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Teaching and Learning Science for Transformative, Aesthetic Experience

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Abstract Drawing from the Deweyan theory of experience (1934, 1938), the goal of teaching and learning for transformative, aesthetic experience is contrasted against teaching and learning from a cognitive, rational framework. A quasi-experimental design was used to investigate teaching and learning of fifth grade science from each perspective across an entire school year including three major units of instruction. Detailed comparisons of teaching are given and pre and post measures of interest in learning science, science identity affiliation, and efficacy beliefs are investigated. Tests of conceptual understanding before, after, and one month after instruction reveal teaching for transformative, aesthetic experience fosters more, and more enduring, learning of science concepts. Investigations of transfer also suggest students learning for transformative, aesthetic experiences learn to see the world differently and find more interest and excitement in the world outside of school.

Keywords Aesthetics · Elementary · Transformative experience · Dewey · Science · Cognitive

Introduction

Like all disciplines, science education includes an array of theoretical frameworks including those aligned with sociological and socio-cultural perspectives (Cole 1996; Latour 1987; Lemke 1990, 2001), and postmodern and feminist perspectives (Barton 1998; Harding 1991; Keller 1985; Wyer et al. 2001). Arguably, the dominant perspective continues to be well-aligned with a cognitive, rational framework. From this perspective learning is viewed as the process of conceptual growth requiring reorganization of ideas, investigation, and problem-solving

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(Greeno et al. 1996). Learning occurs through inquiry, application of science process skills, the construction of mental models or schemas, and is facilitated by the acquisition of language. Teaching and learning is often characterized as following the process of conceptual change (Driver et al. 1985; National Research Council 2000; Vosniadou 2008).

Derived from Piagetian constructivism, conceptual change teaching and misconceptions research has been powerfully influential in science education research (AAAS 1989; Brown and Clement 1989; Clement 1982, 1983; McCloskey 1983; McCloskey et al. 1980). In one of the classics from this genre, Posner et al. (1982) offers a characterization of the underlying tenants of conceptual change approaches, “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.” (p. 212). This process is facilitated through the construction of mental models or representations of key conceptual ideas, systems, and terminology (Halford 1993). The role of prior knowledge and experience is attended to carefully as these may need to be replaced or accommodated to allow for more rich (and accurate) understandings. Student motivation and engagement is driven by the desire for problem solving and for the resolution of discrepancies or cognitive dissonance (Greeno et al. 1996).

The process of conceptual change is often facilitated by application of an instructional approach called the learning cycle (Abraham 1998; Karplus and Their 1967). Though the learning cycle approach was developed 40 years ago it continues to be enormously popular in practice today (Gallagher 2006). The learning cycle approach follows the conceptual change process requiring students to reveal their naïve beliefs, face conceptual conflict or dissonance, and replace their naïve beliefs with more canonically accepted ones (Martin et al. 2008; Moyer 2006).

In the end, high quality science teaching and learning continues to be dominated by the cognitive, rational perspective and values the development of conceptual knowledge through inquiry and the application of science process skills supported by the acquisition of the language of science. It may be argued that this perspective is the default model for quality science teaching and learning at this time.

Linking Aesthetics and Science

Though the goals of science teaching and learning from the cognitive, rational perspective are valuable and important, this approach may misrepresent or overlook important aspects of science and science learning. Strong messages about the importance of art, beauty, and aesthetics are woven throughout science studies (Author 2007; Chandrasekhar 1987; Fischer 1999; McAllister 1996). Scientists themselves speak the loudest as the following quote illustrates.

> 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, p. 154).

Naturalist, Niko Tinbergen, describes what it means to link our cognitive, rational ways of understanding to aesthetic ones. He is clear that the development of one facilitates the other and, ultimately, we achieve something greater by their linkage. Below, physicist Richard Feynman wonders why, in our modern society, we have seemed to separate aesthetic knowing from cognitive, rational knowing when this division is clearly unnecessary.

> 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, p. 373)?

Not only is the separation of aesthetic knowing from cognitive, rational knowing unproductive, it is a hindrance to the development of a more complete understanding (Girod and Wong 2001). We should strive to connect the cognitive, rational goals of canonical understanding to more holistic, aesthetic ways of knowing. John Dewey also considered this blending and it became a core aspect of his epistemological theory (1938).

Dewey on Experience, and in Particular, Aesthetic Experience

Seeking to clarify his relationship to progressive education Dewey described criteria for educative experience as opposed to ordinary experience and the "learning by doing" generalization so commonly attributed to his work (1938). Although doing or experience is essential to Dewey's philosophy, to be educative, experience must open the door to further experience. In other words, we are not true to Dewey's ideas unless the learning opportunities we afford our students necessarily lead them into the world for further, enriched experiences.

In articulation of his aesthetic theory, Dewey argues most compellingly for a relationship between a unique kind of experience—called *an* experience—and action and intelligence (1934). In fact, Dewey argues, using art as his example, that "the having of aesthetic experiences is the objective of all intelligence" (p. 44). Again, the linkage between aesthetic knowing and cognitive, rational knowing is emphasized.

Jackson (1998), commenting on his task of updating Dewey's aesthetic theory in preparation for his book, *John Dewey and the Lessons of Art*, discovered an unexpected secondary agenda.

