weather prediction from data
Day 3: global winds and climate
Day 4: seasons and seasonal change
Day 5: air pressure and local winds
Day 6: severe weather
Day 7: severe weather precautions and preparedness
Day 8: review and post-test</td></tr>
<tr><td colspan="2">Notable differences between the two weather units:

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>Erosion unit:

Day 1: mechanics of erosion (both physical and chemical)
Day 2: sedimentation lab exercise
Day 3: completion of lab exercise
Day 4: erosion overview with Bill Nye
Day 5: soil formation and erosion control
Day 6: review and post-test</td><td>Erosion unit:

Day 1: mechanics of erosion (mostly physical)
Day 2: sedimentation lab exercise
Day 3: erosion overview with Bill Nye
Day 4: erosion control
Day 5: review and post-test</td></tr>
</table>

Table 4.2 (cont'd)

<table>
<tr><td colspan="2">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.</td></tr>
<tr><td>Structure of matter unit:

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

Day 1: properties of matter
Day 2: molecular arrangement and states of matter
Day 3: changes in states of matter
Day 4: review and reinforce key concepts
Day 5: review and post-test</td></tr>
<tr><td colspan="2">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.</td></tr>
</table>

Before describing the precise differences in pedagogical practices between the treatment and control classrooms, I'd like to 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.

Control class vignette

Ms. Parker's 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. However, Ms. Parker is a self-proclaimed science-phobe. Although she was this school district's runner-up for Teacher of the Year last year (quite an accomplishment in such a large district), she feels as though she knows very little about science and admits she occasionally avoids teaching it.

Ms. Parker was thrilled that I wanted to help her with science instruction during the course of this research project and welcomed my efforts to align her curriculum with state and local benchmarks, develop lessons, activities, and even assessment instruments that she could use in her classroom. Although I made it clear to her that I would not teach her units for her, she often asked me to prepare class handouts and help her plan the details of her instruction. Facing pressures from state standardized science tests only several months away, I obliged her. However, for the most part, Ms. Parker had a routine that she used in her science instruction and even when using materials I had created, she followed her own routine.

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 that I’ll return to later.

After this period of instructional conversation ends 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.

Finally, in asking Ms. Parker what her goals were for science instruction she stated this, “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.

Treatment class vignette

Although I was not responsible for the style and content of the materials in the treatment classroom, it was still a room with considerable science appeal. As with Ms. Parker's room, science posters adorned the walls and this room also had a row of miniature greenhouses sitting on the window ledge and a wide variety of science related books for children to read during leisure time. 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 this room is a bit more formal but not less exciting or interesting.

Like Ms. Parker I too followed a fairly specific routine in classroom instruction. Upon beginning a science lesson, I would often write an organizing question, idea, or word on the board around which our daily lesson would be organized. For example, one day I wrote, "What makes the wind blow?" on the board allowing student ideas to launch us into rich discussion. Students rarely had any materials to read but discussions moved rapidly and unpredictably as we followed student lines of inquiry and entertained student hypotheses. Unlike Ms. Parker, I feel it is 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 I focused on the act of transforming student perceptions of the world. My 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 I eventually turn the conversation to the next topic at hand.

Finally, most lessons ended with an activity too – 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 I employed were often whole group, experiential, and perceptually driven. For example, we 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 4.3.

Table 4.3 Differences in pedagogical treatment

Control classroom	Treatment classroom
Content: Framed as science concepts and terminology 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: • "Come on class, use your science words!" • "Who can list the three different forms of precipitation?" • "What are the names of the two different temperature scales?" • "Good question, now ask it again using science words."	**Content: Framed as metaphoric ideas and perceptual lenses** 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: Organizing metaphor: Atmosphere as an ocean of air Weather as unbalanced energy Minor metaphoric description: 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. Also, I make a conscious effort to employ wonderment in my lessons. In other words I share with my students powerful facts, ideas, or ways of looking at the world in an effort to generate a sense of wonderment. This wonderment may or may not be related to a metaphor. For example: • During a lesson on the atmosphere I shared with students that there is 17 miles of air above them – pressing down on them. • During our unit on the structure of matter I shared with students the fact that most matter is actually composed of a great deal of empty space – spaces between molecules. I witnessed no efforts to generate wonderment in the control classroom.

Table 4.3 (cont'd)

Focus of power: Teacher oriented	**Focus of power: Learner 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.	I constantly tried to empower students to see and act with science ideas in ways that fit for students individually. As a result, students in my room told, on the average 8 science related stories per day. Several days were consumed almost entirely with student 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 my classroom, lessons were occasionally jumpy as students moved between seemingly unrelated concepts. However, I believe 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 I told numerous stories related to my own experiences with relevant science ideas and ways of experiencing the world, I did this in an effort to model the power of new perceptual lenses. On the average I told 3 stories related to science ideas and how they helped me to see, understand, and appreciate detail and beauty. My 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 4.3 (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 (I designed it) 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 me but employed by Ms. Parker.	By contrast, across the 20 instructional days in my classroom 12 activities were used. The nature of these activities was qualitatively different, however, than the activities used in the control classroom. Activities in my classroom 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. I 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 5th 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, as any weather-channel-watching person can tell, is an important element of weather. I wanted to make sure my students understood that.

On the first day of the weather unit in my class I took my students outside, we lay on our backs in a circle and stared up into the sky. I 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 to me 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. For me, this brief anecdote captures the essence of the difference between the two instructional programs. However, I will now say more about teaching for aesthetic understanding and specific pedagogical moves useful in doing so.

Unanticipated "noise" that may complicate interpretation

Overall I believe the pre-existing differences between the two classrooms are unimportant ones. I am quite thrilled that they are so similar. However, two other factors may complicate interpretation of the results of this research. First, certainly it will grow to matter that Ms. Parker does not enjoy teaching science. I use the phrase "grow to matter" because pre-measures of student attitude toward and interest in science as well as identity and efficacy beliefs about learning science did not indicate that students in the two classes felt significantly differently. However, because this pre-assessment was given at the beginning of the year, perhaps before Ms. Parker's attitude toward science had a chance to affect student attitudes, the post-test of these qualities may reflect some of this acquired negativity. Then again, Ms. Parker is recognized as an outstanding teacher and has a positive attitude and cheerful disposition toward which children gravitate. Perhaps these qualities of Ms. Parker will counteract her obvious dis-interest in science teaching. It could be that she is aware of this and tries to compensate for her own feelings by decorating her room with a great deal of science accoutrements. It's impossible to know how these factors will influence student's feelings about science.

Second, in both treatment and control classrooms, a university intern is completing student teaching. Between the weather unit and the erosion unit (units 1 and 2) interns in both classes spent a month teaching a different science unit (astronomy in the treatment classroom and ecology in the control classroom). I did not anticipate this disruption in the research process and believe the treatment class lost some of the momentum in developing skills necessary for coming to aesthetic understanding. Also, students in both classes may report feelings toward science that reflect feelings developed as a result of interaction with both interns, regular classroom teacher, or, in the case of the treatment class, me. Again, there's no way to control for the effect of the interns in analyses of these data.

Summary

This summarizes my attempt to investigate the research questions outlined previously. Clearly the burden lies in the ability to adequately describe the pervasive differences in pedagogical treatment. I hope the above discussion is satisfactory in that effort.

Chapter 5 includes an analysis of the data including several rich case studies of students who did and did not come to an aesthetic understanding.

Chapter 5: Analysis of aesthetic experiences

Introduction

Recall the main purpose of this research is a) to investigate the efficacy of the analytic lens referred to as aesthetic understanding and to b) test the efficacy of pedagogy designed to foster it. To accomplish these goals we must develop a sense of the richness of student experience across the three instructional units. This chapter is an examination of those student experiences. Following this chapter, chapter 6 is an analysis of the quantitative data searching for treatment effects on conceptual understanding and feelings toward science.

The vast majority of qualitative data comes from student interviews. As described earlier, all students were interviewed prior to any instruction ($time_1$) and at the end of the semester ($time_4$); at the conclusion of the third unit of instruction. At two points between these ($time_2$ and $time_3$), half the students in each class were interviewed in an attempt to investigate if a) students gained proficiency in their ability to learn for aesthetic understanding, and; b) to investigate the effect of the interview on students emerging aesthetic understanding. It is foreseeable that students may begin to report qualities of aesthetic understanding simply by being asked several times if their perceptions of the world have changed as a result of science learning or if they felt compelled to act or explore their emerging science ideas. Students were chosen at random to participate in these two intermediate interviews. However, the same students were interviewed at $time_2$ and $time_3$. All interviews were conducted in pairs based on student ability. This was done to prevent students with vastly different abilities and successes in learning the science content from feeling uncomfortable with one another as they discuss their experiences. The length of the interviews varied from 15 minutes to 40 minutes each.

The effect of the interview

As described earlier it seems feasible that the effect of the interview may serve to facilitate higher levels of aesthetic understanding in students. To investigate this, total scores of aesthetic understanding were compared using ANCOVA which revealed the effect of the interview to be insignificant ($t = 1.024$, p-value = .21). Therefore we can eliminate the effect of the interview and say it did not serve to act as part of the treatment.

Representative case studies

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 = 2.36). Table 5.1 shows their scores as well as the scores of the remainder of the treatment group students. The two students from the control class, Jill and Joe, however, represent students with slightly higher than average scores of aesthetic understanding (Jill = 2.67; Joe = 1.83; class mean = 1.57). I chose students with slightly higher than average scores for two reasons. First, without choosing students with slightly higher than average scores, I'd be left with very little to write about. Many of the students in the control group rated very low in terms of aesthetic understanding. Although we would expect this, as this is what the treatment is specifically designed to foster, most control group students offered very little substance for such an analysis. Jill and Joe, however, with higher than average scores offer more. Certainly we would expect that if the interview questions were more broad, asking about students general experiences learning science, then perhaps more students would have had more to say. As it was the interview questions centered on investigating aesthetic experiences and most students in the control class simply had nothing to report. Second, particularly in the case of Jill and Margie, whose scores of average aesthetic understanding are equal, the nature of their responses is dissimilar. Their case studies will bear this difference out. I chose Jill, therefore, to purposefully try to "match" the case of Margie. 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 $time_2$ and $time_3$ interviews – another reason they were chose for case study analysis. In summary, students were chosen because they are comparable in terms of quality of their scholarship (prior student achievement, attention to school work, conscientiousness regarding school success), gender, and prior experiences with me as their science teacher. The reader should consider Margie and Jill and Tyler and Joe to be very similar prior to science instruction. In this way, differences should be largely attributed to the effect of the various instructional programs in which they learned science. Following Table 5.1 is Table 5.2 showing control student interview response scores.

Table 5.1: Treatment student responses to interview subsections

Student	T_{1see}	T_{4see}	T_{1excit}	T_{4excit}	T_{1act}	T_{4act}	Avg. item score
Jensine	5	3	3	2	4	3	3.33
Jesse	4	3	2	2	4	2	2.83
Jordan S.	2	3	2	2	4	4	2.83
Olajuwon	0	3	1	2	4	3	2.83
Liz	0	2	2	2	4	2	2.83
Pat	3	3	3	2	4	2	2.83
Tameka	1	4	0	3	4	4	2.67
Margie	**4**	**2**	**3**	**2**	**4**	**2**	**2.67**
Crystal	2	3	1	3	4	3	2.67
Kiya	3	2	2	2	4	2	2.58
Joe	2	3	1	2	4	3	2.5
Cyrus	2	3	2	2	4	2	2.5
Matt	2	3	1	2	4	3	2.42
Toni	2	3	0	3	4	2	2.33
Tyler	**0**	**2**	**2**	**2**	**4**	**2**	**2.33**
Kayla	0	3	0	3	4	4	2.33
Angeline	0	3	2	3	4	2	2.33
Jenna	1	2	2	2	4	2	2.17
Jordan F.	0	2	2	2	4	3	2.17
Marcus	0	3	1	2	3	3	2
David	0	2	0	3	4	3	2
Jacinda	0	2	2	2	4	2	2
Ashley	0	2	2	2	4	2	2
Josh	2	3	2	3	4	2	1.92
Cody	0	2	0	2	4	0	1.92
Shaquista	0	2	0	2	2	2	1.83
Shaneka	0	2	1	2	4	2	0.92
Class Avg.	1.3	2.59	1.44	2.26	3.89	2.44	2.36

Table 5.2: Control student responses to interview subsections

Student	T_{1see}	T_{4see}	T_{1excit}	T_{4excit}	T_{1act}	T_{4act}	Avg. item score
Robert	4	3	3	1	4	2	2.83
Jill	**3**	**2**	**1**	**1**	**4**	**0**	**2.67**
Frank	2	2	2	2	4	1	2.17
Lexi	2	2	2	1	4	2	2.17
Katelyn	2	1	3	1	4	2	2.17
JJ	2	3	2	2	4	3	2.08
Ben	2	2	2	0	4	2	2
Collette	1	2	2	1	4	1	1.83
Joe	**2**	**2**	**2**	**2**	**4**	**2**	**1.83**
Kevin	2	0	1	1	4	2	1.67
Deanna	2	2	2	2	4	2	1.67
Katie	3	3	1	1	4	0	1.58
Jonaca	2	0	1	2	4	0	1.5
Trissy	2	0	1	1	4	0	1.42
Donald	2	2	2	2	4	0	1.42
Aubrey	0	0	2	1	4	2	1.42
Bryan	0	2	1	1	4	0	1.33
Spontania	1	2	1	0	4	1	1.33
Vanessa	0	0	3	1	4	0	1.33
Alex	0	2	1	0	4	0	1.17
Emily	0	1	1	1	4	0	1.17
Devontay	0	0	2	0	4	0	1
Thomas	0	0	2	0	4	0	0.92
Italia	3	2	3	2	4	2	0.75
Dee	0	0	1	2	4	0	0.75
Gabby	0	0	0	0	4	0	0.67
Class Avg.	1.42	1.35	1.69	1.08	4	0.92	1.57

Tables 5.1 and 5.2 show scores from interview subsections for both $time_1$ and $time_4$. Case study students appear in bold. The two tables are presented in anticipation of the concern that the case studies represent atypical or unusually effective results of the treatment. In fact, the two treatment class students (Margie and Tyler) represent moderately high levels of aesthetic understanding. I chose Margie because she was unusually articulate about her experiences learning science and I chose Tyler because the animation and excitement with which he told of his experiences carried over well to a written representation. Neither Margie nor Tyler, however, had the highest level of aesthetic understanding in the treatment class.

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." She began the year by ranking it as her 6^{th} favorite class behind math, music, art, reading, and PE. Nonetheless, Margie works hard in class and might be considered a model student.

