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Using Arts Integration to Make Science Learning Memorable in the Upper Elementary Grades: A Quasi-Experimental Study

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Abstract. *The Next Generation Science Standards (NGSS) have brought a stronger emphasis on engineering into K-12 STEM (science, technology, engineering and mathematics) instruction. Introducing the design process used in engineering into science classrooms simulated a dialogue among some educators about adding the visual and performing arts to the mix. This led to proposals for a STEAM (STEM + arts) curriculum, as well as warnings that integrating the arts would weaken STEM instruction. The study summarized in this article tested the hypothesis that the arts might provide upper-elementary students, who were still concrete thinkers, with a powerful means of envisioning phenomena that they could not directly observe. This study investigated the impact of STEAM lessons on physical science learning in grades 3 to 5. Ten out of the 55 high-poverty (Title 1) elementary schools in a large urban district in California were randomly chosen as treatment schools and divided into two cohorts. Using a quasi-experimental design that holds general student scientific achievement constant, the study found that students exposed to the STEAM lessons demonstrated greater improvement on physical science benchmark assessments than students exposed to a STEM-only physical science curriculum.*

By putting a stronger emphasis on engineering within the STEM (science, technology, engineering and mathematics) curriculum, the Next Generation Science Standards (2013) have introduced a design process into K-12 science classrooms (Bequette & Bequette, 2015). Some educators have begun to push for infusion of artistic creativity into a new iteration of STEM, adding an “A” to the acronym to make STEAM. This article focuses on the opportunities this approach might provide for enhancing engagement and deepening student understanding of science concepts, while broadening access to meaningful visual and performing arts instruction.

After reviewing the research literature on arts integration, we will look at how the arts might help students in the upper elementary grades to clarify their understanding of physical science concepts and vocabulary. We then test the hypothesis that drawing, painting, drama and dance could provide upper-elementary students, who are not yet abstract thinkers, with a powerful means of expanding their science understanding by providing concrete tools for envisioning phenomena (Inhelder & Piaget, 1958) that the students cannot directly observe.

The research study summarized in this article explored the impact of arts-based physical science lessons in grades 3 to 5. Ten out of the 55 high-poverty (Title 1) elementary schools in a

large California district were randomly chosen as treatment schools, in two cohorts of five schools each, across two years. Using a quasi-experimental design that attempts to hold student scientific achievement constant by holding scores in non-target science content constant (i.e. earth science), the study found that students exposed to the STEAM lessons demonstrated significant improvement on physical science benchmark assessments compared to students exposed to a STEM-only physical science curriculum.

Improving Upper Elementary Science Instruction

In the upper elementary grades, students are expected to learn basic scientific concepts that provide a foundation for further learning. The framework for the *Next Generation Science Standards* (National Academy of Sciences, 2012) is built on the assumption that learning is a developmental progression during which children continually revise their initial conceptions about how the world works. However, if teachers are to guide this on-going process of conceptual revision, they must be given the professional training and tools needed to do so.

Unfortunately, the instructional methods used to teach science concepts in the upper elementary grades are not always developmentally appropriate for children who remain concrete thinkers. Piaget (1954) saw this stage, which lasts from around seven to eleven years of age, as marking the beginning of logical or “operational” thought. The child was now mature enough to use logical rules but could only apply logic to physical objects (hence use of the term “concrete” operations). Yet children this age are typically not able to think abstractly or hypothetically.

This can cause problems when children are asked to think like adult scientists. For example, basic astronomy (including an explanation of why Earth has seasons) is usually taught in grades 3 to 5. This timing is challenging because children this age have trouble understanding abstract explanations of the relationship between Earth’s tilted axis of rotation and the amount of heat the Sun’s rays deliver to various areas on Earth’s surface in summer vs. winter. This may contribute to the persistence of a common misconception, made famous in the film *A Private Universe* (1987), that Earth is closer to the Sun in summer than in winter.

Taking “Readiness” into Account

Elementary science education tends to combine curriculum goals adopted by state educational agencies with “discovery learning,” which uses observation and experiments to introduce students to basic scientific concepts and to the process by which scientific progress is made. The use of science kits is intended to correct children’s misconceptions; an assumption is made that children grasp scientific concepts best if the investigations they undertake mirror the scientific explorations and thinking processes of adult scientists. Unfortunately, this approach has not proven effective in achieving scientific literacy (Mayer, 2004). Many students continue to harbor misconceptions about basic science concepts long after the elementary grades.