> …I came upon another set of issues that I found intriguing and far more pertinent to my overall project than the up-to-date-ness of Dewey's theory. These had to do

> with the power of art to be genuinely transformative, to modify irrevocably our habitual ways of thinking, feeling, and perceiving. (p. xiv)

Too often, education is focused on immediate, pragmatic outcomes like problem solving, application of concepts, and acquiring terminology—goals better aligned with a cognitive, rational perspective. We must not turn our backs on loftier goals for schooling—to be genuinely transformative and to modify irrevocably our habitual ways of thinking, feeling, and perceiving—to undergo transformative, aesthetic experience.

Essential Qualities of Transformative, Aesthetic Experience

Dewey (1934) and Jackson (1998) provide lengthy accounts of aesthetic experience detailing its origin, evolution, and effect. Yet both claim it to be an elusive outcome—not easily achieved unless through systematic effort and direction. We have to be educated into transformative, aesthetic experiences. The reward is irrevocable change in both experiencer (person) and experienced (world). This change of both person and world is called transaction.

> Experience in the degree in which it *is* experience is heightened vitality. Instead of signifying being shut up within one's own private feelings and sensations, it 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. 19).

There is transaction between person and world; between experiencer and experienced. This is a departure from our current and overwhelmingly common cognitive, rational perspectives on teaching and learning. Attention here is beyond just the mind of the learner and is extended to include emotions, actions, and perceptions. A person who truly learns exits transformed, not just of mind but of heart, eye, and body. Education should leave us different; understanding more, seeing differently, and willing to act in accordance with these differences. Again, Jackson interprets Dewey, "The experiencer changes by undergoing a transformation of self, gaining a broadened perspective, a shift of attitude, an increase of knowledge, or any of a host of other enduring alterations of a psychological nature" (Jackson 1998, p. 5). Dewey brings us full circle by connecting experience and the transformation of self that occurs as a result, with art and aesthetics, "Because experience is the fulfillment of an organism in its struggles and achievements in a world of things, it is art in germ. Even in its rudimentary forms, it contains the promise of that delightful perception which is esthetic experience" (p. 19).

Recent Efforts to Revive Aesthetic Experience in Science Education

As Dewey's ideas about art and aesthetics have been enjoying a resurgence (Fesmire 1995; Garrison 1995; Greene 1995; Jackson 1995, 1998; Shusterman 1992), we have seen increased efforts to apply these ideas to science education. Following general calls to wed science and aesthetics (Author 2007; Fischer 1999;

Flannery 1991; Root-Bernstein 1999), science education researchers have been applying Dewey's ideas about aesthetics to classroom teaching and learning. For example, Wickman (2006) describes science, and science teaching and learning, from the perspective of practical epistemology suggesting that meaning is better situated in action rather than as in representations. Wickman conducted detailed analyses of science teaching and learning searching for continuity and consummation—two ideas central to Dewey's aesthetic theory (1934). Continuity suggests that experiences are connected in ways that flow and give meaning while consummation refers to the fulfillment of anticipation as we learn new ideas. Similarly, Jakobson and Wickman (2007) describe science teaching and learning as being driven by moments of aesthetic experience. Both call for more research into these essential elements in science teaching and learning. Both argue that learning and doing are enriched by a linkage among the cognitive, rational and the aesthetic.

Similarly, Girod et al. (2003) argue for attention to the beauty of scientific ideas and the role that this beauty can play in assisting student learning. The authors refer to learning that is linked to and driven forward by aesthetic dimensions as teaching and learning for aesthetic understanding. These aesthetic dimensions include the power of new knowledge to transform us, to be dramatic and compelling, and to be unifying or to add coherence to our understanding of the world. Following on these ideas, Pugh and Girod (2007) offer a discussion of the pedagogical strategies, derived from Dewey's aesthetic theory, useful in scaffolding aesthetic science learning. The strategies include: (a) crafting ordinary science content into important and powerful ways of seeing the world; (b) modeling the power of these science ideas to transform our lives, and; (c) scaffolding students' efforts to live differently because of these new ideas.

Summary

The key outcomes of teaching and learning from the cognitive, rational perspective include conceptual understanding and appropriate use of scientific discourse, tools, methods, and inquiry. Key outcomes for teaching and learning from the transformative, aesthetic perspective include seeing the world differently, desiring to live and act differently in the world, seeing oneself differently as a result of new learning, as well as conceptual understanding of powerful content.

The Research

Though there is a resurgence of interest in connecting aesthetics and science both in terms of educational practices and the validation of these processes, few research studies exist in this area. What follows is an extensive study testing the efficacy of a pedagogical framework rooted in teaching and learning for transformative, aesthetic experience against the more common, and well-established cognitive, rational perspective.

In an effort to explore differences in learning of fifth grade science students between those taught from a cognitive, rational framework to those taught for the goal of transformative, aesthetic experience, the following research questions were posed.

When compared against a control group of fifth grade science learners did students taught for the goal of transformative, aesthetic experience:

1. achieve different levels of interest in science, efficacy beliefs about themselves as science learners, and identity beliefs about themselves as "science type" people?
2. achieve different levels of conceptual understanding?
3. retain different levels of conceptual understanding one month after instruction?
4. act differently in the world as a result of new learning? (i.e. transfer to out-of-school settings)

These questions are closely aligned to the hypothesized outcomes posed by Dewey in his theory of experience (1934, 1938) and are codified in the proposed theory of teaching for transformative, aesthetic experience. The following research study was designed to investigate the research questions.