During the previous school year, I taught several science units to Margie's 4th grade class and used some of the same language and activities in trying to get students to come develop aesthetic understandings. Even as a 4th grader Margie gravitated toward seeing or "re-seeing," as a way of enacting her science learning. In the pre-instruction interview at the beginning of the school year ($time_1$) Margie made this comment, "Reseeing made me see things differently than I had before. I unsaw the moon and the water cycle too. Unseeing made me think differently about stuff and I like that." Although one might be tempted to conclude that because of this predisposition toward aesthetic perception Margie should not represent the treatment class as an "average" student. Referring to the table showing treatment student responses to interview questions we see that these concerns do not bear out as 8 other students scored higher than Margie on average per-item scores. Additionally, I will contrast Margie with Jill, a student in the control class who I also taught as a 4th grader and who also spoke of unseeing as powerful at the beginning of the school year.

As we began our unit on weather Margie was quickly taken by the powerful metaphor of "atmosphere as ocean of air" that focused initial instruction. She was one of the students who reported thinking about the ocean of air as she played outside over the weekend and described wondering about 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, however, Margie had begun to describe full-blown instances of changed perception. After having learned that one way to think about weather is that it is simply 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 we learned about erosion, Margie continued to report experiences in which her perception of the world had changed. “When I look around I see erosion now, before I didn’t, but now I do. My friend had a rat and it would go behind this little shelf thing and it would go potty behind there. After a couple years of that it made a little dip in the floor which is kind of like erosion from rat potty!” Part of coming to powerful science learning through aesthetic understanding is an increase in the frequency of connections one makes between science ideas and personal, real-world experiences. Students like Margie who report increased frequencies of thinking about and seeing examples of science ideas is important. Additionally, students with high levels of changed perception may also report feeling deeply engaged by their newfound perspective on the world. For example, one afternoon during students' snack time I noticed Margie 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 making erosion!" Although Margie did not report viewing erosion as a war between forces trying to destroy the world and objects resisting destruction as I framed it at the beginning of the unit, she clearly found the idea compelling. Margie offered 6 examples in her post-erosion interview of situations in which she thought about erosion or saw evidence of it.

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 we watched 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." 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 really 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. 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 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."

I believe Margie represents a compelling case in which a student came to see the world differently through the eyes of particular metaphors used to describe scientific ideas. 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 obviously 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."

Jill: Control classroom, emphasis on language of science

Jill and Margie are similar in many ways. Both are good students with high levels of interest and ability in school, both list science as their sixth favorite subject with music, PE, reading, math, and art listed ahead of science, and both learned science from me in the 4th grade. As with Margie, Jill reported re-seeing as a powerful activity learned in the 4th grade "Last year I learned about the moon and how it moves around the earth and that really changed the way I thought about the moon. I learned how to re-see it." Unfortunately, these are the only comments Jill makes about perceiving the world differently through science throughout the course of this research. 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 very differently, Jill related stories in which she used her science knowledge to verify or confirm her own emerging 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."

Jill's method of learning science by seeking looking for confirmation in the world, checking her understanding, and checking to see if she "right" continue into the next two units. I asked Jill after she learned about erosion if erosion made her think differently about anything or see anything differently than she had before. She had this to say, "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 gives assignments that emphasize 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. One could argue that this is the trademark of successful students.

By the end of the third unit I was not surprised a bit 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. 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. Even after having reported on the power of re-seeing at the beginning of the school year, Jill did not report a single incident that could be interpreted as re-seeing in 5th grade science. By the end of the semester, after studying the same three science units, although with different goals in mind, Jill again rated science as her 6th favorite subject while Margie ranked science as her 4th favorite – having moved up ahead of reading and art. Jill appears not to have found the control class science instruction particularly stimulating or interesting. When asked if learning about science had made the world seem a more interesting and more exciting place to be, Jill responded, "Horses and rainbows make the world seem more exciting, not science." This is a profound statement for such a young student and I believe 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).

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

Tyler is not a student that I had in class as a 4^{th} grader. If the reader harbored concerns over the effect of my instruction on Margie as a 4^{th} grader Tyler should alleviate them. 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 an example 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 less than overflowing with intensity, enthusiasm, and vigor. Across the course of this research Tyler began to report more engaging science learning.

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 this first day of learning for aesthetic understanding Tyler demonstrated a knack for getting the most from metaphoric descriptions. Later during the weather unit, as we framed violent weather 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 metaphor 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 our study of erosion. Tyler reported 6 instances in which he thought about, noticed, or sought out evidence of erosion in his life outside of 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 me claiming "Mr. Girod tells us about erosion. He says 'EROSION BABY!'" excitedly gesturing as I had apparently done in class. It seems reasonable that Tyler derived a sense of motivation and engagement through my dramatic teaching style but I would like to offer a different 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 mater-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 idea is not without parallels to erosion. Fungus breaks down tree bark just as rain wears down rocks and fungus will, if left unchecked, potentially kill the tree just as rain, if left to do its work, will eventually completely wear away a rock. 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 Tyler 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 sort of. 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. I didn't tell anybody about what I was thinking about. I thought it was cool that I knew and they didn't."

Tyler's experiences all seem important and powerful for him as a science learner. Perhaps, though, the most compelling piece of evidence that suggests learning for aesthetic understanding helped Tyler to learn in ways different and more powerful than he had before comes from a story he told after learning about the weather. "I also have some weather machines at home that I bought when we studied weather. I built a little cubby to put my computer in so it doesn't get when I go outside. I check the weather and use my weather instruments. Our weather unit kind of changed my life like that. I tell my mom and dad what the weather is going to be like – I'm like the weather person in my family." Unfortunately the interviewer did not ask Tyler to expand on his claim that learning about weather changed his life. Regardless of his response to such a probe, such a claim is high praise for any learning. Knowing Tyler, I suspect he found an area of knowledge in weather in which he could demonstrate his expertise for his family. It seems likely that this made him feel good as both a person and learner. During each post-instruction interview ($time_2$, $time_3$, and $time_4$) Tyler gave the same response when asked why he felt compelled to tell his family what he was learning, "I like to tell them because they don't know. It makes me feel smart. It makes me feel good." Arguably, science may not be the school subject matter most likely to engender efficacious feelings and positive identity perceptions but, at least with Tyler, this seems to be the case and the result is quite significant. Chapter 5 examines these questions of efficacy and identity statistically. Tyler is now contrasted with Joe who seems to derive his enthusiasm from more instrumental values.

Joe: Control class, emphasis on instrumental value

Joe was also a student of mine as a 4th grader. Perhaps because of this he reports initial levels ($time_1$) of changed perception, action, and excitement regarding science learning at a higher level than the class average. In fact, before instruction began in the fall I asked Joe why a kid 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 I asked three other students the same question. All three children responded with instrumental explanations – "so he can do good in high school," "so he 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.

Because my conversation with Joe reported in the preceding paragraph occurred before any science instruction had taken place, it seems possible that Joe was still operating under the assumption that what was valued in science were things like expanded perception and being swept up with interest and enthusiasm – qualities valued in the previous year when I was his teacher. After the first unit in which Ms. Parker taught it must have become apparent to Joe that the values had changed. 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 we see 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 naming – what's important about this difference is not which activity is better but that they are simply very 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 water vapor" 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" 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 ($time_4$) he didn't mention a single instance in which he felt his learning to be powerful, generative, or even particularly interesting. I 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. I do get excited about other stuff like math. I see numbers all over and I'm always counting things in the car when we're driving along. Science doesn't do that for me." It seems as though although Joe arrived with examples of powerful science learning from his past he failed to report anything particularly powerful during the first half of the 5th grade. Additionally, it is not as though Joe is simply not inclined to be moved by science learning as his comments before instruction indicate otherwise. Also Joe admits that mathematics learning has a powerful effect on him but science, at least as a 5th grader, taught for a goal other than aesthetic understanding, does not.

In my opinion the most interesting difference between Tyler and Joe is the reasons they offer for why science is or is not powerful for them. As discussed earlier, Tyler's reasons are largely egocentric – science makes him feel smart, like a scientist. Joe's reasons are largely instrumental in that science gives him words to describe the world and his experiences in it. Again, the difference can be chalked up to a difference in the held values of the classroom and its pedagogy. Chapter 5 investigates if these differences matter statistically.

Elaborated analysis of all student responses

In an effort to further demonstrate the differences between student interview responses between the two classes I've prepared the following tables which offer the students own words in evidence of these differences. I've provided 6 responses in each category, roughly corresponding to 2 responses regarding subject matter from each of the 3 units that were taught. Again, the examples were chosen to provide a flavor for the qualitative differences between responses while the statistical analyses address quantitative differences. Following the table I highlight some trends in the difference of student responses offering a more detailed analysis of the breadth of student responses.

Table 5.3: Additional examples of student responses to interview questions

Did learning about X help you to see the world differently in any way?	
Control class	**Treatment class**
• Yeah, I didn't know that transpiration comes from trees. • I think a little differently about clouds now because I never knew what they were and now I see them a lot differently and now they are more interesting. • When it rains I think about how the earth might change. • I know that the sand in my sandbox has got to be more than just sand (the size). Its got to be like clay and silt too because nobody would just filter out all the sand. • I think its neat to think about evaporation. If you leave a cup of water out after a couple of days the water might be gone. • I didn't know things could switch from one state of matter to another.	• I learned about air pressure and winds and every time I walk by the flagpole I look at the flag and I think about the pressure that's making the wind blow. • 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. • I was drying my hair with the hairdryer this morning and I thought about how its kind of like erosion and that the land could be eroded by like a bunch of hairdryers and their wind. • I really think differently about stuff now. Like this chair, it freaks me out to think that it's mostly made of nothing and that even though its mostly nothing I can still sit on it and it holds me up. • 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!

Table 5.3 (cont'd)

Did learning about X make the world seem more interesting and more exciting? Why?	
Control class	**Treatment class**
• I used to not really care about clouds and wind strength and the more I learned about it the more interesting it got. • It was kind of exciting to learn about the weather because the next day I knew all the names of the clouds. • Every time I throw a rock and it breaks I think about erosion. • I just thought all little rocks were called pebbles but now I know there's lots of other names. • It's pretty interesting to think about molecules. Most people probably don't really know about molecules so that's pretty interesting. • It's neat to think about molecules because they're small.	• Now when I look up in the sky I have a bunch of questions that I didn't have before. I used to never even think about the weather but now I wonder about lots of things. • I was thinking about 17 miles of air pressing down on us and I wondered why we don't feel that or why it doesn't push us down or make our knees bend. • Usually our science is boring and we just do the science projects but we don't learn about what the world is doing differently like we do this year. It makes it more exciting. • Thinking about the nothing in matter makes it more exciting. That's an exciting way to think about stuff. • We figured out that if we heated up dry ice air hotter and hotter it would eventually turn into the fourth state of matter – plasma! I wonder if absolute zero is the fifth state of matter? • Knowing about the molecules is exciting for me because sometimes I'll just be sitting there like eating dinner or something and that will pop into my head and I'll start thinking about the molecules inside my food.

Table 5.3 (cont'd)

Did learning about X 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...	
Control class	**Treatment class**
• I told my grandma because she asked what I was doing in school and so I told her about the clouds because I didn't want to be rude. • I told my mom and she didn't know the names of the clouds. I told my sister too. I told them because Ms. Parker says if you tell other people about what you learn then you remember it better and I wanted to remember all the names. • I told my sister when she waters her plants it causes erosion. • I tried to tell my sister about erosion and she told me some stuff about sand causing erosion and she was going to bring me a bunch of information about erosion but she didn't. I wanted her to tell me so if we have a test I can do good. • My mom didn't know about evaporation. She didn't know it had to do with the molecules. • I think about molecules sometimes. Yesterday I thought about the molecules.	• Now I watch the weather in the morning with my dad. I didn't before. • I went home and checked 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. • At recess all us girls we normally sing and dance around the school but yesterday we went around the school looking for erosion. • There's this big crack in my driveway and I thought I'd see if this snow causes some erosion so I put down some paper and I traced the crack onto the paper and I'll go back in a month or so to see if the crack has changed. • I'm definitely going to take science in middle school because I like science now. • I taught my little brother how to do re-seeing but he didn't really get it. I tried to show him how to do re-seeing on the molecules.

Upon reading these responses one begins to detect some differences in response between the two classes. For example, as foreshadowed by Margie and Jill, students in the two classes describe their experiences seeing the world anew very differently. Control students seem to see the world in terms of science terminology and in instrumental ways – ways that provide answers to their questions. The treatment students, on the other hand, offer very different examples in which they simply relish in new and unique ways of perceiving the world. Further analysis is necessary. What follows are three tables that further divide student responses to each interview question into similar responses. At the end of each table is the raw number of examples from which I could have drawn as well as statistical data in analysis of these quantitative differences. Unless absolutely necessary, I've tried to offer different student responses in these tables than those either provided in the case studies or in the chart above. Some discussion follows each table.

Table 5.4: Student responses to question of changed perception

<table>
<tr><td colspan="2">Did learning about X help you to see the world differently in any way?</td></tr>
<tr><th>Control class</th><th>Treatment class</th></tr>
<tr><td>Linguistically oriented responses

• I learned that transpiration comes from trees.
• I learned the three different types of precipitation.
• I learned all the different names of the clouds like stratus, and nimbus, and cirrus.
• I thought a lot about clouds and I know which clouds have rain and which ones don't.

18 total examples</td><td>Linguistically oriented responses

• We learned about Maritime weather.
• I learned that patina is green rust and erosion.
• I learned that sublimation is from a solid to a gas.

10 total examples</td></tr>
<tr><td>Conceptually oriented responses

• I've been thinking about what would happen if the earth stopped spinning and how there would be only day on one side and only night on the other.
• The rain hits the mountains and a little bit of the mountain is worn away.
• When I was in Texas I saw a rock wall on the side of the road and the last time I went it looked different. Erosion explains that.

3 total examples</td><td>Conceptually oriented responses

• I learned why its dark in the morning when I get up and I think about how the earth needs to rotate.
• I learned that the most dangerous part of a hurricane is actually the water and how the water can do all the damage.
• I learned that the state of matter depends on the energy in the molecules.

28 total examples</td></tr>
</table>

Table 5.4 (cont'd)

Experientially oriented responses • 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. **2 total examples**	**Experientially oriented responses** • 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! **61 total examples**
23 total examples **mean total examples per student = 1.38** **class standard deviation = 1.33**	**99 total examples** **mean total examples per student = 5.77** **class standard deviation = 2.24** **F-statistic = 36.85** **p-value <.0001**

Recall that the overarching student question is if learning helped them (the student) to see the world differently. While I agree that 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, I simply coded the responses provided by the students. A total of 28 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. The 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%). As the instructor of the treatment class I'm not surprised by this. The treatment class pedagogy focused on the act of seeing the world differently while the control class, as the vignettes showed, focused primarily on the 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*100 = 13%). T-tests revealed no statistically significant differences for the effect of gender, ethnicity, or achievement.