One problem may be that designing upper elementary science investigations to mirror the scientific explorations of adult scientists ignores the issue of “readiness.” Inhelder and Piaget (1958) argued that children do not begin to use abstract reasoning to envision the outcome of specific actions until they reach age 11 or older. This is because, once students have entered the “formal operations” stage (age 11+), they are able to manipulate ideas in their heads without depending on external tools. The difference between the thinking of students who have reached the formal operations stage and the thinking of most students in grades 3 to 5 (who still

depend on “concrete” mental operations) may be illustrated by how they would figure out the answer to the following question: “If Ann is shorter than Sue and Sue is shorter than Kate, who is the shortest?” A child in the concrete operations stage needs to draw pictures or use objects to represent Ann, Sue, and Kate. In contrast, a student who has reached the formal operations stage can figure out the answer in her head because she is able to think about variations in height without representing them physically.

What this means is that, for most children in the elementary grades, sketching or using other arts-based means to create a concrete representation of an abstract quality like height can constitute an important thinking tool. The child who sketches stick figures of Tom, Bill, and Sam—then uses the sketches as tools for reflecting on their relative height—is utilizing a developmentally appropriate means of answering the question. Sketching can also help a child to reflect on the steps in a scientific investigation and grapple with the significance of the result.

Crosscutting Concepts Connect the Arts to STEM

The framework for the *Next Generation Science Standards* (NGSS Lead States, 2013) endeavors to move toward a more coherent vision of science education in three ways. First, it is built on the idea that learning is a developmental progression. The framework is designed to help children to continually build on and revise their knowledge and abilities, starting from their curiosity about what they see around them and their initial conceptions about how the world works. The goal is to guide their knowledge toward a more scientifically-based and coherent view of the sciences and engineering; as their knowledge grows, so does their understanding of the ways in which these disciplines are pursued and their results can be used.

Second, the framework focuses on a limited number of core ideas, both within and across the STEM disciplines. This choice was made in order to avoid shallow coverage of a large number of topics and to allow more time for teachers and students to explore each idea in greater depth. Reduction of the sheer number of details to be mastered is intended to provide time for students to engage in scientific investigations and argumentation, so as to achieve depth of understanding of the core ideas presented. Delimiting what is to be learned about each core idea within each grade band also helps to clarify what it is important to spend the most time on and to avoid the proliferation of detail to be learned with no conceptual grounding.

Third, the framework emphasizes that learning about science involves the integration of knowledge of scientific explanations (i.e., content knowledge) and hands-on experience with the practices needed to engage in scientific inquiry and engineering design. As a result, the framework seeks to illustrate how knowledge and practice must be intertwined in designing learning experiences in K-12 science education.

Of particular interest to arts educators is the focus on important themes that pervade science, technology and mathematics, appearing over and over, whether looking at an ancient civilization, the human body, or a comet. These are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design (American Association for the Advancement of Science, 1989). The *Next Generation Science Standards* point to seven concepts that bridge disciplinary boundaries and provide an organizational framework for weaving knowledge from various disciplines into a coherent understanding of the world. The first two concepts are fundamental to the nature of science: 1) that observed patterns can be explained and 2) that science investigates cause-and-effect relationships by seeking to discover

the mechanisms that underlie them. Both themes (a focus on patterns and on cause-and-effect relationships) also play key roles within the arts.

Yet, John Dewey went further, arguing that science, itself, was a form of art. In *Experience and Nature* (1929), he suggested that the history of human experience can be seen as a history of the development of arts. Dewey saw fine art, *consciously* undertaken as such, as peculiarly instrumental in quality because the origin of the art-process lies in human responses spontaneously called out by situations that occur without any reference to art. Seen from this perspective, art is a type of experimentation that leads to new modes of perception, which then enlarge and enrich the world of human vision. Therefore, Dewey argued that the emergence of science from the ceremonial and poetic arts was, essentially, a differentiation among the arts; it was not the appearance of a distinctly different mode of human activity. As Dewey put it:

Thinking is pre-eminently an art; knowledge and propositions which are the products of thinking, are works of art, as much so as statuary and symphonies ... Scientific method or the art of constructing true perceptions, is ascertained in the course of experience to occupy a privileged position ... But this unique position only places it the more securely as an art (1981, pp. 316-317).