Design

A quasi-experimental study was conducted in a large, urban elementary school in a Midwestern city with the goal of exploring teaching for transformative, aesthetic experience and its effect on student interest, efficacy, identity, conceptual understanding, and transfer to out-of-school settings. Two 5th grade classrooms and the teaching and learning that occurred there were examined across an entire 9-month academic year. Teaching and learning in the treatment classroom focused on the goal of transformative, aesthetic experiences while teaching and learning in the control classroom emphasized more traditional cognitive, rational approaches. Table 1 shows the design of the research project with associated dates indicating how each phase progressed across the school year.

Participants

The student participant population was a heterogeneous mix of Caucasian and African American students from mostly lower and middle class families distributed almost evenly by gender and ethnicity between treatment and control classrooms. As all children were in the 5th grade, ages ranged between 10 and 12 years. As was practice at this school, students were randomly assigned to the two classroom teachers before school began and it did not appear that any unusual groupings had occurred that might be confounded with the variables of interest. However, pretests for all outcomes were administered and used in analyses.

The first author served as the science teacher in the treatment classroom designing and delivering all instruction related to teaching for transformative, aesthetic experience. At the time of this research, he was a 30-year old Caucasian doctoral student and had previously been a science teacher for six years. The pseudonym of Mr. Jones is used to identify him throughout this research.

Table 1 Schedule of research activities

Phase	Date	Activities
Pre-testing	Late September	Pre-test of interest, efficacy, and identity
Unit 1 (weather)	Early October	Pre-test for unit 1
		Instruction begins for unit 1
	Mid-November	Post-test for unit 1
		End of unit transfer interviews
	Mid-December	1-month post-test for unit 1
Unit 2 (erosion)	Early January	Pre-test for unit 2
		Instruction begins for unit 2
	Mid-February	Post-test for unit 2
		End of unit transfer interviews
	Mid-March	1-month post-test for unit 2
Unit 3 (matter)	Early April	Pre-test for unit 3
		Instruction begins for unit 3
	Mid-May	Post-test for unit 3
		End of unit transfer interviews
	Mid-June	1-month post-test for unit 3
		Post-test of interest, efficacy, and identity

The control classroom teacher had been teaching in this elementary school for her entire 12-year career and was the previous year's runner-up, Teacher of the Year for this large, urban school district. She was 38-years old Caucasian and, in a meeting with the research team, was characterized by the school principal as "one of the best teachers I've worked with." She was chosen for participation because she was better at science teaching than most of her peers and employed many pedagogical strategies well aligned with a cognitive-rational perspective on teaching and learning. This selection was purposeful so as not to build a case for innovative pedagogical moves in teaching for transformative, aesthetic experiences against a weak or ineffective pedagogical model and strategies. The pseudonym of Ms. Parker is used to identify the control classroom teacher. Overall, Table 2 summarizes these classroom differences.

Table 2 Student and teacher demographics in treatment and control classrooms

	Control classroom	Treatment classroom
Girl/boy ratio	14:12	15:12
Minority/Caucasian ratio	11:15	12:15
Teacher gender	Female	Male
Teacher ethnicity	Caucasian	Caucasian
Teacher years experience	12	6

Analysis of Pedagogical Fidelity

All science instruction was observed in both classrooms across each of the three units. During the first unit of instruction, all lessons in both classrooms were videotaped. Both units lasted five weeks, included 12 days of instruction spread across a total of 480 min in the control classroom and 440 min in the treatment classroom. Six videotaped lessons were randomly selected from each of the control and treatment classrooms and analyses were performed independently by two researchers. Each researcher watched the 12 video lessons and developed a coding scheme to categorize the kinds of instructional activities and the duration of each used during the lessons. After developing these initial coding schemes independently, the two researchers met to discuss their work and collaboratively extended and refined their coding schemes into a single framework. This agreed-upon framework was then used to review the remaining 12 videotaped lessons (six for each class) from this first unit of instruction. After some adjusting, refining, and clarifying the two researchers agreed on a six-category framework for describing classroom practices. Throughout the remainder of the research study, all lessons were videotaped and reviewed by these two researchers using this categorization scheme. Rater agreement on the remainder of the videotaped lessons was .94 and a summary of how time was spent during instruction is found in Table 3.

The two instructional programs appear very similar in terms of time spent in collaborative activities, assessment, and time spent in transitions or behavior management. Large differences existed, however, in time spent in teacher-led discussions, independent seatwork, and in inquiry-oriented activities. Mrs. Parker, in the control classroom, stated explicitly that her goal was to "…not talk too much in front of the class and to get them going on work at their desks." On the contrary, Mr. Jones used large blocks of time to lead students through discussions about class content.

Though both control and treatment class teachers were striving for conceptual understanding, the two approaches for reaching this goal were quite different. Both teachers targeted the same outcomes for conceptual understanding that were aligned with the state content standards and benchmarks for 5th graders in this state. The list of instructional goals and benchmarks for conceptual understanding for both classrooms across each of the three units can be found in "Appendix 3".