Table 5.5: Student responses to question of increased interest and excitement

Did learning about X make the world seem more interesting and more exciting? Why?	
Control class	**Treatment class**
It makes me feel smart – egocentric. • Learning all the different names of clouds made me feel smart. • It felt good to tell my mom about the molecules because she didn't know. • I never knew about the different things that caused erosion. **6 total examples**	**It makes me feel smart – egocentric.** • It makes me feel smart because my family didn't know about erosion and now I do. • It made me feel good to tell my mom about the molecules and the dance. She had never heard about the dance. • I feel like the a weather genius now! **22 total examples**
It's a neat way to look at things – perceptually enticing. • Thinking about how the energy is related to the state of matter is interesting. I like to think about how hot stuff has faster molecules. **1 total example**	**It's a neat way to look at things – perceptually enticing.** • I don't know why exactly but thinking 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. **37 total examples**

Table 5.5 (cont'd)

It helps me understand lots of other things – explanatory power. • 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. **1 total example**	**It helps me understand lots of other things – explanatory power.** • 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! **9 total examples**
8 total examples **mean examples per student = .23** **class standard deviation = .57**	**68 total examples** **mean examples per student = 3.62** **class standard deviation = .65** **F-statistic = 190.43** **p-value <.0001**

Similar to the analysis for question one above, regarding changed perception, question two regarding reasons for increased interest and excitement in science reveal a similar trend. The difference between treatment and control students' responses is smallest when comparing responses that are conceptually oriented. In both classes 13% of student responses were conceptually oriented, claiming that because a particularly subject matter knowledge explains some aspect of the world it is exciting or interesting (treatment group - 9/68*100 = 13% : control group –

1/8*100 = 13%). Perhaps 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 did not decrease treatment class students' notions about the power of conceptual knowledge below the level of the control class. Once again the power lies in the perceptual nature of the pedagogy. Student responses that correspond to perceptual interest and excitement vary greatly between classes – from 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%). T-tests reveal that minority students in the treatment class were more likely to reply with egocentric responses than majority students (p-value = .05) but achievement and gender did not matter.

Table 5.6: Student responses to question regarding changed action

Did learning about X 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...	
Control class	**Treatment class**
Thought about X/told others about X (but didn't mention either of the other levels of action) • 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. **23 total examples**	**Thought about X/told others about X (but didn't mention either of the other levels of action)** • 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 total examples**
Searched for examples of X • 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. **1 total example**	**Searched for examples of X** • 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 total examples**

Table 5.6 (cont'd)

Pursued further inquiry or experience regarding X	**Pursued further inquiry or experience regarding X**
• 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. **3 total examples**	• 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. **17 total examples**
27 total examples **mean examples per student = 1.00** **class standard deviation = 1.47**	**84 total examples** **mean examples per student = 4.54** **class standard deviation = 2.60** **F-statistic = 18.22** **p-value <.001**

The categorization above lends itself 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 possible level of commitment – i.e. a student who pursues further inquiry scores at the highest level of commitment, subsuming the previous two levels. Given this we see that 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 that only 3 students discussed seeking out further experiences with ideas learned in class (3/27*100 = 11%). 20% of treatment class student responses, corresponding to 17 examples, were indicative of this highest level of commitment to changed action. Again, statistical tests revealed no significant difference for the effect of gender, minority, or achievement.

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 is significantly 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 oriented. In other words, analysis of student responses to the three interview questions are not surprising given the nature of the treatment. However, large differences in the quantity of student responses was found suggesting that the methods of teaching for aesthetic understanding were effective – equally so for students of various gender, achievement, and ethnicity. It should be noted that in each case of analysis (analysis of responses to the three interview questions) 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.

Shifting norms, values, and summary

One of the most interesting results of this research is illustrated nicely 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? What does aesthetic understanding depend on? ANCOVA modeling, controlling for entry-level aesthetic understanding, with predictors of treatment, gender, ethnicity, prior student achievement, whether the student participated in between-unit interviews, and whether or not I was the students' 4^{th} grade science teacher, offers only the pretest of aesthetic understanding and the treatment as statistically significant predictors of post aesthetic understanding (A.total-aesthetic-understanding: $F = 10.335$: $p = .013$ – treatment: $F = 80.613$: $p = .001$). This is a fairly surprising result that none of the predictors predict post aesthetic understanding. In most classrooms in which conceptual understanding is the valued outcome, prior student achievement would likely predict newly learned conceptual understanding. However, changing the goals to teaching for aesthetic understanding eliminates prior student achievement as a predictor. 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. When we return to the table showing treatment student responses to interview subsections we see evidence of this. Josh and Shaneka, two students of very high prior achievement score near the bottom of the class in terms of aesthetic understanding while Pat and Jesse, also two students of very high prior achievement score near the top of the class in terms of aesthetic understanding. In the reverse case, Olajuwon and Liz, two students of very low prior achievement score near the top of the class in terms of aesthetic understanding while Shaquista and Marcus, also two students of very low prior achievement score near the bottom of the class in terms of aesthetic understanding. Statistically, the correlation between prior student achievement and aesthetic understanding is very low (r=.09 p=NS). However, prior student achievement is very highly related to treatment students post-tests of conceptual understanding (weather*achievement r=.66 p=.001 : erosion*achievement r=.67 p=.001 : matter*achievement r=.64 p=.001) meaning that although prior achievement predicts success on tests of conceptual understanding it is not useful in estimating 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.

If neither prior student achievement nor any of the other predictors mentioned earlier effectively predict aesthetic understanding what student qualities might? This is a question around which I had originally done some theorizing but strategically chose not to pursue these questions in a simple effort to streamline this research. I will speculate on possible predictors and systematically investigate them in future research. As I see it, such a project would require scale development activities too time consuming to engage in at this point, as an addendum to this dissertation research.

I believe three student qualities might predict aesthetic understanding. 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 what's in front of the student in terms of ideas and the world to what's possible in new ways of thinking, seeing, and acting. Highly creative and imaginative students might be more likely 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 it's use, that student will close himself 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 all more effective learners or learning environments. Again, these are topics which I will systematically investigate in future research.

We now turn to analysis of additional effects of teaching for understanding on student feelings toward science and conceptual understanding in chapter 6.

Chapter 6: Analysis of the effect of teaching for aesthetic understanding

Introduction

This chapter offers an analysis of the effect of teaching for aesthetic understanding on students' feelings toward science as well as their conceptual understanding. The chapter will proceed as follows: First, I offer an analysis of the performance of the Feelings Toward Science measure. Second, is an examination of the effect of the treatment on the four factors measured by the Feelings Toward Science measure. Third, is an analysis of student conceptual understanding as affected, or not, by the treatment.

Performance of the Feelings Toward Science measure

Because of the small sample size (n=53) I was unable to perform a confirmatory factor analysis on the Feelings Toward Science measure. As described in chapter 3, each of the four factors (science affect, science interest, science efficacy, and science identity) were taken from other sources and had been established as fairly reliable. Table 1 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 on all four factors for both classes.

Table 6.1: Means and standard deviations of Feelings Toward Science factors by condition and time of administration

Attitude scale		Treatment class			Control class			Total sample		
		Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
Affect	Mean	27.07	36.04	8.96	27.23	29.81	2.58	27.15	32.98	5.83
	SD	9.20	2.92	-6.28	8.26	7.18	-1.07	8.67	6.24	-2.43
Interest	Mean	19.52	27.33	7.81	20.31	22.15	1.85	19.91	24.79	4.89
	SD	6.93	2.53	-4.40	6.52	4.45	-2.06	6.68	4.42	-2.26
Efficacy	Mean	24.89	30.11	5.22	24.08	27.15	3.08	24.49	28.66	4.17
	SD	6.46	2.90	-3.56	7.69	5.50	-2.19	7.03	4.58	-2.45
Identity	Mean	10.93	14.52	3.59	10.73	13.04	2.31	10.83	13.79	2.96
	SD	3.98	3.52	-0.46	4.44	3.41	-1.03	4.17	3.52	-0.66

Table 6.2 shows the reliabilities of each of the four factors for the total population as well as for both treatment and control classes. For the total population, reliabilities on the pre-test range from a low of .80 on the identity factor to a high of .93 on both the affect and interest factors. Reliabilities on the post-test for the total population drop across all four factors. At first this might sound like a problem but when we check the reliabilities for each factor between treatment and control classes we begin to see the reason why this might occur. The standard deviations are decreasing a great deal more for the treatment group than the control group on affect, interest, and efficacy. This is probably because the treatment group's mean posttest scores are approaching the maximum possible scores on each of these factors. They are each

converging near the upper limit of their respective scale. However, that this did not happen for the identity scale is also explainable. The standard deviation did not decrease for the treatment group, but then it didn't approach the maximum possible score either. Treatment students' scores increased more than control student scores, but not so much that there was no room for the highest scoring pretest students to move upward (as in the other scales). Also notice that standard deviations decreased on all four factors for both treatment and control groups. This is likely attributable to the general effect of group science instruction on feelings toward science, meaning that engaging as a group in a science course has a homogenizing effect on feelings toward science because those feelings may not have had a sound experiential basis before engagement in the course. That is, students that have similar experiences around science will tend to have more similar feelings toward science. Table 6.3 showing minimum and maximum possible scores also lends support to this "ceiling effect" hypothesis. Treatment class means are much closer to the maximum possible score on each factor than control class means.

Table 6.2: Reliabilities of Feelings Toward Science factors by condition and time of administration

Attitude scale	Total sample			Treatment class			Control class		
	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
Affect	0.93	0.88	-0.06	0.94	0.63	-0.31	0.93	0.88	-0.06
Interest	0.93	0.84	-0.09	0.94	0.65	-0.29	0.92	0.80	-0.12
Efficacy	0.89	0.76	-0.14	0.88	0.41	-0.47	0.92	0.83	-0.09
Identity	0.80	0.68	-0.13	0.77	0.74	-0.03	0.84	0.63	-0.22

Table 6.3: Minimum and maximum possible scores

	Feelings toward science scale			
Measure	Affect	Interest	Efficacy	Identify
Minimum	8	6	7	4
Maximum	40	30	35	20

Overall reliabilities for each of the four factors is high and although we see a fairly large decrease in reliability from pre to post test this is easily explained by a ceiling effect and we should not be suspicious of the measure.

The effect of teaching for aesthetic understanding on feelings toward science

Modeling of students' feelings toward science after learning for aesthetic understanding was done using analysis of covariates (ANCOVA) controlling for the effect of the pretest. Because I 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
- achieve The effect of teaching ranking of student achievement
- dmebefore The effect of having me as their 4^{th} grade science teacher

The following models describe the effect of teaching for aesthetic understanding on students' feelings toward science. As a rule of thumb, I will not interpret main effects that also appear in interactions. Interpretation of interactions is challenging and because they can sometimes account for significance of main effects, I will only interpret interactions and main effects that stand alone.

Modeling of affect factor

Student affect toward science was measured using an 8-item factor including the following items:

1. I feel a positive reaction to science.
2. I have a good feeling toward science.
3. I do not like science and it bothers me to have to study it.
4. I feel comfortable with science and I like it very much.
5. If I knew I would never have science again, I would feel sad.
6. Science makes me feel uncomfortable, restless, irritable, and impatient.
7. When I hear the word science, I have a feeling of dislike.
8. Learning about science is fun.

Items 3, 6, and 7 were reverse coded before analysis. Table 6.4 shows descriptive statistics for the affect factor including treatment and control class means as well as the significance of the overall affect model (F = 15.246, p-value = .001). Table 6.5 gives parameter estimates for main effects and interactions within the final B.affect model.

Table 6.4: Descriptive statistics for affect factor

	Pre		Post				
	Mean	**St.dev.**	**Mean**	**St.dev.**	**df**	**F-statistic**	**p-value**
Control class (n=27)	27.231	8.257	29.808	7.183			
Treatment class (n=26)	27.074	9.198	36.037	2.915	52	15.246	.001

Table 6.5: Final model parameter estimates for model of B.affect

Parameter	B	Std. error	t	p-value
Intercept	11.838	4.091	2.894	.006
dtreatment	17.133	4.388	3.905	.001
dfemale	13.755	4.363	3.152	.003
A.affect	0.611	0.138	4.419	.001
dtreatment*A.affect	-0.382	0.154	-2.475	.017
dfemale*A.affect	-0.44	0.153	-2.872	.006

An examination of table 6.5 showing parameter estimates for the B.affect ANCOVA model the parameters of dtreatment, dfemale, and the pretest (A.affect) are all significant. However, all three of these parameters are accounted for in the two interactions of dtreatment*A.affect and dfemale*A.affect which are both significant at (t = -2.475, p-value = .017) and (t = -2.872, p-value = .006). The first suggests the treatment has a greater effect for students who report initially lower levels of affect than students with initially higher levels of affect. This is a sensible conclusion because of the ceiling effect discussed earlier in the section on instrument reliability. Because students with higher levels of affect couldn't report much higher levels on the posttest (they hit the ceiling scale) it appears that the treatment is more effective for students of lower pretest score. More likely, this result is a function of the instrument and a ceiling effect than anything regarding the treatment. The second interaction, dfemale*A.affect, suggests that females who scored higher on the pretest actually scored lower on the posttest. At first this may seem odd but Figure 6.1 represents the interaction quite well. The vast majority of treatment class females who had low scores on the pretest made dramatic gains on the posttest. However, a small number of treatment class females did score very high on the pretest and their scores dropped a bit, on average, on the posttest. It might be said that perhaps these treatment class females who initially scored very high may have come to have more realistic levels of affect as shown by their decrease on the posttest. Again, this is likely an effect of the measure rather than the treatment. In general the effect of the treatment is still quite dramatic – for both males and females. Control class males and females also increased from pre to post but not nearly as dramatically as treatment class students.