Many will disagree with Dewey's philosophical stance on this issue. Yet cognitive science has shown that even young children think, draw conclusions, make predictions, look for explanations, and even do experiments (Gopnick, Meltzoff & Kuhl, 2001). These inborn capacities allow us to learn about the world. Given the infant's drive to explore and experiment, it has become commonplace to note that all children share some of the characteristics of adult scientists. However science also requires disciplined inquiry. So, an effective elementary school science curriculum must not only build on children's natural curiosity, but also help them to reflect meaningfully on what they discover. Unfortunately, there is abundant evidence that the science instruction methods in use in United States schools have not delivered the level of mathematics and science achievement desired by educators, policy makers and the general public. In the next section, we will look at how arts-based strategies may enable children to bring their own real world experiences to bear when attempting to visualize science concepts.

Using Movement to Help Students Visualize Science Concepts

As mentioned earlier, a number of crosscutting concepts pervade science and technology, transcending disciplinary boundaries and proving fruitful in explanation, theory, observation, and design (National Research Council, 2012). Similar crosscutting concepts (e.g., pattern, cause and effect) are present in the visual and performing arts. As a result, well-designed experiences with the arts may provide young students with experiences that they can make use of to reach evidence-based conclusions about scientific phenomena. The integrated science/dance lesson described below provides an example of how children can gain new insights into natural phenomena through creative movement. Dance-based strategies are being used to check—and deepen—students' understanding of an earlier science kit lesson about the connection between the time of day and the position of the sun in the sky.

A third grade teacher stands in the front of the room, backed by a construction paper representation of the Sun. The class has just finished an introductory lesson in which they learned about axial movement in dance (which is any movement organized around the axis of the body while the body is anchored to one spot). Now the children stand facing their teacher, an arm's length apart. The teacher starts a recording of the *Largo* movement of Antonin

Dvorak's *New World Symphony*. The children, each pretending to be the Earth, follow the teacher in rotating slowly to the music, in a counterclockwise direction. When the children are directly facing the "Sun," the teacher pauses the music and asks: "In the place on the surface of the Earth, from which you are now looking up at the sky, what time is it?" Children look at her quizzically. She reminds them of their science lesson, in which they learned that when the Sun is directly above, it is noon.

The music and the dance continue. When the children are facing directly away from the Sun, the teacher pauses the music again and asks: "Can you see the sun?" [No.] "Now it is midnight. You are facing away from the Sun. But did the sun move?" [No.] Then the teacher poses a new challenge. "Rotate to the position you would be facing at 6 a.m. That's half-way between midnight and noon." At 6 a.m., the children can begin to see the Sun out of the corner of their eye. "When we keep on rotating, notice how you can see the Sun better and better. That means the light is getting brighter." When they arrive at "noon" they stop to predict what will happen to their ability to see the "Sun" as they continue rotating toward 6 pm and midnight.

To test their understanding, the teacher has 12 children join hands in a circle, facing outward so that their backs are toward the center of the circle. The circle rotates slowly in a counter-clockwise direction. When the teacher stops the music, she asks different children about the time of day. By playfully probing their comprehension, the teacher is able to guide the children to think more deeply about the connection between the rotation of the Earth and their experience of the time of day. For the child directly facing the Sun it is noon, but for the child facing directly away from the Sun it is midnight, etc. Finally, the teacher gives every second child a badge; these say *California, New York, England, Egypt, India* and *Japan*. This time, when the music stops, the teacher asks the whole class whether it is day or night—or whether the sun is now rising or setting—at the specific places named on the student's badges. Then the teacher asks the children how they could tell what time of day it was.

The lesson just described was created through a three-year project funded by an Improving Teacher Quality grant, which was received by the San Diego Unified School District and administered by the California Department of Education. In another lesson, third graders danced the role of the "Moon" orbiting "Earth," using gestures to indicate the changing phases of the moon. Later, each child played the role of "Earth" orbiting the "Sun"; their task was to complete an orbit for each year she or he had lived.¹ These lessons were not created to replace traditional science lessons. The schools participating in the project continued to use the district's adopted science materials in addition to the STEAM lessons. However, the project did provide students with increased experience in the arts. Before implementation of the project, there was little visual art, theater or dance instruction in these schools. The next section describes the integrated arts/science program of which these lessons were a part.