Table 3 Percentage of time spent during three science units in various instructional tasks or activities

Tasks or activity	Unit 1 (weather)		Unit 2 (erosion)		Unit 3 (matter)	
	Control	Treatment	Control	Treatment	Control	Treatment
Teacher-led discussion	16	35	18	36	14	36
Collaborative activities	20	24	25	24	21	28
Seatwork	28	15	23	13	27	13
Inquiry	18	7	19	6	20	7
Assessment (formative or summative)	10	12	6	11	8	10
Transitions or behavior management	8	7	9	10	10	6

In addition to these relatively objective assessments of pedagogical acts in the control and treatment classrooms, each teacher was asked to identify their major goals, outcomes, and instructional aspirations during the three units. This information was solicited from each teacher at the end of each instructional unit and their comments remained remarkably consistent across the duration of the year. Each teacher was asked the following question in an open interview: “What are the major instructional approaches or strategies you used during the lessons in this unit?” The sections below are brief synopses of these conversations quoting actual snippets of dialogue when possible.

Teaching and learning in the control classroom

Five pedagogical values or goals were identified consistently by the control classroom teacher, Mrs. Parker.

First, building students’ science vocabulary was an explicit goal for Mrs. Parker. “There is so much embedded language and terminology in science and it is important for students to acquire as much of that as possible. Without it, they will struggle in science in the future.” Mrs. Parker spoke about her goal of helping students “use their science words” when they spoke in class. It was not uncommon for Mrs. Parker to use a rapid quizzing technique in class in which she provided definitions of science terminology and students were asked to supply the correct science phrase, or vice versa in which she would provide the terminology and students would be asked to define it.

Second, helping students to build conceptual models in their minds was also stated as an explicit goal for Mrs. Parker. During the unit on erosion, for example, Mrs. Parker stated, “I want students to have an image in their minds that gravel, sand, silt, and clay are just a continuum of grain size.” During the weather unit, Mrs. Parker claimed her goal was to help students “develop a visual picture of the water cycle in their minds and then be able to run that model and see how the water cycle works.”

Third, Mrs. Parker wanted students to be engaged in investigations learning and using inquiry skills to explore the world. A favorite line she used frequently in class was, “Scientists investigate the world. So should you!”

Fourth, related to the goal of student inquiry, Mrs. Parker provided a clear emphasis on science process skills particularly measuring and graphing. “So much of science involves taking measurements and then representing those measurements in ways that others can understand.” During each of the three instructional units, students in Mrs. Parker’s control classroom used rulers and balance beams to gather data and then graphed that data accordingly.

Fifth, Mrs. Parker expressed the specific goal of having fun. “It is very important to me that my students enjoy what’s happening in science class. If they enjoy science they will be more likely to remember the concepts we learn.” As an illustration of how these values were expressed in Ms. Parker’s classroom, the following illustrative example is provided.

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 approximately 80,000 feet thick and is divided into 4 major layers: the troposphere, mesosphere, ionosphere, and exosphere, and contains specific ratios of gases. Students recited the names of the four layers, wrote down these details on concept maps they had just begun, and then used rulers, calculators, and large sheets of paper to draw scale models of the atmosphere with each layer at a scale of 1 centimeter = 1,000 meters of thickness. The children had fun measuring, coloring, and labeling the different components of their models and, in the end, could talk fairly extensively about the atmosphere and its nature.

Teaching and learning in the treatment classroom

Following closely from the theoretical framework of teaching for transformative, aesthetic experiences the treatment classroom teacher, Mr. Jones, identified five instructional approaches or strategies that he used regularly.

First, Mr. Jones emphasized the importance of focusing teaching and learning on the most important and powerful science ideas. “I believe too much of what most teachers teach is stuff that isn’t all that important—bold-faced words, simple understandings, and useless facts—what’s important are ideas that change the way we think about the world.” This emphasis was illustrated by focusing content in the erosion unit around the idea of “erosion as war” between forces trying to denude and the resistance of the earth’s surface and features. During the weather unit, atmosphere was described as an “ocean of air” rather than as simply the “layer of gases that surrounds the earth” as it was defined in the control classroom. Mr. Jones used these “big ideas” as conceptual organizers for unit content.

Second, Mr. Jones expressed the importance of helping students to see the world differently as a result of new learning. “I call it re-seeing. I ask my students everyday if they noticed anything different about the world because of what we learned in science class. The stories they tell are awesome!” It was quite common for Mr. Jones to model re-seeing by describing how he was seeing differently using the science ideas discussed in class.

Third, creating a sense of wonderment was also identified as an explicit value in Mr. Jones’ classroom. He stated, “The world is an infinitely interesting place and I want my students to recognize that.” During each of the instructional units Mr. Jones used story-telling, relayed interesting statistics, and described the worlds biggest and most dangerous (hurricanes, landslides…) in an effort to engender student wonderment.

Fourth, Mr. Jones emphasized the importance of personalizing experiences. For example, during the weather unit he described how important it was to let students talk about their experiences in severe weather. “If you don’t let kids link their own lives to learning you’re missing out on a very effective teaching strategy.” Recall Deweyan transaction where both person and world are changed as a result of transformative, aesthetic experience. To be so transformed required opportunities to personalize or “try on” new ideas and the power they carry to illuminate aspects of the world previously hidden.