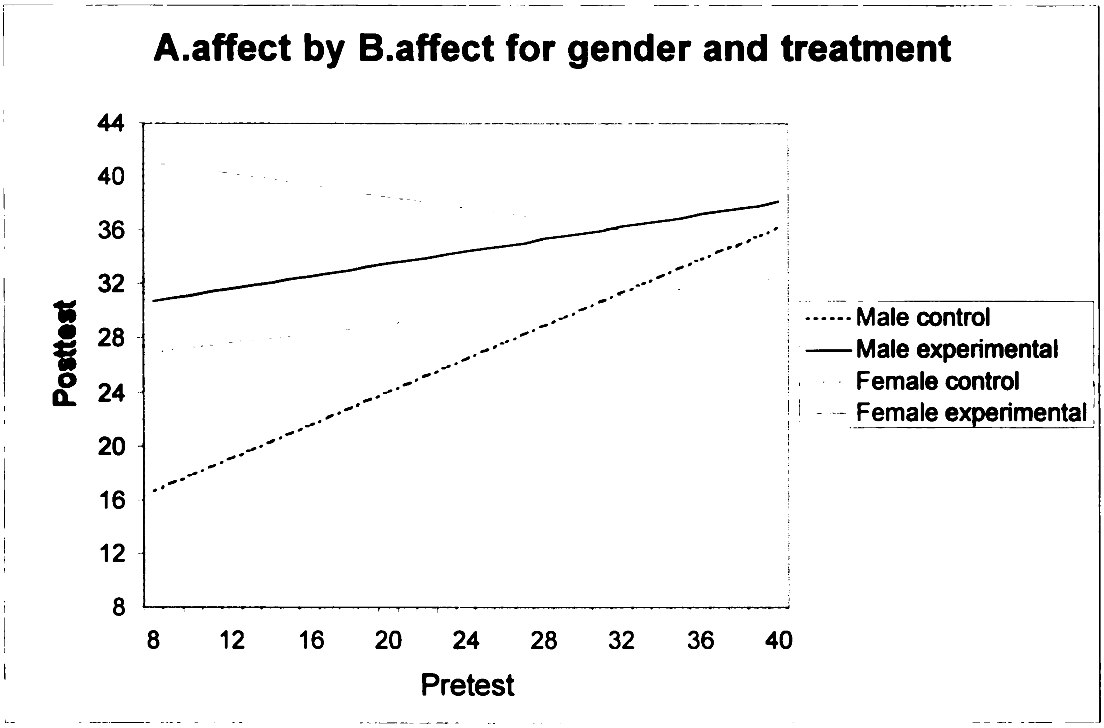

Figure 6.1: Treatment by pretest interaction for affect

Modeling of interest factor

Student interest was measured by a 6-item factor including these items:

1. Science is boring.
2. Science is fascinating.
3. I would like to learn more about science.
4. Science is interesting to me and I enjoy it.
5. During science class, I usually am interested.
6. Science is a topic which I enjoy studying.

Items 3, 6, and 7 were reverse coded before analysis. Table 6.6 shows descriptive statistics for the interest factor including treatment and control class means as well as the significance of the overall interest model (F = 18.496, p-value = .001). Table 6.7 gives parameter estimates for main effects and interactions within the final B.interest model.

Table 6.6: Descriptive statistics for interest factor

	Pre		Post				
	Mean	St.dev.	Mean	St.dev.	df	F-statistic	p-value
Control class (n=27)	20.308	6.516	22.154	4.451			
Treatment class (n=26)	19.519	6.93	27.333	2.527	52	18.496	.001

Table 6.7: Final model parameter estimates for model of B.interest

Parameter	B	Std. error	t	p-value
Intercept	19.742	1.482	13.320	.001
dtreatment	8.886	2.066	4.301	.001
achievement	1.120	.609	1.839	.072
dtreatment*achievement	-1.722	.849	-2.029	.048

An examination of table 6.7 showing parameter estimates for the B.interest ANCOVA model shows the main effect of treatment and achievement as significant. However the interaction dtreatment*achievement is also significant (t = -2.029, p-value = .048) and so we interpret it rather than the main effects alone. The interaction suggests that higher achieving treatment class students scored higher on the posttest of interest. This isn't surprising as it seems reasonable that higher achieving students would have higher levels of interest in science, however, why this is differentially apparent for the treatment class is unknown. This should not lead one to the conclusion that the treatment is only effective at increasing interest for students of higher achievement as achievement alone is not significant. The treatment is simply more effective (for a measure of interest in science) for students of higher achievement.

Modeling of efficacy factor

Efficacy beliefs regarding science learning were measured using a 7-item factor including the following items:

1. I expect to do well on science tests, quizzes, and assignments.
2. I think I am capable of learning science ideas.
3. I think I will earn a good grade in science.
4. I think I will know a great deal about science at the end of this year.
5. I do not believe that I will do very well on the science tasks in this class.
6. Mastering the science ideas taught this year has been hard for me.
7. I have had a hard time understanding the science ideas taught in this class.

Items 5, 6, and 7 were reverse coded before analysis. Table 6.8 shows descriptive statistics for the efficacy factor including treatment and control class means as well as the significance of the overall efficacy model (F = 10.357, p-value = .01). Table 6.9 gives parameter estimates for main effects and interactions within the final B.efficacy model.

Table 6.8: Descriptive statistics for efficacy factor

	Pre		Post				
	Mean	**St.dev.**	**Mean**	**St.dev.**	**df**	**F-statistic**	**p-value**
Control class (n=27)	24.08	7.694	27.154	5.504			
Treatment class (n=26)	24.89	6.459	30.111	2.9	52	10.357	.002

Table 6.9: 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 6.9 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 6.2 represents these result graphically including ethnicity, pretest, posttest, and treatment effects.

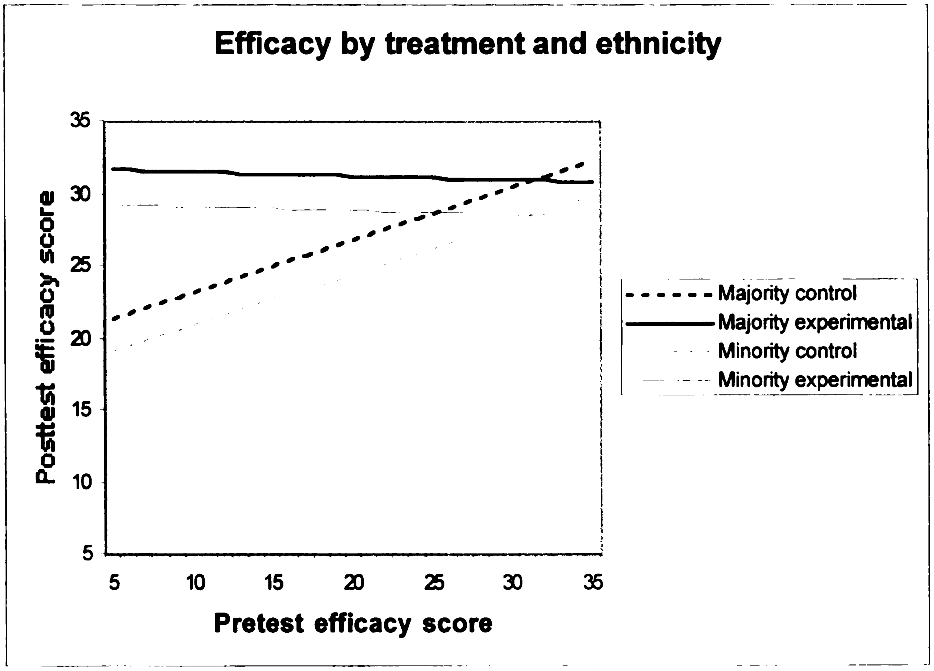

Figure 6.2: Efficacy by treatment and ethnicity

It is clear from Figure X 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. Again, we see that all students in the treatment class are essentially reaching the ceiling of the efficacy measure.

Modeling of identity factor

Identity beliefs regarding science learning were measured using a 4-item factor including the following items:

1. Science just isn't for me.

2. I am a science-type person.

3. Other people think of me as a science-type person.

4. When I hear the word science, I have a feeling of dislike.

Items 1 and 4 were reverse-coded before modeling began. Table 6.10 shows descriptive statistics for the identity factor including treatment and control class means as well as the significance of the overall identity model (F = 1.857, p-value = NS). Table 6.11 gives parameter estimates for main effects and interactions within the final B.efficacy model.

Table 6.10: Descriptive statistics for identity factor

	Pre		Post				
	Mean	**St.dev.**	**Mean**	**St.dev.**	**df**	**F-statistic**	**p-value**
Control class (n=27)	10.731	4.441	10.926	3.98			
Treatment class (n=26)	13.038	3.412	14.519	3.523	52	1.857	.179

Table 6.11: 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 6.11 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. Again, as with interest and identity, this should not lead one to conclude that the treatment is not effective for male students, just more effective in increasing efficacy for female students. Figure 6.3 shows a graphical representation of the estimated marginal means for B.identity.

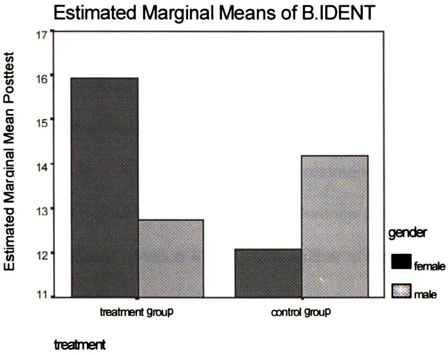

Figure 6.3: Estimated marginal means of B.identity

To assist in interpretation of Figure 6.3 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 6.12 gives us this information.

Table 6.12: 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

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 (p-value = .015). The difference between treatment group males and control group males, the next largest difference according to Figure 6.3, 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 rank factor

At the end of the Feelings Toward Science inventory 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 – 1 being most favorite class and 8 being least favorite class. Table 6.13 shows descriptive statistics for the science rank factor including treatment and control class means as well as the significance of the overall science rank model (F = 3.689, p-value = .061). Table 6.14 gives parameter estimates for main effect and interactions within the final B.science rank model. I 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, I analyzed this data with ANCOVA.

Table 6.13: Descriptive statistics for science rank

	Pre		Post				
	Mean	St.dev.	Mean	St.dev.	df	F-statistic	p-value
Control class (n=27)	4.731	1.991	5.185	2.039			
Treatment class (n=26)	4.269	1.93	3.37	1.41	52	3.689	.061

Table 6.14: 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
achievement	.293	.269	1.089	.282
dtreatment*dfemale	-1.732	0.839	-2.063	.045
dminority*achievement	-0.901	0.402	-2.243	.030

An examination of table 6.14 showing parameter estimates for the B.science rank ANCOVA model we shows the main effects of treatment, gender, achievement, and ethnicity as significant. However, each of these are including in interactions so we only interpret these. The interaction of dminority*achievement is significant (t = 2.243, p-value = .03). This suggests that high achieving minority students ranked science as more favorable. This interaction suggests nothing about the treatment so I am only marginally interested in it. The interaction of dtreatment*dfemale is also 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 6.4 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 is more favorable.

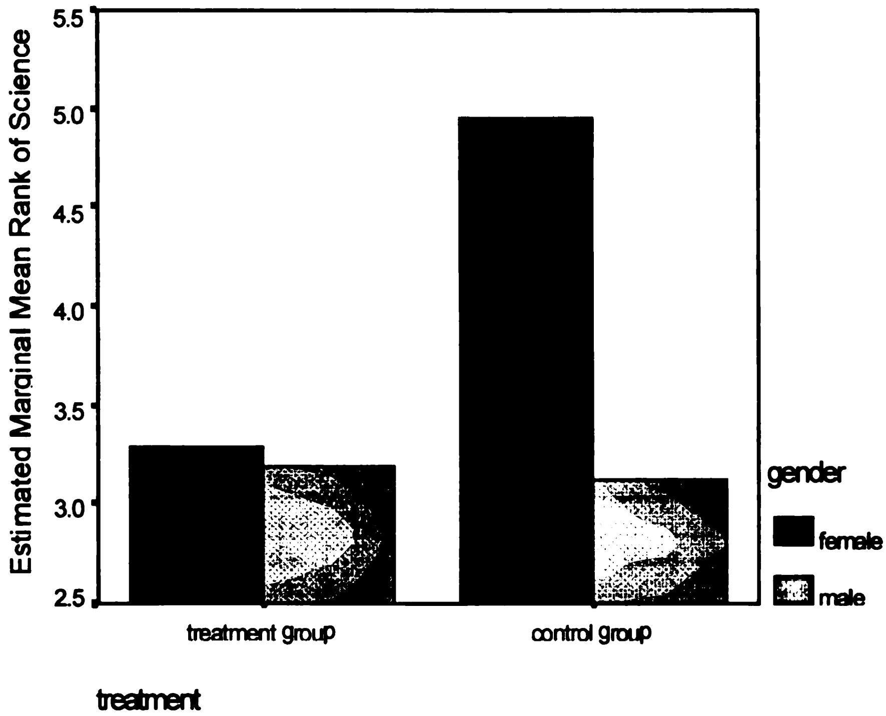

Figure 6.4: Estimated marginal means for B.science rank

The effect of the treatment on students' feelings toward science seems powerful. Although several interactions exist that prohibit us from drawing direct conclusions about the treatment, the group differences are always in favor of the treatment class. Additionally, the interactions we have, that suggest differential effectiveness for the treatment for various groups of students (low pretest students or female students in most cases) can most likely be attributed to a ceiling effect of the measure. For the most part, most treatment class students' scores approached the ceiling of the measure – and so students with more room to grow (low pretest scores and sometimes female students) grew more – yielding significant interaction terms. In fact we might simply refer to treatment biases toward female students as anomalous data. To explain this position Table 6.15 below shows growth on all factors by treatment and gender.

Table 6.15 Growth on all factors of feelings toward science by treatment and gender

Factor	Control students						Treatment students					
	Male students			Female students			Male students			Female students		
	pre	post	Δ	pre	post	Δ	pre	post	Δ	pre	post	Δ
Affect	29.1	29.8	0.67	25.6	29.9	4.22	26.3	34.8	8.58	27.7	37	9.27
Interest	22.1	23.1	1	18.8	21.4	2.57	18.3	26.6	8.25	20.5	27.9	7.46
Efficacy	26.3	27.7	1.42	22.2	26.7	4.5	24	29.3	5.25	25.6	30.8	5.2
Identity	12.4	14.2	1.75	9.29	12.1	2.78	10.4	12.8	2.33	11.3	15.9	4.6
Science rank	3.92	3.58	0.34	5.43	4.86	0.57	5.17	3.42	1.75	5.2	3.33	1.87

An examination of table 6.15 gives two interesting results. First, the growth in the control class is greater for female students across all factors. For example, average control class male student growth on affect is only .67 but it's 4.22 for female control class students. In fact, as table 6.15 shows above, the parameter estimate for dfemale is significant in the model for B.affect and appears again in the interaction dfemale*A.affect. This suggests that perhaps the effect of instruction in the control class is differentially effective for female students. However, it doesn't bear out as significant in the whole model of B.affect because the effect in the treatment class is much larger and not biased toward female students. The second interesting observation is that the growth in the treatment class does not seem to be generally in favor of female students. On two factors (interest and efficacy) growth actually favors male students. For some reason growth favored female students on identity and science rank to a statistically significant degree. It seems logical that science rank would be closely correlated with science interest and affect and yet these do not show significant female bias. However, identity seems to be a construct sufficiently different that an interaction between treatment and gender might be a legitimately important result. Overall, the treatment does not favor either gender with the exception of identity and science rank and it seems logical not to invest much in these biases. For now, I will hold these results loosely – leaving room for them to be anomalous effects in need of further investigation. In chapter 7, I submit to the temptation to offer one interpretation of the gender bias on identity as a factor of feminist epistemology.