Implementing STEAM Lessons in Grades 3 to 5

The program described above was called the San Diego Teaching Artist Project (TAP) for Grades 3 to 5 because, during the first year the schools were in the program, teaching artists made weekly visits to each teacher's classroom, where they co-taught a 50-minute integrated science/arts lesson with the teacher. The second year, the classroom teachers taught the lessons themselves with support from the district's resource teachers. The TAP lessons supplemented

¹ Classroom videos showing variations of these lessons are available at: <http://sites.uci.edu/teachingartistproject/gallery/videos/grade-3-videos/earth-science/>

the district's adopted science curriculum for grades 3-5; that curriculum was the Full Option Science System (FOSS), developed by Lawrence Hall of Science at the University of California, Berkeley. The FOSS kits had helped elementary schools in the district's affluent neighborhoods to boost science achievement. However, a large gap had opened up between science achievement at schools in affluent neighborhoods and at schools serving less affluent neighborhoods where many of the students were English language learners (ELLs).

In an effort both to close the science achievement gap and to bring more arts instruction into schools in low-income neighborhoods, the California Department of Education funded a proposal for an arts integration project that would 1) use the visual and performing arts to help students to understand science concepts and 2) help students to become more comfortable using the science vocabulary utilized in the FOSS science kits. The first step was to determine which concepts students had, in past years, most frequently missed on school district benchmark tests. STEAM lessons were designed to correct student misconceptions and clarify concepts students had struggled with. Physical science was targeted first because this was the discipline in which students had experienced the greatest trouble envisioning phenomena explored in their science kits. Just before the school year began in the fall, a daylong professional development workshop was held to introduce teachers to the integrated science/arts (STEAM) lessons.

What do the STEAM lessons look like?

Each lesson started with a *warm up* activity (10 minutes), during which the children stretched and loosened up their bodies, reviewed past activities, and got a preview of the day's lesson. New vocabulary words were introduced and there was a *modeling* segment (20 minutes) when new material was presented and the activities for the day were demonstrated. Next there was a *guided practice* segment (15 minutes), during which students applied new knowledge, engaged in problem solving, and received corrective feedback. During the final segment, the teacher *debriefed* the students *and evaluated* progress toward accomplishing the lesson goals.

As Ainsworth, Prain and Tytler (2011) pointed out, visualization is integral to scientific thinking. Scientists do not just use words; they rely on diagrams, graphs, videos, photographs, and other images to make discoveries, explain findings, and excite public interest. Scientists imagine new relationships, test ideas, and elaborate knowledge through visual representations. In keeping with this tradition, the TAP visual art lessons invited students to draw and to look closely at natural objects and works of visual art, with the goal of improving their observation skills. The careful sketches students made in their science notebooks while working with the science kits helped them to observe closely and keep an accurate record of their work. For teachers, student drawings were a powerful means of picking up on misconceptions, so that teachers had the opportunity to address any student misconceptions in the next lesson.

Comprehending the academic language in which scientific literature (including textbooks) is written and discussed is challenging for many students (Snow, 2010). Scientific language is concise, precise, and authoritative; it uses sophisticated words and complex grammar. The complex vocabulary used in science instruction can easily interfere with student comprehension. To help students become comfortable with the academic language in which key scientific concepts are conveyed, the TAP teaching artists utilized classroom drama activities. Through role-playing, students were able to explore the way scientists carried out research, described their findings, and looked at the intersection between science and daily life.

According to teacher reports, dance/creative movement proved to be the most powerful tool for helping students to envision phenomena that cannot easily be physically observed. The active physical involvement required by dance appeared to be especially effective in (1) getting students to actively focus on the lesson and (2) helping students to transform the conceptual information contained in science lessons into memorable personal experience. These teacher reports were in line with Kress' (2009) research on science learning, especially his description of classrooms as semiotic spaces where meaning-making occurs across modes ranging from visual and written to spoken and gesture. As Kress explained, "the world of meaning is multimodal" (p. 19).

Making Life Science Concepts Memorable through Dance

The nature of the dance lessons varied widely, from the slow movements of the third grade astronomy lesson described earlier to fast rap-like songs such as the one that reviewed concepts from the fourth grade life science unit on ecosystems. In preparation for this lesson, students practiced the words for five minutes each day for three days. The first rap was:

*"Small as a puddle or large as the sea, living and non-living **thrive** in harmony.
Animals, plankton, water, soil, air. **Ecosystems** are everywhere!"*

After students had memorized the words, they learned the steps that went with them. To help teachers remember how the rap and movements fit together, videos were made of the lessons taught by teaching artists. The lesson plans and videos are available, free of charge, on-line.²