Fifth, Mr. Jones described his role as, "to model passion and enthusiasm for science." He described two of his most memorable teachers and how they had taught him the importance of demonstrating passion. "I want my kids to see me excited about science because then they are more likely to also be excited about science." As an illustration of how these values were expressed in Mr. Jones' classroom, the following illustrative example is provided.

On the first day of the weather unit in Mr. Jones' classroom he took his students outside, had them lay on their backs in a circle and stared up into the sky. He began a calm and tightly designed lecture:

> 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 about 17 miles of air pressing down on you and your face right now and that air has weight. Air matters.

Following his opening speech, students asked questions for 15 min including "Why don't we feel the air? What would happen if our atmosphere was twice as deep? And, What kind of gases are in our atmosphere?" Students were particularly struck by the metaphor of atmosphere as ocean as five days later (this lesson took place on a Wednesday and the next science day was the following Monday) 11 different students mentioned that they had either thought about the ocean of air as they enjoyed their weekend, mentioned the idea to somebody else, and in the case of two students, tried to recreate the experience of lying on their back and "seeing" up into the ocean of air for their friends and family.

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. These descriptions illustrate the degree to which pedagogy in each classroom is well-aligned with the conceptual framework of cognitive, rational teaching and learning in the control setting and teaching for transformative, aesthetic experience in the treatment setting.

Duration of Investigation

Across the entire academic year, all science teaching and learning that occurred in the two classrooms was studied including three different instructional units on weather, erosion, and the structure of matter. Science instruction took place two-three times a week for 45–60 min at a time.

Because of imminent state testing and rigid curricula and pacing, both classes were taught on almost exactly the same schedule. Both used many of the same activities, assignments, and lab activities. All students in both classes took the same tests of conceptual understanding. The only significant differences between the two classrooms were the instructional strategies employed by the two teachers. The treatment class was taught using strategies to facilitate transformative, aesthetic experiences while the control class was taught using strategies to facilitate a more generic conceptual understanding emphasizing cognitive, rational beliefs about learning.

Measures

Interest Factor

Originally, we had planned to measure student attitude toward science more broadly and had selected the Attitude toward Science in School Assessment (ATSSA) (Germann 1988) as the means to do so. However, in pilot tests of this instrument we found items from its interest inventory tended to load onto two factors; one related to pure affect (i.e. "I like science") and another that seemed to link affect and cognition (i.e. "I'm interested in science"). Because affect seemed potentially less stable than interest and more easily influenced by friends, time of day, and a number of other unrelated issues, we opted to use only the six items that loaded on the interest factor.

Efficacy Factor

Efficacy is a well-explored psychological construct referring to one's sense of competence or efficaciousness. In this case, we hoped to measure participants' efficacy beliefs about themselves as science learners. Efficacy is strongly linked to achievement so is essential to explorations of classroom teaching and learning (Bandura 1997; Pajares 1996; Schunk and Zimmerman 2006). Efficacy items used in this investigation were taken from a scale used widely (Pintrich and DeGroot 1990) but needed slight modifications of word choice to accommodate participants' reading levels. Seven efficacy items were included.

Identity Factor

Identity affiliations are a rich area of psychological investigation that can involve explorations of self-concept, self-esteem, and identity development (Slavin 2009). In this investigation, however, we were most interested in how children affiliate with science. In other words, how they may or may not express an identity as "a science-type person." The identity factor consisted of four total items written specifically for this investigation, each well aligned with this goal.

Interest, efficacy, and identity factors were all measured with a single instrument. This instrument was piloted at a cross-town elementary school with 100 5th and 6th graders. Factors yielded a high degree of internal consistency returning Cronbach's alphas of .92 for the interest factor, .84 for the efficacy factor, and .82 for the identity factor. These factors and items have been used together in other successful investigations of science teaching and learning (Author 2009). "Appendix 1" lists items by each factor.

Conceptual Understanding

Participant conceptual understanding was measured on each of the three instructional units (weather, erosion, and matter). Tests consisted of short answer and multiple-choice items written collaboratively by the treatment class and control class teachers. All items were well aligned to content standards and benchmarks for 5th graders in this state. Accompanying scoring criteria for the short-answer items were constructed jointly by the two participating teachers.

Investigations of Transfer

At the conclusion of each instructional unit, half of all children in each classroom were interviewed to investigate the degree to which new knowledge and experiences led to changed action in out-of-school settings or increased interest and excitement about the world around them. Using an alphabetical list of students in each class and a random number generator, half of all children in each grade were identified to participate in end-of-unit interviews. This procedure was repeated for each unit so different children were interviewed after each unit. Students were interviewed individually by a research assistant (unfamiliar to all student participants) using the semi-structured interview protocol included as "Appendix 2". Only half of participating students were interviewed to allow sufficient time to conduct rich, exploratory interviews. Protocol questions were carefully mapped to the theoretical framework of transformative, aesthetic experience. Questions focused on changed perception, increased interest about the world, and changed actions as a result of new learning. This measure may be considered an indicator of the fidelity of the treatment and the unique outcomes associated with the experimental pedagogy.

Results

Analysis of Science Interest, Efficacy, and Identity

The science interest, efficacy, and identity surveys were scored blind for condition (treatment or control), timing (pre- or post-test), and student identity. Descriptive statistics for the interest, efficacy, and identity factors are included in Table 4.