We now turn to analyses of the effect of teaching for aesthetic understanding on student conceptual understanding.

The effect of teaching for aesthetic understanding on student conceptual understanding

Methods used to analyze data regarding student conceptual understanding

Three additional achievement outcomes (conceptual understanding of weather, erosion, and matter) were analyzed using a different method of analysis because each student completed a test of conceptual understanding three times—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. 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 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).

Hierarchical Linear Modeling

A typical method for addressing this problem is to include each student in the model as a fixed effect, thus accounting for the source of dependence among errors. If the aim of the analysis is to control for the individual effects of each student, but not to estimate their effects, this is a wasteful approach. It is wasteful because one degree of freedom must be expended to estimate the unique effect of each student, reducing the degrees of freedom available to test the effects of interest, such as the treatment effect (Bryk & Raudenbush, 1992).

To counter this problem, when many students are sampled from a larger population, the student to which each observation belongs may be included as a random effect in a random effects ANCOVA. This approach expends only one degree of freedom to estimate the variance of student effects rather than estimating each student's effect separately, reserving additional degrees of freedom to test the effects of interest. This approach is suited to equal numbers of observations within each student. Because in this analysis, individual student effects need to be controlled for, but are of no interest; and because the data being analyzed contains three observations of each outcome for each student, a random effects ANCOVA may appear to be an adequate methodology for analysis.

However, there is one advantage that HLM provides over a random effects ANVOCA: HLM adjusts the degrees of freedom used to student-level effects (e.g. the treatment effect), thus providing more accurate, uninflated tests of their significance (Bryk & Raudenbush, 1992). For example, in this study, there are 53 students, with three administrations of each outcome measure. Thus, there are 159 data points for each outcome. Using a random effects ANCOVA analysis, the treatment effect would be tested using the degrees of freedom derived from the full sample of 159 data points, but HLM would test the treatment effect using the degrees of freedom derived from the reduced sample of 53 students. Since the treatment was assigned at the student level, deriving the degrees of freedom for the test of the treatment effect from the number of students is a more accurate, uninflated test of its statistical significance.

All HLM models in this analysis were estimated using the HLM for Windows (version 5.0) computer program by Raudenbush, Bryk, and Congdon (2000).

Time-level predictors of change

It was assumed that instruction over time would have a positive effect on scores of conceptual understanding of weather, erosion, and matter. It was further assumed that as a result of the passage of time after the instructional unit was completed, there would be some loss of conceptual understanding. That is, the pretest scores were expected to be low, the posttest scores immediately following instruction were expected to be high, and the extended posttest scores were expected to be lower than the posttest scores immediately following instruction. This expected increase and subsequent decrease cannot be adequately modeled using a linear model of the effect of time, but it can be modeled using a quadratic model of the effect of time. For this reason, the two predictors of each individual outcome at the three timepoints were:

Days: Number of days elapsed since the pretest

$Days^2$: Square of the number of days elapsed since the pretest

It should be noted that a small number (16) students took the pretest, posttest, and/or extended posttest at a different time than the majority of students due to absence from school. This variability in time of administration actually assists in achieving a more accurate model of the effect of time, but its effect is limited because the variability of administration times itself is limited. The table below shows the timing for the administration of the various tests of conceptual understanding for the vast majority of students.

Table 6.16: Conceptual understanding testing timing schedule

Elapsed days for each test									
	Weather unit			Erosion unit			Matter unit		
	$test_1$	$test_2$	$test_3$	$test_1$	$test_2$	$test_3$	$test_1$	$test_2$	$test_3$
control class	0	28	62	0	14	43	0	14	48
treatment class	0	30	63	0	19	46	0	16	52

test1 = unit pretest
test2 = unit posttest
test3 = unit extended posttest

Student-level predictors of change

The classroom-level predictors investigated were the following:

- 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
- achieve — The effect of teaching ranking of student achievement
- dmebefore — The effect of having me as their 4^{th} grade science teacher

Because we're modeling conceptual understanding in an effort to investigate differences between the two treatment groups, treatment and achievement must be included in the model. It makes sense that higher achieving students would experience higher degrees of conceptual understanding. Including achievement in the model attempts to control for that fact. In an effort to investigate differential effectiveness of the treatment between males and females and between minority and majority students, we include these predictors as well. Table 6.17 shows descriptive statistics for the predictors for the HLM model. As you can see the differences between the two classes are very small.

Table 6.17: HLM predictors

Predictor	Treatment class	Control class
dtreatment	n=27	n=26
dfemale	15 girls : 12 boys	14 girls : 12 boys
dminority	12 minority students	11 minority students
dmebefore	9 students had me as 4th graders	10 students had me as 4th graders

Modeling process

All time- and student-level predictors previously listed were considered theoretically important predictors, so all of these predictors were entered into the models at various steps. In addition, interactions of student-level variables with time-level variables were investigated, as well as interactions among student-level variables. When these predictors did not meet the statistical criteria for inclusion in the model, they were excluded to obtain a more parsimonious model.

Unconditional model

To begin the modeling process, an "unconditional model" was estimated. In this model, only the overall mean outcome score (the intercept), and the variance of student effects were estimated.

Time-level model

Using the estimate (obtained from the unconditional model) of the variation within classrooms as a baseline for comparison, a respondent-level regression model was estimated. Theoretically important respondent-level predictors were entered into the respondent-level model one at a time and then together. To determine whether these predictors should remain in the model, five criteria were considered.

First, the significance level of each time-level predictor's regression weight was considered. When statistical significance was observed, this provided evidence that the predictor should remain in the model by showing that differing levels of the predictor predicted statistically significant differences in the outcome.

Second, the unique percent increase in respondent-level variation explained by each respondent-level predictor was considered. By comparing models with new predictors to the most predictive model nested within the new model, an estimate of the unique explanatory contribution of each predictor could be obtained. The nested model used for comparison always contained all predictors from the new model except the new predictor. This provided a measure of the practical utility of including the predictor in the model as opposed to the statistical utility of including the predictor in the model (step four).

Third, the collinearity of each respondent-level predictor with all other predictors was examined. The standard errors of each predictor in each model were recorded, and compared across all models in which they occurred. When standard errors became inflated, this was taken as a sign of collinearity with one or more of the other predictors in the model. The last two criteria also apply to determining whether to allow the effect of time-level predictors to vary across students.

Fourth, the significance level of the variance of each time-level predictor's regression weight across students was considered. When statistical significance was observed, this also provided evidence that the predictor should stay in the model by showing that the predictor's regression weight varied in a statistically significant manner from student to student. In addition, observing statistical significance indicated that the effect of the time-level predictor in question should be allowed to vary across students.

Fifth, the significance level of the change in model fit attributable to adding each predictor to the time-level model was considered. When a statistically significant change in model fit was observed, it provided evidence that the added predictor should remain in the model, and that its effect should be allowed to vary across students.

Student-level models

After the respondent-level model was finalized, the final respondent-level model was used as a baseline for comparison to models including student-level effects. First, a student-level model of the time-level intercept (or base model) was developed. Next, student-level models of the time-level regression slopes were investigated.

Intercepts model

Using the estimated variation in time-level intercepts as a baseline comparison, the intercepts model was developed. Theoretically important student-level predictors were entered into the student-level intercepts model one at a time and then together. To determine whether these predictors should remain in the model, three criteria were considered: First, the significance level of each student-level predictor's regression weight was considered. This criterion is analogous to the first criterion for the time-level model. Second, the unique percent increase in student-level variation in the intercept explained by each student-level predictor was considered. This criterion is analogous to the second criterion for the time-level model. Third, the collinearity of each student-level predictor with all other predictors (at both the time and student levels) was examined. This criterion is analogous to the third criterion for the respondent-level model.

Slope models (or models of the time-level regression weights)

Using the estimated variation in time-level slopes as a comparison, the slope models were developed. Models of the respondent-level regression weights (or slope models) were developed in the same way as the intercepts model.

Assessing the assumptions of HLM

Four of the assumptions of HLM can be assessed directly. All other assumptions are logical exercises that must be addressed theoretically (e.g. that all important covariates and confounding variables have been measured and included in the model). The four assumptions that can be addressed empirically are described below. Note that all assumptions may be checked at each stage of model development, but as is standard procedure, only the final model was checked for violations of the assumptions.

Normality of time-level residuals. HLM assumes that the time-level residuals are normally distributed. However, this assumption is not typically checked in HLM, since it is typically robust to minor violations of this assumption.

Homogeneity of time-level residuals. HLM assumes that the time-level residuals (or difference between observed and predicted values) are homogeneous within each student. HLM reports a test of this assumption with each run of the models.

Normality of student-level residuals. HLM assumes that the residual variation in prediction of time-level intercepts and slopes is normally distributed. This is checked individually for each intercept and slope by inspecting histograms of student-level residuals. This was only done for time-level predictors that varied across students, since the variance of these effects were estimated only for these variables, and thus only these variables could provide residuals.

Homogeneity of student-level residuals. HLM assumes that the residual variation in prediction of time-level intercepts and slopes is homogeneous across all values of the classroom-level predictors. This is checked by inspecting scatterplots of time-level predicted values versus residuals for both the intercept and the slopes being predicted. This was also only done for time-level predictors that varied across students.

Results

Identical procedures to those described above were employed in analysis of each of the three instructional units. I will provide a complete description of the results of the model for the unit on matter but not the first two units on weather and erosion. The matter unit proves the most complex as it requires modeling a few additional effects not necessary in the models for weather and erosion. For those units I will provide statistics on overall percent variation explained by the various models, the effect sizes of the parameter estimates, and figures to display the results of conceptual understanding. As with the matter unit all assumptions were met and these analysis should be considered reliable.

Conceptual understanding of matter

The final time-level model included two time-level predictors: *Days*, and *Days*^{2}. The final student-level model of the time-level intercepts included three student-level predictors: *Achievement*, *Treatment*, and *Minority*. The final student-level model of the time-level slope of *Days* included three student-level predictors: *Treatment* and *Minority*. The slope of *Days*^{2} did not depend upon any student-level characteristics, so no student-level model of the *Days*^{2} slope was developed.

All other respondent and classroom-level predictors were not statistically significant, and no other interactions were statistically significant either at the respondent level, classroom level, or across levels.

The final model may be represented by equations (2) through (5):

$$Matter_{ij} = \beta_{0j} + \beta_1 Days_{ij} + \beta_2 Days_{ij}^2 + r_{ij} \quad (2)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} Achievement_j + \gamma_{02} Treatment_j + \gamma_{03} Minority_{ij} + (u_{0j}) \quad (3)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} Treatment_j + \gamma_{12} Minority_j + u_{1j} \quad (4)$$

$$\beta_{2j} = \gamma_{20} \quad (5)$$

Which can be represented as a combined model as in equation (6):

$$\begin{aligned} Matter_{ij} &= \gamma_{00} + \gamma_{10} Days_{ij} + \gamma_{20} Days_{ij}^2 + \gamma_{01} Achievement_j + \gamma_{02} Treatment_j \\ &+ \gamma_{03} Minority_j + \gamma_{11}(Days * Treatment)_j + \gamma_{12}(Days * Minority)_j + (u_{oj}) + u_{1j} + r_{ij} \end{aligned}$$

Where

$Matter_{ij}$	=	Person j's *conceptual understanding of matter* score at time i.
$Days_{ij}$	=	Number of days from the time student j completed the pretest until student j completed the test at time i.
$Days^2_{ij}$	=	The square of $Days_{ij}$.
$Achievement_j$	=	Teacher report of student j's achievement level.
$Treatment_j$	=	Whether student j is in the treatment group ($Treatment_j$ = 1) or in the control group ($Treatment_j$ = 0).
$Minority_j$	=	Whether student j is a minority student.
$\_{0j}$	=	The intercept of the *Matter* scores for student j.

$-_{00}$ = The average predicted *Matter* pretest score for the lowest achieving (achievement = 0) non-minority control students that did not have me as a teacher the prior semester. This is the overall intercept of $Matter_{ij}$.

$-_{10}$ = The linear rate at which students grow each day, controlling for all other predictors in the model. This is the main effect of *Days*.

$-_{20}$ = The quadratic rate at which students grow each day, controlling for all other predictors in the model. This is the main effect of $Days^2$.

$-_{01}$ = The effect on $Matter_{ij}$ of a one-unit increase in achievement at all timepoints, controlling for all other predictors in the model. This is the main effect of *Achievement*.

$-_{02}$ = The effect on $Matter_{ij}$ of being in the treatment group (this can be considered a pre-existing difference since it affects the pretest), controlling for all other predictors in the model. This is the main effect of being in the treatment group. However, this is not the effect of interest, since it can be considered pre-existing.

$-_{03}$ = The effect on $Matter_{ij}$ of being a minority student, controlling for all other predictors in the model. This is the main effect of being a minority student.

$-_{11}$ = The additional linear rate at which treatment students grow each day, controlling for all other predictors in the model. This is the interaction between treatment group and time, or the effect of the treatment on growth rate. **This is the effect of interest.**

$-_{12}$ = The additional linear rate at which minority students grow each day, controlling for all other predictors in the model. This is the interaction between time and minority status.

(u_{0j}) = The unique effect of student j on $Matter_{ij}$ that is not accounted for by other predictors in the model. This is the difference between the predicted intercept for student j and student j's observed intercept, or the student-level (intercept) residual. This is not actually a part of the final model, but is include here because it was included in intermediate models and is discussed later in this section.

u_{1j} = The unique contribution of student j to effect of *Days* on $Matter_{ij}$ that is not accounted for by other predictors in the model. This is the difference between the predicted *Days* slope for student j and student j's observed slope, or the student-level (slope) residual.

r_{ij} = The difference between the observed and predicted *Matter* score of student j at time i, or the time-level residual.

The variation of residual scores (or variance components of u_{0j}, u_{1j}, and r_{ij}) for different models created in the modeling process are shown in Table 6.18. A typical method for determining whether HLM analysis is warranted is to inspect the percent variation within and between students. The column for model 0 is typically inspected to look for a great deal of variation within students, but in this model it is shown to be zero percent. However, because it was expected that instruction in the subject matter would cause there to be large intra-individual differences over time, this is not a concern here. The column for model 1 should be the baseline model to determine the utility of HLM modeling. That column shows that approximately 39 percent of variation is between students, warranting the use of HLM as an analysis method. The decrease in percent variation between students from model 1 to model 4 shows that the subsequent models explained a great deal of variation within students.

Table 6.18 also shows that the percent variation between student intercepts was so small after creating the base model that student intercepts could no longer be considered random, and are thus listed as not applicable (n/a) in later models.

Table 6.18: Variance components of intermediate and final models of *Matter*.