The fifth grade life science rap lessons require a room large enough that a simplified version of the circulatory system can be mapped out on the floor with painter's tape.³ Students, playing the role of blood cells, follow the taped pathway, chanting "*Left from the heart, away through the arteries*" as they energetically exit (dancing) from the left side of the heart through the aorta. Later, as they return through the veins to the right side of the heart, they chant: "*Right to the heart, the veins, the veins.*" To show that the oxygen in these cells is now depleted (resulting in a loss of energy), the students' shoulders droop as they make their way back to the heart. The heart then pumps the blood cells onward to the lungs, where they are reenergized (given an "oxygen" card by students who represent the lungs). Returning to the heart, the blood cells are again pumped out into the rest of the body, where they give up their "oxygen" card and take a "carbon dioxide" card. Lesson 2 in this unit depicts the activity of the digestive system. Lesson 3 shows how the circulatory system picks up nutrients from the digestive system, distributes the nutrients through the body, and brings back waste materials to be disposed of.

During these life science lessons there were a few sheepish giggles as the students made mental connections between the body parts they were imitating and the workings of their own bodies. But this personal connection also made the lessons inherently interesting. Students found it more difficult to relate to physical science lessons than to either the life science lessons or the astronomy lessons. Therefore, the physical science lesson described below includes the verbal interactions between teacher and students that helped to keep the students focused.

2 Ecosystem videos: <http://sites.uci.edu/teachingartistproject/gallery/videos/grade-4-videos/life-science/>

Ecosystem lesson plans: <http://sites.uci.edu/teachingartistproject/lessons/grade-4/life-science/>

3 Circulatory system lesson plan: <http://sites.uci.edu/teachingartistproject/files/2014/08/G5LSD-Lesson-1-We-Got-The-Beat-The-Circulatory-System.pdf>

Circulatory system video: <http://sites.uci.edu/teachingartistproject/gallery/videos/grade-5-videos/life-science/>

What does it take to turn on an electric light bulb?

The physical science lesson “Get Your Motor Running: Circuits and Motors”⁴ reviewed the concepts 4th graders had explored through their science kit on magnetism and electricity. During the warm-up segment, children reviewed their last STEAM lesson, in which they played the role of electrons. Dancing in a conga line, the electrons moved out of the negative pole of a D-Cell battery, then moved along a wire (D-cell and wire were both marked with tape on the floor) to the positive pole, where they re-entered the D-cell. Next a student volunteer was asked to play the role of the “switch”. The switch was inserted between the positive pole of the D-Cell and the wire, making it possible to easily turn the electric current on and off.

The children then learned two short chants. The words for the *Closed Circuit* Chant were: “The *switch* is on; the *circuit* is *closed*; electricity flows.” The chant was accompanied by a gesture. With hands clasped in front of the body, the arms made a circle at chest height. The words for the *Open Circuit* Chant were: “The *switch* is off; the *circuit* is open; electricity stops.” This was also accompanied by gestures. The hands stopped, separated, then flipped up with elbows bent. The student who played the switch signaled the on and off positions by using these gestures, while saying the Open Circuit Chant or the Closed Circuit Chant. The rest of the group (except for the student “electrons”) said the chant and performed the gestures at the same time. The electrons danced along the wire when the switch was closed and stopped when it was open.

Once the children were comfortable with the chant, the “switch” was removed, leaving just the wire and the D-cell. The teacher asked the class to help her make a model of a one-wire *circuit* that used the battery to light a bulb, using creative movement. The conversation went like this: *How would someone play the role of a light bulb.* [The person who plays the light bulb could make flashing movements with his arms and hands when the electricity is flowing.] *Where would we place the bulb so that the electricity in the D-cell would cause it to light up?* [The metal tip on the bottom of the light bulb would touch the positive pole of the D-cell. The wire coming from the negative pole of the D-Cell would touch the metal screw-in part at the bottom of the bulb so that the electrons could move through it.]

When the teacher saw that the concept was understood by all of the students, the teacher made the activity memorable by introducing music and encouraging the student “electrons” to dance along the wire—using a flowing locomotor movement—from the negative pole of the battery, along the wire to the light bulb (which “lit up”), through the positive pole and back into the battery. After this, the music was turned off and the class tackled a new challenge. They discussed how they would create a circuit that included two wires and a switch, allowing the light bulb to be turned on and off without unhooking the wires.

What is needed to create an electric motor?