Examination of Table 4 shows that differences between control and treatment class scores on pre-tests for each of the three factors were very small. It is also important to notice that standard deviations tended to decrease more dramatically for the treatment class scores from pre- to post-test suggesting a ceiling effect.

Modeling of the outcome variable after learning for transformative, aesthetic experience was done using analysis of covariance (ANCOVA) controlling for the effect of the pretest. The interest factor demonstrated high internal consistency with Cronbach's $\alpha = .90$ at pre-test and .91 at post-test and the main effect of treatment returned a $F(2, 52) = 18.49$ (2,52), $p = .001$. The efficacy factor also performed consistently yielding Cronbach's alpha of .86 at both pre and post-test. Modeling indicated a significant effect for the treatment returning a $F(2, 52) = 10.35$,

Table 4 Descriptive statistics for outcome variables by condition and time of administration

	Control class		Treatment class	
	Pre	Post	Pre	Post
Interest factor (range 6–30)				
Mean	20.30	22.15	19.52	27.33**
SD	6.51	4.45	6.93	2.53
Efficacy factor (range 7-35)				
Mean	24.08	27.15	24.89	30.11*
SD	7.69	5.50	6.46	2.90
Identity factor (range 4–20)				
Mean	10.73	13.04	10.93	14.52
SD	4.44	3.41	3.98	3.52

* $p < .01$, ** $p < .001$

$p = .002$. The identity factor performed less consistently with Cronbach's $\alpha = .82$ at pre-test and .81 at post-test) and returned a $F(2, 52) = 1.85$, $p = .179$.

Analysis of Conceptual Understanding

Descriptive statistics for each of the three tests of conceptual understanding are provided below in Table 5.

All tests of conceptual understanding were scored twice, independently, blind to student name, condition, and time of administration and inter-rater reliability was very high at .90. Descriptive data for the tests of conceptual understanding show that average differences at pre-test, on each of the units of instruction, were small. Pre-test scores on the weather unit, for example, ranged from an average of 18.25% in the control class to 17.07% in the treatment classroom. Subsequent units showed larger pre-test differences but overall, pre-test scores in both classes were very low. Post-test scores improved consistently in both classes ranging from just less than

Table 5 Means and standard deviations for tests of conceptual understanding by condition and test administration

	Pre-test		Post-test$_1$		Post-test$_2$	
	Control	Treatment	Control	Treatment	Control	Treatment
Weather unit						
Mean (%)	18.25	17.07	80.50	84.13*	66.50	75.72***
SD (%)	19.90	17.46	22.05	17.16	19.51	19.71
Erosion unit						
Mean (%)	17.00	10.90	69.33	84.29*	55.00	76.92**
SD (%)	13.92	10.48	30.12	18.76	25.91	25.75
Matter unit						
Mean (%)	12.00	9.94	72.67	82.37*	42.33	66.99***
SD (%)	8.36	14.53	18.09	14.01	19.08	23.98

* $p < .05$, ** $p < .01$, *** $p < .001$

70% to over 84%. Treatment class post-test scores were quite consistent across the three instructional units ranging from a low of 82.37% on the matter unit test to a high of 84.29% on the erosion unit test. Scores in the control class, however, ranged much more widely from a low of 69.33% on the erosion test to a high of 80.5% on the weather test. Standard deviations on post-test scores were consistently larger for the control class but this may be a ceiling effect as post-test scores in the treatment class were closer to the maximum score for the measure. Effect sizes were calculated using Cohen's d for each of the three units and ranged from a low of $r = .09$ on the weather unit to $r = .29$ on both the erosion and the matter unit. In other words, the effect of the treatment, on tests of conceptual understanding immediately following instruction, appear quite modest. However, analysis of covariance (ANCOVA) was used to investigate differences in post-test scores controlling for the effect of the pre-test. In all models the main effect of the treatment was significant on post-test scores. Estimates ranged from a low of $F(2,52) = 2.22$ in the weather unit to a high of $F(2,52) = 2.95$ in the matter unit. Each of the three post-test differences were statistically significant $p < .05$.

Arguably, more interesting are differences between performances on the immediate post-tests of conceptual understanding and those administered one month after instruction had ended. Scores on the one-month post-test were more consistent in the treatment class ranging from a low of 66.99% on the matter test to a high of 76.92% on the erosion unit. By contrast, scores in the control class ranged from a low of 42.33% on the matter test to 66.50% on the weather unit test. Interestingly, standard deviations on one-month post-test scores were much more comparable between classes than on either the pre-test or post-test scores. In each unit one-month post-test scores were statistically significant ranging from a low of $F(2, 52) = 3.89$, $p < .01$ to a high of $F(2, 52) = 5.55$, $p < .001$.

Cohen's d was used to calculate effect sizes and the effect of the treatment increased across each of the three units starting at $r = .23$ for the weather unit, progressing to $r = .39$ in the erosion unit, and ending at $r = .50$ in the matter unit. These increases in effect size are clearly a factor of the dramatic decrease in one-month post-test scores in the control classroom across each of the three units while the scores remained relatively consistent across time in the treatment class.