Source of residual variation	Model 0: Unconditional model	Model 1: Final level-1 model	Model 2: Model 1 plus Intercepts model	Model 3: Final model **without** treatment effect on slopes	Model 4: Final model **with** treatment effect on slopes
Time (r_{ij})	16.45066	1.9547	2.17043	2.17348	2.00751
Student intercepts (u_{0j})	0.00559	1.2764	0.18043	n/a	n/a
Student Days slopes (u_{1j})	n/a	0.0058	0.00467	0.00440	0.00177
Percent within students (r_{ij})	100	60	92	100	100
Percent between student intercepts (u_{0j})	0	39	8	n/a	n/a
Percent between student Days slopes (u_{1j})	n/a	0	0	0	0

Table 6.19 translates the variance components in Table 6.18 into percent of variation explained by various models created in the modeling process. Table 6.19 shows that by accounting for time elapsed since the beginning of instruction (*Days* and *Days*^{2}), model 1 was able to account for 88 percent of the raw variation between students, and 80 percent of the total raw variation in scores. This shows that *Days* and *Days*^{2} are important predictors of student scores, and should unquestionably be included in the model.

Table 6.19 also shows that the intercepts model (model 2) explained 86 percent of the variation in student-level intercepts (from model 1), showing that the predictors included in the intercepts model

(*Achievement* and *Treatment*) together were important predictors of student-level intercepts—so much so that there was no longer any need to model variation in student-level intercepts.

In addition, the final model (model 4) explained 62 percent of the variation in student slopes. Removing only the effect of the treatment on growth rate (model 3), only six percent of the variation in students slopes was explained. Thus, the treatment accounts for 62 − 6 = 56 percent of the variation in growth rates observed in this data, showing that treatment group is the most important predictor of growth rates.

Table 6.19: Percent variation explained by intermediate and final models of *Matter*.

		Explanatory model			
		1	2	3	4
Baseline model	Type of variation explained	Final level-1 model	Model 1 plus Intercepts model	Final model **without** treatment effect on slopes	Final model **with** treatment effect on slopes
0 Unconditional	Within student variation	88%	*	*	*
	Total unconditional variation	80%	*	*	*
1 Final level-1	Variation between student intercepts	*	86%	*	*
	Variation between student slopes	*	19%	24%	62%
	Total model-1 variation	*	27%	33%	38%
2 Model 1 plus Intercepts model	Variation between student slopes	*	*	**6%**	**62%**
	Total model-2 variation	*	*	**8%**	**15%**

* Does not make sense to interpret

The resulting coefficients ($\_{00}$ through $\_{12}$) of the final model are shown in Table 6.20, with the effect of interest displayed in bold face. Table 6.20 shows that neither the main effect of *Minority* nor the main effect of having had me as a teacher the prior semester (*MeAgain*) was statistically significant. They are included in the model as main effects, however, because. their interactions with *Days* are statistically significant.

Before discussing the effect of interest, the linear and quadratic effects of time (*Days* and *Days*^{2}, respectively) must be explained. Table 6.19 shows that the linear effect of time is positive ($\_{10}$ = 0.6247, t = 23.51, df ≈ 50, p < 0.0005), but the quadratic effect of time is negative ($\_{20}$ = -0.0117, t = -25.36, df ≈ 151, p < 0.0005). This situation results in a strong increase in *Matter* scores over the course of instruction, and a decline in *Matter* scores.

Table 6.20: Coefficients of the final *Matter* model

	Coefficient					
Effect	Label	Value	Standard error	T-test	Approximate df	p-value
Intercept	$\_{00}$	-0.5146	0.43454	-1.18	151	0.237
Treatment	$\_{01}$	-0.8393	0.32021	-2.62	151	0.009
Minority	$\_{02}$	0.6019	0.38023	1.58	151	0.113
Achievement	$\_{03}$	0.9401	0.13761	6.83	151	0.000
Days	$\_{10}$	0.6427	0.02733	23.51	50	0.000
Days * Treatment	$\_{11}$	**0.1234**	**0.01412**	**8.74**	**50**	**0.000**
Days * Minority	$\_{12}$	-0.0442	0.01475	-3.00	50	0.005
Days^2	$\_{20}$	-0.0117	0.00046	-25.36	151	0.000

From Table 6.20 we can see that the effect of interest was statistically significant (t = 8.74, df ≈ 50, p < 0.0005). Because this effect is positive ($\_{11}$ = 0.1234), students in the treatment group grew at a faster rate than students in the control group, by 0.1234 points per day. What is encouraging about this result is that this holds both for the time during which students were being instructed about matter, and for the time between the end of instruction and the extended posttest. That is, the difference between experimental and control students' *Matter* scores continued to increase even after the termination of instruction. It should be noted that the treatment does not interact with any other effect in the model, meaning that the treatment was apparently equally effective for minority and majority students; students of differing achievement levels; and (since *Female* and *MeAgain* are not included in the model) for males and females, and for students who did and did not have me as their 4th grade science teacher.

Table 6.20 also shows that treatment students started the study with statistically significantly lower scores ($\_{01}$ = -0.8393, t = -2.62, df ≈ 151, $p < 0.009$), that students whose teachers reported them as being higher achievers scored higher in general regardless of whether they were in the treatment group ($\_{03}$ = 0.9401, t = 6.83, df ≈ 151, $p < 0.0005$), and that minority students tended to grow more slowly than majority students, regardless of whether they were in the treatment group ($\_{12}$ = -0.0442, t = -3.00, df ≈ 50, $p < 0.005$).

A graphical representation of the results of this model is given in Figure 6.5. In Figure 6.5, the treatment students are represented by a thick line and minority students are represented by a dashed line.

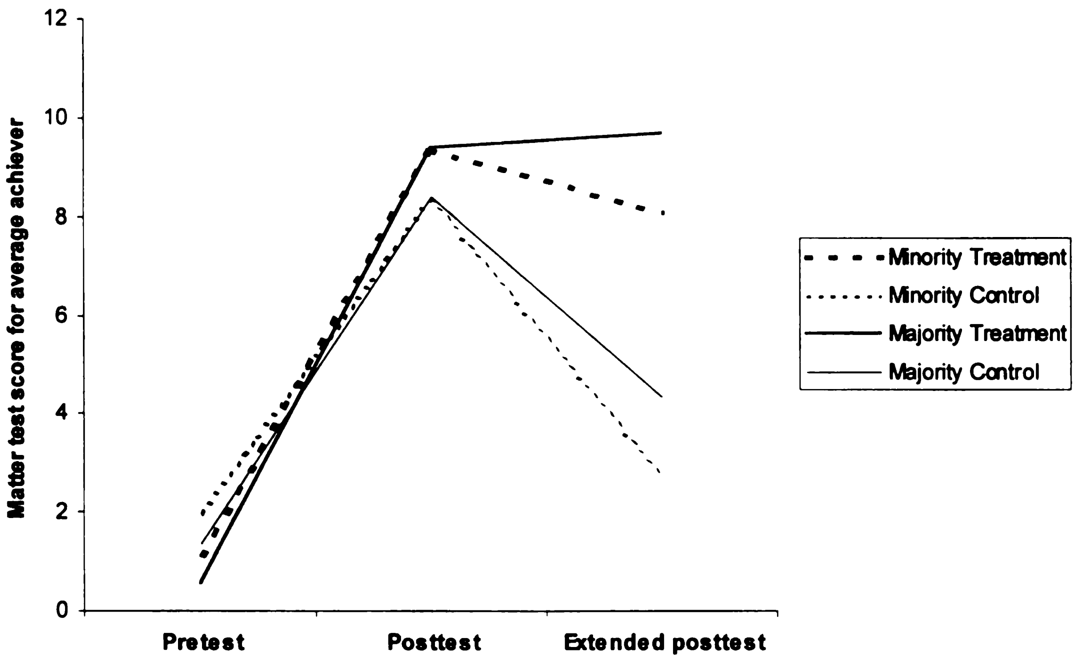

Figure 6.5. Predicted *Matter* scores for the average achiever (Achievement = 2)

Figure 6.5 shows predicted scores for average achieving students. For higher achieving students, all lines on the graph would be shifted the same amount upward, and for lower achieving students, they would all be shifted the same amount downward. Figure 6.5 shows that the treatment students gained more during instruction and lost less after instruction than did control students, and that minority students tended to gain less during instruction and lose more after instruction. It would be easy to interpret Figure 6.5 to mean that the treatment was most effective for majority students and less effective for minority students. As mentioned above, this was not the case: the treatment was equally effective for all types of students, regardless of minority status, having had me as a teacher previously, and for student of all reported achievement levels. The differences shown in Figure 6.5 occur because minority students grew at different rates than majority students, regardless of whether they were in the treatment group.

As described at the beginning of the results section, I will not provide the same level of detail in building HLM models and describing the thought processes involved as I did in analysis of the matter unit. I will provide tables of variance components, variance explained, parameter estimates, and a graphical representation of the data.

Conceptual understanding of weather

Table 6.21 shows variance components of the weather models, decreasing percent variation indicating better and better HLM models. The table indicates the wise and efficient use of HLM. In fact, the unconditional model explains an unusual 100% of within student variation, dropping only to 71% in the final model, indicating a highly reliable model.

Table 6.21: Variance components of intermediate and final models of *Weather*.

Source of residual variation	Model				
	0	1	2	3	4
	Unconditional model	Final level-1 model	Model 1 plus Intercepts model	Final model **without** treatment effect on slopes	Final model **with** treatment effect on slopes
Time (r_{ij})	29.57938	3.77482	3.77476	3.71602	3.48018
Student intercepts (u_{0i})	0.01315	5.67870	1.34282	1.35930	1.43456
Percent within students (r_{ij})	100	40	74	73	71
Percent between student intercepts (u_{0i})	0	60	26	27	29

Table 6.22 shows variation explained by intermediate and final models for weather. The final model (model 4) explained only 4% of the variation in student slopes. Removing the effect of the treatment on growth rate (model 3) drops variation explained to 1%. Therefore the treatment accounts for only 3% of the variation in growth rates observed (4%-1% = 3%). Although the treatment only explains 3% of the variation the model itself is highly reliable and the treatment effect is significant. A short discussion of this low explained variation follows explanation of the analysis of the erosion unit. Unlike models for the matter unit,

minority and achievement were not warranted main effects in models of weather.

Table 6.22: Percent variation explained by intermediate and final models of *Weather*.

Baseline model	Type of variation explained	Explanatory model			
		1	2	3	4
		Final level-1 model	Model 1 plus Intercepts model	Final model **without** treatment effect on slopes	Final model **with** treatment effect on slopes
0 Unconditional	Within student variation	87%	*	*	*
	Total unconditional variation	68%	*	*	*
1 Final level-1	Variation between student intercepts	*	76%	76%	75%
	Total model-1 variation	*	46%	46%	48%
2 Model 1 plus intercepts model	Total model-2 variation	*	*	**1%**	**4%**

* Does not make sense to interpret

Table 6.23 shows coefficients of the final weather model indicating that the effect of the treatment*days is statistically significant ($t = 2.97$, df ≈ 152, p-value = .003). Because the effect is positive ($_{11}$ = .03297), students in the treatment group grew at a faster rate than students in the control group by .03297 points per day. These results are true for students of both gender and all ethnicity as the treatment interacts with neither of these.

Table 6.23: Coefficients of the final *Weather* model.

	Coefficient					
Effect	Label	Value	Standard error	t-ratio	Approximate df	p-value
Intercept	$-_{00}$	6.10488	0.641862	9.51	50	0.000
Treatment	$-_{01}$	-0.04040	0.567428	-0.71	50	0.480
Achievement	$-_{02}$	1.54575	0.228222	6.77	50	0.000
Days	$-_{10}$	0.09959	0.010605	11.15	152	0.000
Days * Treatment	$-_{11}$	**0.03297**	**0.011092**	2.97	**152**	**0.003**
Days * Achievement	$-_{12}$	0.00869	0.004304	2.02	152	0.043
$Days^2$	$-_{20}$	-0.00661	0.000327	-20.20	152	0.000

Figure 6.6 shows a graphical representation of conceptual understanding for the weather unit across all three timepoints. As with the matter graph, the lines represent predicted scores for average achieving students. Again, treatment group students gained more and lost less than control group students and although the graph suggests the treatment is differentially effective for majority students, this interaction was not significant. In other words, the treatment was equally effective for students of both gender and all ethnicities. The difference

can be explained in that minority students experienced slower rates of growth than majority students – but no significantly so.

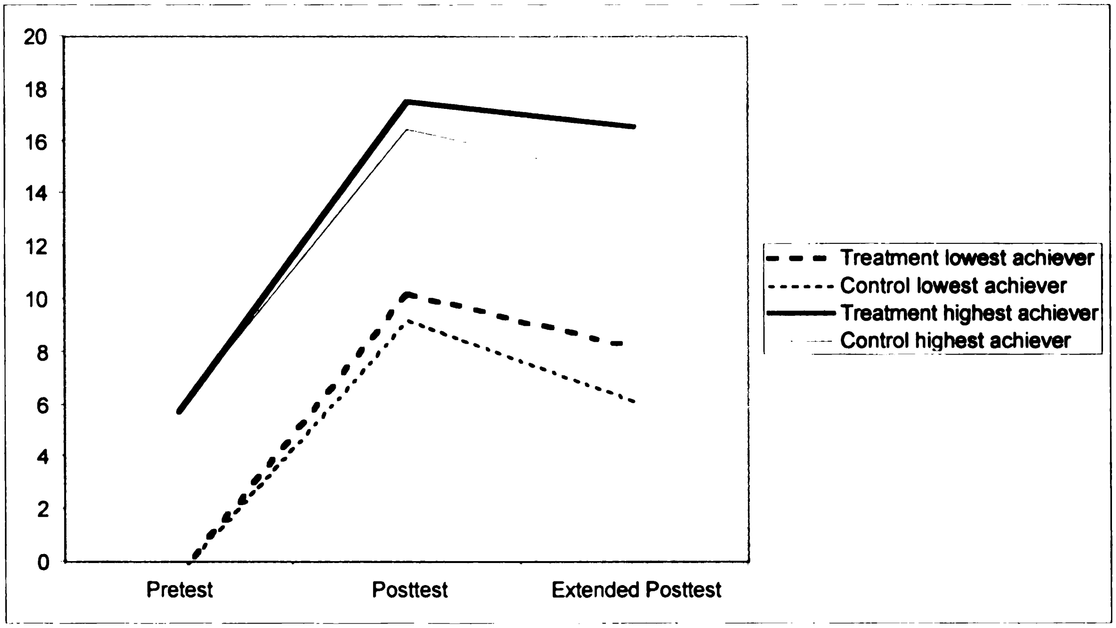

Figure 6.6: Predicted *Weather* scores for the average achiever (Achievement = 2).