Now the class was ready to apply their knowledge in a new way. Instead of converting electricity into light, they would now convert electricity into motion by creating a motor. First they discussed how to represent the various “parts,” consisting of a battery, two wires, a switch, and a motor. The teacher arranged students into groups of approximately ten:

4 Circuits and Motors Lesson Plan: <http://sites.uci.edu/teachingartistproject/files/2014/08/G4PSD-Lesson-2-Get-Your-Motor-Running-Circuits-and-Motors-.pdf>

1. Four students would create the D-cell. In pairs, they faced one another, raising their arms and clasping hands to create an arch, under which an “electron” could crouch.
2. Four students would create the *motor*. Students would create a way to show each of the four parts of the imaginary motor working together. To do this, they used *contrasting* movement. (Example: student #1 bent down and stood up; student #2 pressed on student #1’s head or back to make the down movement and released to cause the up movement; student #3 connected to student #2, lifting and lowering leg; student #4 connected to student #3, providing lift to raise the leg and pressing to lower the leg of student #3). All four students (who were pretending to be the parts of a *motor*) moved at the same time.
3. Another student was the switch. *Where should we place the switch?* [The switch should be next to the motor.] The “switch” showed on and off positions by using the gestures to show open and closed circuits. This student said the Open Circuit Chant or the Closed Circuit Chant and performed the gestures to open and close the circuit. Students who were not in the group currently performing, said and performed the chants with the “switch”.
4. This time the flow of electricity in the *circuit* was to be shown by taking a long piece of yarn or string and tracing the pathway from the D-cell, to and from the *motor*. When the circuit was closed, a single student acted as an “electron” dancing along the “wire”.

Culminating Activity: “Making the Motor Run”

This culminating activity, in which a group of students cooperated to play the role of a “machine”, was videotaped for students to watch later. Everyone began in an opening pose in stillness. The “switch” started the exercise by performing the chant and creating a closed circuit. Students not in the group currently performing also repeated the words. (The next steps happened almost simultaneously.) The electricity (a student “electron”) began to flow in the circuit. All four parts of the motor began to move. Background music began and the demonstration continued for 15 seconds. Then the music stopped. The student “switch” (and others) performed the chant to open the circuit. The electron and motor stopped. (There was stillness). The exercise was repeated two more times. Then, after each group had demonstrated their “machine”, the teacher debriefed the students, asking such questions as:

What does a motor do in a circuit? [The motor converts electric energy into the energy of motion.] *What is the role of the switch?* [The switch controls the flow of electricity through the wire by opening or closing the circuit.]

Rationale. So as not to undermine the discovery process associated with the science kits, the STEAM lessons were taught as review lessons after students’ work with the science kits was finished. Yet, although the class had already carried out the science kit activities, many students still had trouble remembering the relevant vocabulary and concepts. Scores on district benchmarks had demonstrated that, for students who were still struggling with academic English, long-term retention was limited. The STEAM lessons not only gave students an exposure to the arts, which they would not have had otherwise, but provided an opportunity to experience the science concepts and vocabulary from an engaging new perspective. But how do we know the STEAM activities had an impact on science learning? The next section describes a quasi-experimental study that was carried out to determine the impact of the STEAM lessons.

Impact of Arts Integration on Student Achievement

The purpose of the quantitative study summarized below was to investigate the effect of

nine STEAM lessons on the physical science achievement of elementary students in grades 3-5. Physical science had proven to be the most challenging area for elementary students because so many of the phenomena studied take place at the atomic level; therefore, they cannot be directly observed. Yet, at the high school level, physics and chemistry made up 2/3 of the high school science courses taken by a majority of students preparing to apply to four-year universities.

Analysis of Student Test Scores

This study looked the impact of nine hour-long arts/physical science lessons that were implemented during the 2011-2012 school year across two randomly selected cohorts of schools with cohorts differing by degree of experience with the curriculum. These nine lessons used a combination of dance, theater, and visual art to review science vocabulary and concepts over a nine-week period. The first cohort of the treatment group consisted of 893 students across five schools whose teachers had one year of training prior to the experiment; the second cohort of the treatment group consisted of 1,263 students across five schools whose teachers were currently co-teaching with teaching artists (professionals trained in our curriculum). The control group consisted of 5,683 students with the usual course curriculum. There were differences in baseline characteristics across cohorts, which may contribute to biased results if not corrected for in the study. Descriptive statistics for this sample are provided in *Table 1*.

Table 1.