Investigations of transfer

Interviews were conducted in a meeting room away from the normal classroom, were audio-recorded, and were between 5 and 20 min in length yielding a total of just less than 13 h of audiotape. All recordings were transcribed verbatim and examined by the lead author and the research assistant independently. Participant student responses to the three interview questions were treated as separate data sources and analyses attempted to look within these groups for themes. During this within question analysis, several themes for student responses were identified, collapsed, expanded, combined, and re-emerged following the procedures of the constant-comparative method (Glaser 1978; Glaser and Strauss 1967). These analytic procedures were executed together and the two researchers spent a total of almost 50 h categorizing, discussing, refining, and checking the robustness of the categorization schemes. Final categories were checked against the entire data set by having three graduate student researchers re-categorize all student responses. This method yielded an inter-rater reliability of .84 with the first categorization lending some sense of trustworthiness to the analysis. It should be noted that a small number of student responses simply defied categorization. In most cases these student responses were bizarre or outlandish in ways that did not contribute to the analysis. These responses were excluded.

Table 6 summarizes participant responses to the three interview questions and provides illustrative examples from both control and treatment classroom participants.

In examination of participant responses to the first interview question about seeing the world differently as a result of new learning, we see large average number of responses per participant ranging from a low of 1.12 responses per participant in the control group to a high of 3.66 in the treatment group. Examining category responses indicates that only 10% of treatment student responses were of the linguistic category while 78% of control group students' responses were categorized as linguistic. This is not surprising as treatment class pedagogy focused explicitly on learning science vocabulary. In contrast, 62% of treatment class student responses were experientially oriented, heavily emphasizing changed perception and experiences in the world while only 9% of control class student responses were experiential in nature. 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 while control class students reported 13% conceptually oriented responses.

Investigating responses to the second interview question in which participants were asked if new learning made the world a more interesting and/or exciting place, we again see large overall average differences ranging from .32 responses per student in the control group to 2.52 responses per student in the treatment group. This is an enormous difference that suggests very clear differences in class outcomes. Relatively small differences existed between treatment and control classrooms on the number of responses categorized as being related to the explanatory power of new ideas (1 example in the control group and 9 in the treatment group). Larger differences exist when examining those responses coded as increasing interest for egocentric reasons (75% in the control group to 32% in the treatment group) or for reasons deemed perceptually enticing (22% in the control group to 54% in the treatment group). Large percentage differences should be viewed with caution, however, as the totals in the control class are very small.

The final question asked if new learning led the student into the world to pursue further inquiry, to tell anyone about it, or continue to wonder about the ideas. Responses lent themselves to a scale from less of a commitment to changed action (thought about science idea or told others about science idea) to more of a commitment (sought further inquiry or experiences with science idea). In this way, responses were coded to the highest level of commitment. This analysis assumes a hierarchical framework that may not be supported empirically at this time but does give a crude lens to examine differences. For example, we see 85% of control

Table 6 Summarized participant responses to interview questions

Example of category response	Number of category responses	Control student response	Number of category responses	Treatment student response
Question: Did learning about X help you see the world differently in any way? If so, in what ways?				
Linguistically oriented	18	I learned all the different names of the clouds like stratus, nimbus, and cirrus.	10	I learned that sublimation is from a solid to a gas.
Conceptually oriented	9	As more and more erosion happens it keeps wearing down the earth.	28	I think about how spinning of the earth causes morning and night.
Experientially oriented	2	When I'm outside I think about where the wind might be coming from.	61	I look up in the sky and see energy moving around.
Total responses	29		99	
Average examples/participant	1.12		3.66	
Question: Did learning about X make the world seem more interesting and/or exciting? If so, in what ways?				
Egocentric	6	Learning all the different names of clouds made me feel smart.	22	I feel like a weather genius now!
Perceptually enticing	2	Thinking about how the energy is related to the state of matter is interesting.	37	Thinking about the nothing in matter makes it more exciting.
Explanatory power	1	Knowing how the molecules move faster and faster as they get more energy makes it easier to see why hot water can burn you.	9	Before I thought, "Why did the workers make the road so bumpy?" Now I know it didn't start out that way—erosion!
Total responses	9		68	
Average examples/participant	.32		2.52	
Question: Did learning about X lead you to further investigate, explore, wonder about, or tell others about it?				
Thought about X/told others	23	I told my mom that when it rains stuff can be eroded and the chemicals in the rain can erode stuff too.	39	I told my whole family that there's 17 miles of air pressing down on them.

Table 6 continued

Example of category response	Number of category responses	Control student response	Number of category responses	Treatment student response
Searched for examples of X	2	I went outside with my science book and tried to see the different kinds of clouds. I tried to find examples of the different kinds.	28	At recess I look around on the blacktop for weeds and bugs and stuff that might be causing erosion.
Pursued inquiry or experience	3	I put books about weather and volcanoes on my Christmas list.	17	I found stuff on-line on the sizes of tornadoes and I read stories of people who had lived through tornadoes.
Total responses	28		84	
Average examples/participant	1.06		3.11	

student responses were at the lowest level of commitment while only 46% of the treatment student responses ended here. Moving up the scale, 4% of control class student responses discuss seeking examples of science ideas in the world while 33% of treatment class responses referenced seeking examples of class ideas outside of school. Only 11% of control class responses correspond to the highest level of commitment indicating only three students sought further experiences with science. However, 20% of treatment class student responses were indicative of this highest level of commitment to changed action. The mean treatment student action score of 3.11 responses per student was much higher than mean control action score of 1.04 responses per student.