Conceptual understanding of erosion

Table 6.24 shows variance components of the erosion models, decreasing percent variation indicating better and better HLM models. The table indicates the wise and efficient use of HLM. As with the model of weather, the final model for erosion explain 100% of the within student variation indicating a very reliable model.

Table 6.24: Variance components of intermediate and final models of *Erosion*

Source of residual variation	Model				
	0	1	2	3	4
	Unconditional model	Final level-1 model	Model 1 plus Intercepts model	Final model **without** treatment effect on slopes	Final model **with** treatment effect on slopes
Time (r_{ij})	18.31437	2.99776	2.99714	3.32202	3.10781
Student intercepts (u_{0j})	0.01001	1.10558	0.71383	n/a	
Student Days slopes (u_{1j})	n/a	0.00362	0.00364	0.00210	0.00128
Percent within students (r_{ij})	100	73	81	100	100
Percent between student intercepts (u_{0j})	0	27	19	n/a	n/a
Percent between student Days slopes (u_{1j})	n/a	0	0	0	0

Table 6.25 shows percent variation explained by the intermediate and final models for the erosion unit. The final model (model 4) explained 65% of the variation between student slopes. Removing the effect of the treatment on growth rate (model 3), 42% remains explained. This indicates that the final model explains a total of 23% of the variation in growth rates (65%-42% = 23%).

Table 6.25: Percent variation explained by intermediate and final models of *Erosion*.

Baseline model	Type of variation explained	Explanatory model			
		1	2	3	4
		Final level-1 model	Model 1 plus Intercepts model	Final model **without** treatment effect on slopes	Final model **with** treatment effect on slopes
0 Unconditional	Within student variation	84%	*	*	*
	Total unconditional variation	78%	*	*	*
1 Final level-1	Variation between student intercepts	*	35%	*	*
	Variation between student slopes	*	-1%	42%	65%
	Total model-1 variation	*	10%	19%	24%
2 Model 1 plus Intercepts model	Variation between student slopes	*	*	**42%**	**65%**
	Total model-2 variation	*	*	**11%**	**16%**

* Does not make sense to interpret

Table 6.26 shows coefficients of the final erosion model indicating that the effect of the treatment*days is statistically significant (t = 5.50, df ≈ 50, p-value = .000). Because the effect is positive (_$_{11}$ = .016538), students in the treatment group grew at a faster rate than students in the control group by .016538 points per day. These results are true for students of both gender and all ethnicity as the treatment interacts with neither of these.

Table 6.26 Coefficients of the final *Erosion* model.

	Coefficient					
Effect	Label	Value	Standard error	t-ratio	Approximate df	p-value
Intercept	_00	5.77563	0.70028	8.25	152	0.000
Treatment	_01	-0.82185	0.412221	-1.99	152	0.046
Achievement	_02	0.81603	0.194817	4.19	152	0.000
Days	_10	0.03955	0.018202	2.17	50	0.034
Days * Treatment	_11	**0.09100**	**0.016538**	5.50	**50**	**0.000**
Days * Achievement	_12	0.02491	0.007366	3.38	50	0.002
$Days^2$	_20	-0.01088	0.000569	-19.11	152	0.000

Figure 6.7 shows a graphical representation of conceptual understanding for the erosion unit across all three timepoints. Again, treatment group students gained more and lost less than control group students. Although the graph shows high and low achieving students, the treatment was not differentially effective for differently achieving students, or students of different gender or ethnicity.

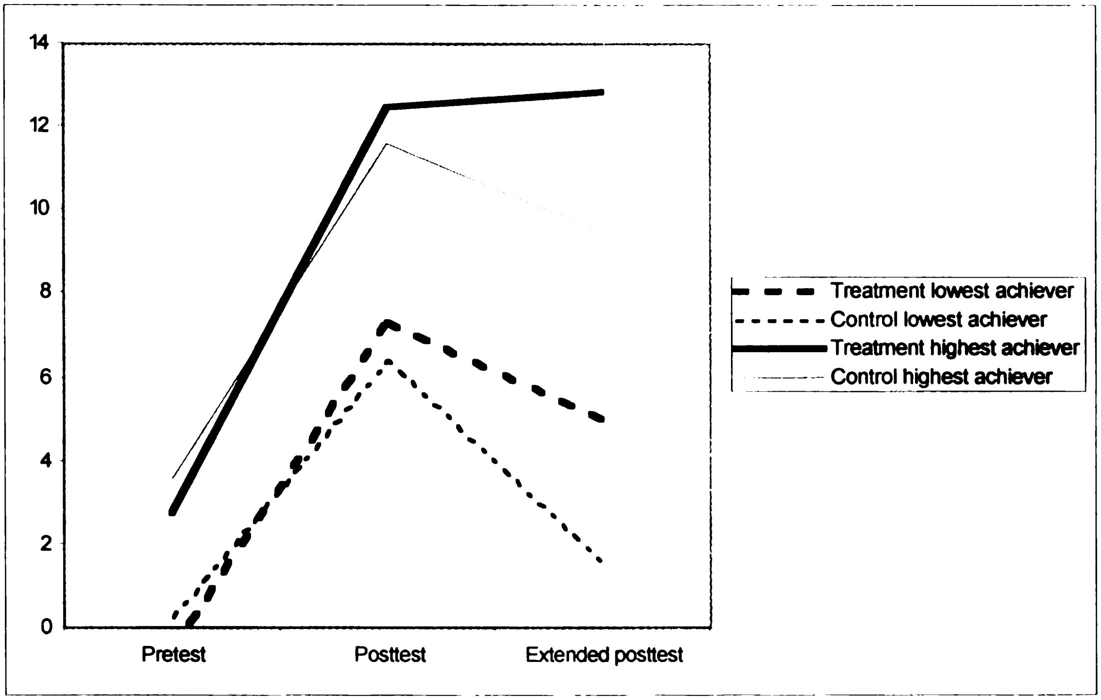

Figure 6.7: Predicted *Erosion* scores for the average achiever (Achievement = 2).

Summary

It appears that the effectiveness of the treatment does not depend on students of different gender, ethnicity, or previous achievement but that the treatment helps students to learn more and forget less over time. Another interesting phenomenon is in the degree to which within student variation is explained to an increasing degree across the three units. Percent variation for the first unit, weather, is only 3%, increasing to 23% for the second unit (erosion), and finally to 56% for the unit on matter. Similarly, the value for the coefficient of treatment*days (the effect of interest) increases as well from .03297 on weather, to .091 on erosion, and to .1234 on matter. When examined as a percentage of the total test score, this indicates that treatment group students can be expected gain .2%, .8%, and 1% of the final test score over the control class everyday – a remarkable rate of added growth. This suggests that the value-added to conceptual understanding is substantial when goals are shifted to teaching for aesthetic understanding. It also suggests that the treatment is different enough from control class pedagogy that it takes practice for students to learn how to learn for the goal of aesthetic understanding. As these numbers indicate, the learning progressed across each of the three units and students became more efficient at learning (learning as defined by conceptual understanding) through these perceptual means. Further, although it seems to take time for students to learn how to learn for aesthetic understanding, their initial attempts still indicate a positive result as demonstrated by the small but reliable improvement in conceptual understanding of the treatment class over the control class on the weather unit. Again, powerful conclusions. An alternative explanation for this increase in percentage of within student variation explained is that perhaps I improved in my ability to teach effectively for aesthetic understanding as time went on. It is most probable that some combination of improved teaching and learning explain the increase in variation explained.

Chapter 7: Implications

Introduction

This research began with 4 central research questions. They were:

- Can I teach in ways that facilitate aesthetic understanding?
- How similar or different will students' aesthetic experiences be to those predicted by the theory in chapter 2? Why might differences exist?
- Will teaching for aesthetic understanding foster more positive attitudes, science efficacy beliefs, science identity beliefs, and interest in science than teaching that is not for the goal of aesthetic understanding?
- Will teaching for aesthetic understanding yield a comparable level of conceptual understanding than teaching tat is not for aesthetic understanding? Will teaching for aesthetic understanding perhaps yield a more enduring conceptual understanding?

The data reported in chapters 5 and 6 clearly support positive answers to questions 1, 3, and 4. It appears that I was successful in teaching for aesthetic understanding, as defined by the theoretical framework articulated in chapter 2, and that the result of this was more positive student attitudes toward science as well as more and more enduring conceptual understanding. The interesting issue, that of existing differences between hypothesized student experiences and those actually described by students, an issue addressed in question 2, remains to be explored. Clearly, from reading the student accounts in chapter 5, students came to experience science ideas in ways that fit with the Deweyan framework from chapter 2, but, their descriptions do not seem to match very closely those described by scientists in chapter 1. One solution might be simply to dismiss the importance of any similarity between student experiences and scientists experiences as unimportant – pointing instead to similarities to the hypothesized account of aesthetic understanding from chapter 2. I'm inclined, however, to attempt some discussion of the issues as there may be a valuable lesson to learn – a lesson that could help guide future pedagogical development or facilitate a more clear and robust description of the theoretical framework. I proceed in that regard offering three reasons why perhaps student experiences deviate from those described by scientists.

In chapter 1 I identified three themes under which I grouped scientists' descriptions of beauty and aesthetics in science. One theme, that of beauty as a factor of some universal truth, or, science as explaining God's plan or design for creation, wasn't echoed at all by students in this research. Considering science and scientific ideas as a lookingglass through which one can peer into the mind of God is quite an advanced perspective to take. It necessitates one have a clear and robust realist epistemological stance, firm parochial faith, as well as such a deep level of scientific understanding that one could begin to ponder the top-level significance of science ideas. I believe these criteria are too stringent to expect 5th graders to articulate similar feelings and experiences in learning science.

The second theme, that of beauty in science ideas, is perhaps more developmentally appropriate for 5th graders. As with the first theme it does force one to have criteria for judging something as beautiful or artful. I know from one conversations with treatment class students, as a group, they held quite liberal beliefs regarding qualities of beauty and art. In a vote, all but 3 students agreed that beauty was a quality best evaluated personally – in the minds of these students – beauty lies in the eye of the beholder. The three dissenters did not offer an alternative. Margie, one of the treatment class students described in a vignette in chapter 4, actually used the word beautiful in her description of molecules and molecular motion. "I feel like I can almost see the molecules... hear the music of the dance. It's beautiful." Unfortunately, we don't know if Margie is referring to the idea of dancing molecules as beautiful or the hypothetical music she was imagining in her mind. In one sense it doesn't matter as she connects science to beauty in ways that are meaningful to her. The fact that Margie's is the only example isn't a concern either as students weren't asked in any systematic way if they found the science ideas they were learning to be beautiful. I see this as an unfortunate mistake in this research. In future investigations I will inquire more specifically into students' notions of beauty in science, and if they encounter beauty in their school science learning. However, this second theme is also largely unechoed by student responses.

The final theme, beauty as in the experience facilitated by science ideas, is the theme developed in chapter 2 in the description of aesthetic understanding. In the language of Dewey, we can distinguish <u>an</u> aesthetic experience from ordinary experience when it has the qualities of transforming our perception and our interactions with the world. Arguably, these are precisely the qualities discussed by scientists under the third theme. Recall Boltzmann describing Maxwell's mathematics, "If you are not swept along with the development lay aside the paper." Clearly enthralled Boltzmann continues, "One result after another follows in quick succession till at last, as the unexpected climax, we arrive at the conditions for thermal equilibrium together with the expressions for the transport coefficients" (Boltzmann as quoted in Chandrasekhar, 1990, pg. 53). The mathematics is compared to an impressive symphony of ideas and consequences. For Boltzmann, Dewey would argue, the experience of reading Maxwell's mathematics is an experience. Similarly, but perhaps not to the same extreme, treatment class students reported significantly greater numbers of examples in which the science they learned had the same transformative power. Numerous examples were provided by treatment class students in which the way they saw and thought about the world had changed as a result of new science learning. I argue, therefore, that perhaps because students lack a depth of experience with art, aesthetics, and even art objects, and because they also lack the depth of content knowledge and interest that scientists commonly have, that it is unreasonable for them to describe science as beautiful in ways that reflect either theme 1 or 2. I believe that theme 3 does have the potential to be expanded upon in ways that could provide more powerful and experiential pedagogy – beyond the power explored in this research. I leave that for future work.

Related to ideas regarding aesthetic experiences comes theorizing and more autobiographical accounts of scientific practice that speak specifically to women, science, and transformative experience that may be helpful in explaining the treatment*female interaction effects shown on measures of identity and science rank. On these two factors, the treatment showed differentially effective results for females than for males. In fact, when girls and boys ranked their classes from most to least favorite, treatment class girls ranked science as equal to the science ranking for treatment and control class boys – essentially closing the gender gap. On a measure of science identity, the treatment effectively moved female students' identity beliefs beyond the level of both treatment and control class boys. These are impressive results that do not depend on ethnicity or prior academic achievement. Once again, I believe the words of scientists themselves offer an explanation for this phenomenon.

Gender effects, body metaphor, and feminist epistemology

Science is often perceived as the ultimate in logical endeavors. The scientific method, rigorous methodological control, objectivity, micro-analysis – these are all cornerstones of the discipline. However, as suggested in the first few paragraphs of chapter 1, scientists themselves often speak of science as a creative process, one that relies on imagination, creativity, and leaps of faith as much as logical method. 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. The 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. 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 (from Prawat, 1999). 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. The Root-Bernsteins, in their recent book *Sparks of genius*, describe the critical tools of science to be methods of imagination, analogizing, and playing with scientific ideas (1999). In an early work by Robert Root-Bernstein (1989), he 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, particularly from the third theme in chapter 1 – that of beauty in 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, in his book *The body in the mind* argues that all human understanding is based in metaphor and imagination taken directly from bodily experiences in the world (1990). 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 an experience as described by Dewey and similar to those accounts from other scientists articulated in theme 3 from chapter 1. In fact, when we return to that section of chapter 1 we find the majority of scientists mentioned in that section as ones who describe as something experienced, as something similar to aesthetic understanding, are women - Jane Goodall, Dian Fossey, Barbara McClintock, Temple Grandin... the list goes on. This finally leads us to a potential explanation for the gender effects the research data suggest. Keller 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 (1985; 1992). 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 perhaps account for the improved rating of science as we saw in data as analyzed in chapter 6.

Finally, what emerges from this research is a lesson about pedagogy in teaching for aesthetic understanding. This lesson is crucial as it has ramifications for how this research gets replicated and extended.

A more refined pedagogical model

I realized shortly after this research began that I did not have a very clear pedagogical model by which to steer my teaching. Although I had several guidelines useful in this regard I lacked an overall model. In spite of this the research continued and my efforts to teach for aesthetic understanding continued in earnest, and with at least some success. Now, at the conclusion of the research, and after much reflection I see that through the course of my efforts I did develop a more coherent pedagogical model that I will now describe.