Descriptive Statistics, Whole Sample and 5th Grade Sample by Group

		Cohort 1	Cohort 2	Control
		N (%)	N (%)	N (%)
Gender				
	Male	439 (49.2)	648 (51.3)	2965 (52.2)
	Female	454 (50.8)	615 (48.7)	2717 (47.8)
Race				
	African American	44 (4.9)	217 (17.2)	513 (9.0)
	Asian	59 (6.6)	93 (7.4)	475 (8.4)
	Latino	730 (81.8)	697 (55.2)	4187 (73.7)
	White	19 (2.1)	65 (5.2)	377 (6.6)
	Filipino/ Pac. Islander	39 (4.4)	188 (14.9)	118 (2.1)
	Other/ Multi-ethnic	2 (0.2)	3 (0.2)	12 (0.2)
Parental Education				
	Declined to State	170 (19.0)	156 (12.4)	994 (17.5)
	Less than HS Graduate	254 (28.4)	240 (19.0)	1568 (27.6)
	High School Graduate	276 (30.9)	365 (28.9)	1595 (28.1)
	Some College	109 (12.2)	298 (23.6)	922 (16.2)
	College Graduate	49 (5.5)	173 (13.7)	411 (7.2)
	Graduate School	35 (3.9)	31 (2.5)	192 (3.4)
Grade				
	3 rd Grade	291 (32.6)	429 (34.0)	1928 (33.9)
	4 th Grade	327 (36.6)	437 (34.6)	1791 (31.5)
	5 th Grade	275 (30.8)	397 (31.4)	1963 (34.6)

	Mean (SD)	Mean (SD)	Mean (SD)
Avg. Sch. Length in days	315 (19)	300 (24)	303 (24)
Physical Sci. Benchmark	3.4(1.1)	3.6(1.0)	3.4(1.1)
Earth Sci. Benchmark	3.2(0.98)	3.5(0.99)	3.5(1.0)
Life Science Benchmark	3.2(1.1)	3.7(1.0)	3.4(1.1)
Total	893	1263	5682

Note: Percentages or standard deviations are in parentheses. Not all Ns add up to total due to missing data.

We expected students of the teachers who were implementing the STEAM lessons to perform better on benchmark tests covering the targeted curriculum (i.e. physical science) than students of teachers who were not implementing the STEAM lessons, without showing significant improvement in science areas that were not targeted by our curriculum that year (i.e. earth science and life science). Scientific knowledge was measured by standardized district-wide tests, which the school district required teachers to give to all students in third, fourth and fifth grade. Additional analyses were conducted on English learner subgroups and by student grade, but no significant differences were found and these results are omitted from this paper.

Results of the Quantitative Study

We used OLS regression to demonstrate the effectiveness of the STEAM curriculum while controlling for socio-demographic covariates and non-targeted science scores that may naturally vary by school. We provide three models to demonstrate the importance of these covariates as experimental schools did already have higher achievement going into the program. Model 1 simply controls for the effect of being within an experimental cohort, either cohort 1 or cohort 2. Model 2 includes control over socio-demographic characteristics, which may correlate with performance, and Model 3 adds control over non-targeted science benchmarks. All outcome variables are standardized within the sample for comparison reasons. Results for the analysis are provided in *Table 2*.

Table 2.
Benchmark Scores, by Regression Model

	(1)	(2)	(3)
Cohort 1	0.08 (0.04)	0.09 (0.04)*	0.35 (0.03)***
Cohort 2	0.23 (0.03)***	0.15 (0.03)***	0.10 (0.02)***
3 rd Grade	0.17 (0.03)***	-0.05 (0.03)	0.04 (0.02)
4 th Grade	-0.11 (0.03)***	-0.08 (0.03)	-0.14 (0.02)***
Female		0.00 (0.02)	-0.03 (0.02)
African American		-0.27 (0.06)***	-0.06 (0.05)
Asian		0.20 (0.05)***	0.10 (0.05)*
Latino		-0.13 (0.05)*	-0.02 (0.04)
Pacific Islander		0.19 (0.07)	0.13 (0.06)*
Other/Multi-ethnic		-0.01 (0.24)	0.06 (0.19)
Refused Parent Ed		-0.07 (0.03)	-0.03 (0.03)

Less than HS Ed		-0.02 (0.03)	0.03 (0.02)
High School Grad Ed			
Some College Ed		0.12 (0.03)***	0.04 (0.03)
College Grad Ed		0.18 (0.05)***	0.01 (0.04)
Graduate Ed		0.20 (0.07)**	0.01 (0.05)
ELL Status		-0.43 (0.03)***	-0.09 (0.02)***
Earth Sci. Benchmark			0.38 (0.01)***
Life Sci. Benchmark			0.37 (0.01)***
R-Squared	0.02	0.08	0.49
N	7376	7376	6570

Standard errors in parentheses. Parental education compared to High School Graduate.