Discussion

As emphasized in the opening pages, it may be unnecessary and even unproductive to limit teaching and learning to methods solely aligned with a cognitive, rational perspective. Students learning for transformative, aesthetic experiences reported higher levels of interest in science and experienced greater increases in efficacy beliefs about themselves as science learners. Though differences in identity affiliations trended toward an effect for the experimental pedagogy (control class overall change = 2.31; treatment class overall change = 3.59) this difference is not statistically significant. There is likely some conceptual overlap between these constructs and it is difficult to be certain exactly which outcomes are most attributable to the treatment.

Analysis of conceptual understanding provides important data suggesting students taught for transformative, aesthetic experience learn more than those taught from a cognitive, rational framework. Though these differences were fairly small they were statistically significant. More exciting, in our opinion, is the result that treatment class students continued to score well on identical post-tests of conceptual understanding one month after instruction ended. For some reason, perhaps associated with increased interest and efficacy, treatment class students appear to have forgotten much less over time than control class students. This finding suggests teaching for transformative, aesthetic experience could be a powerful new pedagogical model for 21st century science teaching and learning. Replication seeking validation of these findings is warranted.

Interview analyses also suggest large differences between pedagogical frameworks on the degree to which students felt compelled to see and act differently in the world. In each case interview questions were centered on science content and whether or not this new learning changed student out-of-school living. Arguably, this should be the major goal of education—for in-schooling learning to influence out-of-school living (Pugh and Bergin 2005). Overall differences between classes were large but categorical level analyses also revealed that treatment class students were much more inclined to see the world differently and continue to investigate the world using ideas learned in class. This difference could also explain differences in one-month post-test scores. By contrast, control class students were much more focused on science terminology and sought to learn and apply new knowledge not because it was interesting to do so but because it made them feel smart. Perhaps the individual, pure mentation of schooling from the cognitive, rational framework simply does not contribute to enduring changes of self necessary for changed action in the world (Resnick 1987).

Limitations

This investigation has several limitations that must be considered when weighing the potential promise of teaching for transformative, aesthetic experience. Most significant is the mediating role of the teacher in delivery of the different curricular approaches. Though much detail was provided around how these different pedagogical approaches were implemented there are many other variables that could also have interacted with the instruction in either positive or negative ways. For example, how each teacher used humor in the classroom, built relationships with students, smiled, or meted out reward and punishment could have had an impact on the outcomes of interest. As with any innovation, replication studies must be conducted with larger groups of teachers randomly assigned to either treatment or control pedagogical models—to more thoroughly control for these differences.

In addition to idiosyncratic teacher effects, larger studies involving multiple teachers randomly assigned to treatment and control would also help control other contextual factors that may be inadvertently interacting with outcomes of interest. In fact, school-level effects are a very serious concern with this study and future studies should consider hierarchical linear modeling to deal with this issue of nestedness. This is true for almost all studies of classroom practices.

Finally, it is important to recognize the small sample sizes under analysis. Though ANCOVA is a fairly robust statistical procedure, ceiling-effects on the measures and other factors likely created non-normal distributions that mitigate the trustworthiness of inferential modeling. Again, this concern could be mediated by increasing sample sizes and replicating the investigation. Increasing statistical power would allow for investigations of other important confounding variables that may include student gender, teacher gender, student prior achievement in science, ethnicity, and even student socio-economic level.

Conclusions

Science education is under intense scrutiny in the United States. Test scores in international comparisons, flagging numbers of graduates in math, science, technology and engineering programs, and an increasing share of the market going to foreign economies signals to some, a crisis in American science education. Perhaps there is no better time than the present to consider refocusing science education goals not only around cognitive, rational outcomes like problem-solving and conceptual understanding but to also include teaching and learning for transformative, aesthetic experience. Tentative data suggest the effect may be powerful and help us achieve our goals of deep sustainable learning, increased interest, and learners actively engaged with science outsides beyond the walls of the school.

Appendix 1: Interest, Efficacy, and Identity Items

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

Interest factor items

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

Efficacy factor 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.

Identity factor 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. I cannot imagine myself as a scientist.

Appendix 2: Interview protocol

1. Did you learn anything during the course of this unit that made you think differently or see things differently? If so, tell me what you thought about or

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

Appendix 3: Major curricular goals for Each Unit

Weather unit

- The student will (TSW) use weather data and weather maps to predict up-coming weather.
- TSW learn about severe weather and the necessary precautions for severe weather.
- TSW describe the atmosphere and how conditions there influence weather.
- TSW describe weather conditions and climates in various locations.
- TSW describe seasonal changes in weather and the causes of these changes.

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 and the various kinds and qualities of soil.
- TSW describe ways to control erosion and mass wasting.

Structure of matter unit

- TSW understand the relationship between the states of matter and the energy of the molecules of each.
- TSW describe phase changes using appropriate terminology such as evaporation, condensation, melting, freezing.
- TWS will understand atomic structure and simple chemical bonding.
- TWS will understand the composition of common molecules such as water, oxygen, and carbon dioxide.

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