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 that "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" (cited in Prawat, 1999, pg. 62). We must teach students how to see the world through science ideas before their ways of thinking and speaking will conform to canonical understandings. Once a teacher makes this transition to valuing "perceptual change," the task becomes how to teach in ways that move students toward this goal. I 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 help 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. I 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. I'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. If science ideas fail to connect with individual, real-world experience, deep learning will not occur.

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 7.1 shows a summary of the pedagogical model followed by an example from this research that illustrates the model.

Table 7.1: 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 • use the lens to generate wonderment of the phenomena • 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 • test or verify the power of the lens/metaphor in student world • provide time and space for students to personalize the science content
Step 3: Formalize the language	• formalize the lens/metaphor through scientific language • exiting this formalization is an idea (in the Deweyan sense)

An example: Teaching erosion

I taught a unit on erosion and weathering for the goal of aesthetic understanding. I framed the unit 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 try so hard to resist this destruction. Here's an excerpt from the opening day of the erosion unit:

> *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, I held up full color posters of the Grand Canyon, a coastal seascape, and an alpine/glacial scene. 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, in vain, to resist erosion. I used the metaphoric lens of "the battle" to frame the instructional unit. I crafted my presentation using richly descriptive and highly imaginative descriptions. And I presented the metaphor in an artistic and compelling way. Students were drawn into the engagement with the metaphor in a way that created drama and wonderment.

Next, I pushed my students 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 my class took a short fieldtrip around the outside of our school building looking for evidence of the battle. At the conclusion of the instructional day I challenged each student to search out evidence of the battle, describe the battle to someone else, and try to help them see the world through the lens of the metaphor.

Upon returning to class the following day students reported on 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.

At this point, I began the process of formalizing student's metaphoric language into more canonical ways of talking about the processes of erosion. Interestingly, students readily appropriated the new science language because their metaphoric descriptions were limited in the detail that they were able to provide. I used 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.

This research suggests some compelling affects in teaching for aesthetic understanding. Having a more clear pedagogical model, such as the one described above, will make replication and extension of this research easier and more systematic.

Contributions

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. Although a large literature exists in which scientists discuss the role of aesthetics and beauty in their science and inquiry, no empirical research, in my investigations, have been conducted with the goal of drawing on aesthetics to foster children's science learning. 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 and aesthetic understanding could be offered as one pragmatic solution.

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. One reviewer of a recent paper I submitted for publication commented, "Do you mean to say that I have some transaction with a forest as I walk through it?" This is exactly what I mean to say. 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 my strong opinion that few scientists would disagree.

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 sentence I downplay the connection between this work and conversations in the field of aesthetics but I believe my ideas do contribute in a small but important way. Although my intent was never to contribute to aesthetic theory my 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 I have done in the field of science. Like art, I believe powerful science ideas have the same potential to facilitate transformative experiences. As this work demonstrates, not only is this possible, but the results are powerful 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).

Weaknesses of this study and next logical steps for this line of inquiry

The most serious weakness of this research exists in the fact that teacher is confounded with treatment. We have no way of knowing whether the effectiveness of the treatment should be attributed to the treatment, as I have argued previously, or to the effect of the teacher – my attitude toward science, the energy and excitement I bring to science learning – these qualities could account for the effects we've seen. It's my suspicion that I, and the energy I bring to science teaching, probably account for an important part of the treatment effect. Related to this is the fact that I had to prepare and teach only the subject of science while the control class teacher, being the regular classroom teacher, had to prepare for and deliver instruction for all subjects. One might expect positive treatment effects from instruction that was probably more thoroughly planned and carefully delivered. The solution would be to conduct similar research in a situation in which I was not the teacher – a situation perhaps in which several instantiations of the pedagogy were going on simultaneously. A large-scale study such as this would force me to a) come to an even more clear pedagogical model and b) discover ways to effectively teach others how to use the pedagogical model effectively. Assuming this could be done and many teachers could be convinced to participate, such a study would best be completed with a more broad age range of students, across a more broad range of science subjects (two of my three units were in earth science – my personal subject-matter specialty while many of the aesthetic experiences described by scientists fell in the realm of the life sciences), with an equal number of control students studying equal science curriculum but for different learning goals. A larger sample size would increase the statistical power of the study and perhaps allow the main effect of treatment on identity to be born out as significant. Additionally, several other interactions between treatment and gender, minority, and achievement may also bear out as significant. In other words, I don't believe the full effect of teaching for aesthetic understanding was investigated in the course of this research study.

Conclusions

Science education has long pointed to scientists and the act of scientific investigation as the standard by which we should measure student inquiry and learning. In one example, it has been argued that scientists employ some method of systematic inquiry and that we should teach our students similar manners of inquiry if they are to develop an understanding of the nature and practice of science. Scientists, however, also discuss the power of science to illuminate beautiful aspects of the world, to foster aesthetically pleasing experiences with the world and to provide generative ideas that help to explain its phenomena. Very little of this discourse has been appropriated by the science education community and this research was designed to do just that. Given the theoretical framework of teaching for aesthetic understanding, derived from an aesthetic theory first articulated by Dewey, could powerful and meaningful learning be facilitated? If so, what are the effects of such efforts? These were the questions that guided the inquiry and the data as described in chapters 5 and 6 support positive answers to each. A greater number of students reported more varied and more complex perceptions and interactions with the world when learning for aesthetic understanding. These same students also reported greater feelings of interest, and affect in science as well as stronger positive efficacy beliefs, and in some cases, more positive identity beliefs about themselves as science learners. Finally, students learning for aesthetic understanding also appear to learn more and forget less when it comes to conceptual understanding. In and of itself, this result is groundbreaking. As demonstrated by this research, pedagogy that supports more and more enduring understanding, delivered in real schools with real children, in a setting with rigid curricular standards, should be regarded as a potent innovation.

The data also suggest that these effects are not generally dependent on gender, ethnicity, or student ability. The effect of the treatment does not appear differentially effective for groups of various characteristics. The act of teaching for aesthetic understanding seems to have powerful effects that ought to be recognized as more faithful to the language and beliefs of practicing scientists. Not only does there seem to be room for aesthetics in elementary school science but it seems that making the act of creating this space and engaging students in learning within that space has important practical consequences.

APPENDICES

Appendix A: Feelings About Science Inventory

Name: ________________________

Please complete each item as best you can. Circle the answer that best describes the way you feel about science. Use the following scale for all items.

Circle	**DISAGREE**	if you strongly disagree with the statement
Circle	**Disagree**	if you disagree with the statement
Circle	**neutral**	if you don't have feelings one way or the other
Circle	**Agree**	if you agree with the statement
Circle	**AGREE**	if you strongly agree with the statement

1. I feel a positive reaction to science.

   DISAGREE -- Disagree -- neutral -- Agree -- AGREE

2. I expect to do well on science tests, quizzes, and assignments.

   DISAGREE -- Disagree -- neutral -- Agree -- AGREE

3. Science is boring.

   DISAGREE -- Disagree -- neutral -- Agree -- AGREE

4. I think I am capable of learning science ideas.

   DISAGREE -- Disagree -- neutral -- Agree -- AGREE

5. I have a good feeling toward science.

   DISAGREE -- Disagree -- neutral -- Agree -- AGREE

6. Science just isn't for me.

   DISAGREE -- Disagree -- neutral -- Agree -- AGREE

7. I think I will earn a good grade in science.

   DISAGREE -- Disagree -- neutral -- Agree -- AGREE

8. I do not like science and it bothers me to have to study it.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

9. I feel comfortable with science and I like it very much.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

10. I am a science-type person.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

11. I think I will know a great deal about science at the end of this year.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

12. Science is fascinating.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

13. I do not believe that I will do very well on the science tasks in this class.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

14. I would like to learn more about science.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

15. If I knew I would never have science again, I would feel sad.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

16. Other people think of me as a science-type person.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

17. Mastering the science ideas taught this year has been hard for me.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

18. Science is interesting to me and I enjoy it.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

19. Science makes me feel uncomfortable, restless, irritable, and impatient.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

20. When I hear the word science, I have a feeling of dislike.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

21. Learning about science is fun.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

22. I cannot imagine myself as a scientist.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

23. During science class, I usually am interested.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

24. I have had a hard time understanding the science ideas taught in this class.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

25. Science is a topic which I enjoy studying.

DISAGREE -- Disagree -- neutral -- Agree -- AGREE

26. Rank these classes from 1 (most favorite) to 8 (least favorite).

_____ Art
_____ Math
_____ Music
_____ Gym
_____ Reading
_____ Science
_____ Social studies
_____ Spelling

Appendix B: Aesthetic understanding interview protocol

I only included a copy of the final protocol, administered to all students in both classes, immediately following the structure of matter unit. The other protocols were similar but tailored to reflect the content of the other lessons.

Post Structure of Matter Unit Interview Protocol

Have kids complete erosion test – (test of enduring conceptual understanding)

Have kids state their names as you begin recording.

Oral directions to child:

Listen to these two short stories about kids who learned science. At the end of these two short stories I'm going to ask you which kid sounds most like you and why.

Girl stories

Patrice really likes science. Patrice likes science because she likes to learn about new ideas that make things seem more exciting and interesting. Patrice learned about flowers recently and she began to see flowers very differently than she did before. She began to see flowers as tiny little factories that manufacture pollen, use "advertising" like bright colors and a nice smell to attract bees and insects, and then distribute that pollen on the legs of bees and other insects. She couldn't help but stop to look closely at the tiny little factory every time she passed a flower. Patrice works hard in science class but she works hard because science makes her think differently about the world and helps her to see things in ways she hadn't before.

Wendy really likes science too. What Wendy likes about science is different than what Patrice likes. She really enjoys learning all the different names of things and how stuff works. She likes to do worksheets and experiments where she finds out the answers to things. Wendy works hard in science class to get all the right answers. Wendy just learned about flowers too and she had fun learning to name all the parts of flowers, how to identify different kinds of flowers, and how flowers grow.

Boy stories:

Del really likes science. Del likes science because he likes to learn about new ideas that make things seem more exciting and interesting. Del learned about flowers recently and he began to see flowers very differently than he did before. He began to see flowers as tiny little factories that manufacture pollen, use "advertising" like bright colors and a nice smell to attract bees and insects, and then distribute that pollen on the legs of bees and other insects. He couldn't help but stop to look closely at the tiny little factory every time he passed a flower. Del works hard in science class but he works hard because science makes him think differently about the world and helps him to see things in ways he hadn't before.

Kevin really likes science too. What Kevin likes about science is different than what Del likes. Kevin really enjoys learning all the different names of things and how stuff works. He likes to do worksheets and experiments where he finds out the answers to things. Kevin works hard in science class to get all the right answers. Kevin just learned about flowers too and he had fun learning to name all the parts of flowers, how to identify different kinds of flowers, and how flowers grow.

Questions:

Which of these two kids sounds most like you? Why do you say that? What kinds of things did they do or feel that you think you might do or feel? How are you different from (the student they identified with)?

On to the structure of matter unit

1. Did you learn anything during the structure of matter unit that made you think differently or see things differently? If so, tell me what you thought about or saw differently? Why did you do this? If not, why

didn't learning about the structure of matter make you think differently about the world or see it differently?

2. Was learning about the structure of matter interesting or exciting? In what ways? Was it more interesting or exciting than other stuff you learn in science? If so, what was so different about it? If not, why not?

3. Did you tell anybody else what you learned about the structure of matter? If so, tell me about that. Did you try to learn more about the structure of matter on your own? Did you look for examples of matter in various states? Tell me why or why not.

4. Do you think differently about the structure of matter now than you did before the unit? If so, how? In what ways?

Probes:

5. Mr. Girod says he can literally see molecules everywhere he looks and he gets so fired up about it. Was learning about the structure of matter that powerful for you? Do you think about the structure of matter like Mr. Girod does?
6. Did you do any re-seeing during your structure of matter unit?
7. Did you think about the dance of the molecules at all?
8. Did you try to teach anybody else about the structure of matter or show them different states of matter?
9. What about weather? Have you been thinking about weather anymore?
10. What about erosion? Have you been thinking about erosion lately?
11. Is the way you've been learning science with Mr. Girod different from the way you've learned science in the past? If so, in what ways?
12. If this is the way science was done all the time do you think you'd like it more? Feel like you were better at it? Feel like you were more of a science-type person?

Appendix C-E: Tests of conceptual understanding

I've included only pre-tests but post-tests and enduring post-tests included identical items.

C: Weather

Name: ____________________

What do you already know about the weather?

I realize we have not yet studied weather but we don't want to learn stuff you already know so... answer each question as best you can. If you don't know the answer that's ok – this will not be graded!

1. Describe the atmosphere.

2. What's the difference between weather and climate?

3. What would you do to prepare for a tornado if we were about to have one?

4. How would you predict what the weather would be like in Lansing tomorrow? Not what do you predict it to be but how would you go about making a prediction?

D: Erosion

Name: ____________________________

What do you know about erosion?

I realize we have not yet studied erosion. Answer the questions as best you can. If you don't know or don't have anything to say, that's ok – this is not a test! If you do have something to say, try to use as many science words as you can.

1. How is soil made?

2. How can we help control erosion?

3. Describe how a valley might be carved by erosion?

E: Structure of matter

Name: ____________________________

Let's see what you know about the structure of matter...

I realize we have not yet studied the structure of matter. Answer the questions as best you can. If you don't know or don't have anything to say, that's ok – this is not a test! If you do have something to say, try to use as many science words as you can.

1. How are the molecules arranged in each of the three states of matter? Draw pictures for each state if that helps. Be sure to label your drawings too.

2. How is the state of matter related to the amount of energy in its molecules?

3. What happens during condensation? What happens to the molecules? Condensation is a change from which state to which other state?

Appendix F: Interview Coding Scheme

The following coding scheme was used to code all student interviews and assign responses a gross numerical ranking.

<u>Do you see the world differently now that you know about X?</u>

0 = no
1 = yes, no example
2 = yes, with one example
3 = yes, with two examples
4 = yes, with three examples
5 = yes, with four examples

<u>Does the world seem more interesting and exciting now that you know about X?</u>

0 = no
1 = yes to either question, no example
2 = yes to both questions, no example
3 = yes to both questions with one example
4 = yes to both questions with two examples
5 = yes to both questions with three examples

<u>Have you done to further explore the idea or have you told anybody about the idea?</u>

0 = no
1 = yes, no example
2 = yes, thought about idea outside of class
3 = yes, told somebody about the idea
4 = yes, showed somebody example of idea
5 = yes, investigated idea on own or tried to teach or recreate an opportunity to learn about the idea for someone else

Extended aesthetic understanding for weather and erosion

<u>Have you continued to think about the stuff we learned during the weather/erosion unit?</u>

0 = no
1 = yes, no example
2 = yes, with one example
3 = yes, with two examples
4 = yes, with three examples
5 = yes, with four examples

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