* $p > 0.05$; ** $p > 0.01$; *** $p > 0.001$

Initially, Model 1 suggests that only students in the second cohort (those students whose teachers were currently co-teaching the STEAM lessons with a teaching artist each week) saw improvements in their test scores by 0.23 of a standard deviation. This is misleading, however, as later models reveal that cohort two benefited from better overall scores in general, meaning that these Model 1 results may be biased in their favor. Control over socio-demographic characteristics and, more importantly, non-targeted curriculum reveal that cohort 1 saw moderate improvements in benchmark scores over controls (0.35 of a standard deviation; $p < 0.001$) with cohort 2 trailing behind with slight improvements in benchmark scores over controls (0.10 of a standard deviation; $p < 0.001$). In layman's terms, this amounts to an improvement, with a student moving from 50th percentile to 63rd percentile in the targeted curriculum when assigned a teacher well-trained in the STEAM curriculum, all other factors equal. This is a fairly impressive effect for only nine hours of exposure to the intervention.

Limitations. The standardized tests used to measure science knowledge in this quasi-experimental study did not focus on the naïve misconceptions that were a primary target of the STEAM lessons. This is because we were not able to arrange for a suitable control group to take the Misconceptions-Oriented Standards-Based Assessment Resources for Teachers (MOSART) inventory from the Harvard-Smithsonian Center for Astrophysics. Furthermore, this study covers only one year of data and so long-term memory is not assessed in this paper.

In conducting our analysis, we also attempted to examine the effect curriculum had on CST scores provided to 5th grade students within our study. Unfortunately, this proved problematic as the sample at that grade level was too small to detect any meaningful changes and it was difficult to find a meaningful way to control for differences in student ability (e.g. no pre-test, limited availability of non-targeted scores, etc.). Likewise, we did not find any differences in results for various subgroups within the sample, such as English learners.

Future Research. The finding that the STEAM lessons were as beneficial to children who spoke English at home as to English learners was unexpected. Earlier research with K-2 English learners in San Diego (Brouillette, Grove & Hinga, 2015; Greenfader & Brouillette, 2013, 2017; Greenfader, Brouillette & Farkas, 2015) led us to believe that arts integration was especially helpful for young English learners. But our findings suggest that, at least in the high-poverty urban schools where we worked, all children benefitted equally from the use of

STEAM lessons to help them to envision phenomena that they were not able to directly observe. More research is needed to better understand the role that developmental readiness plays in student understanding of scientific concepts in the upper elementary grades.

Elementary school science teachers often lack adequate content preparation, especially in the physical sciences; almost three-fourths of elementary teachers perceive a need for professional development to deepen their own science content knowledge (Fulp, 2002). Additional research will be needed to measure the success of the STEAM lessons in correcting the naïve misconceptions of students in grades 3-5.

Teacher Focus Groups

Focus groups were held with teachers at each participating school. The teachers were enthusiastic about the opportunity to co-teach the STEAM lessons with a teaching artist in their own classrooms. They found that working with a coach provided a more effective professional development experience than after-school workshops or meetings held away from the school site. When asked about the impact of the program, teachers mentioned students who had not met with success when traditional teaching methods were used. A typical observation was: “The different learning style engaged kids who might not participate normally.” One teacher noted:

I have a student who has a lot of behavior issues. I think maybe in other lessons he thinks he can't do it because it's too hard. But, in the arts lessons, he feels he can be successful. So, it isn't this huge academic pressure on him. Yet he is still learning.

Because the lessons got students up and moving, even students who were often restless became more engaged. Teacher perceptions of the impact on science learning are described below.

Science Learning. Teachers spoke of the benefits of giving students a “double dose” of science, starting with the science kit investigations and following up with the arts-based review lessons. They commented that the opportunity to learn the same concept in different ways was especially helpful for students whose limited academic vocabulary made it difficult to follow the discussion at the end of the science kit units. Typical comments included:

- I think the students were highly engaged. They definitely learned science concepts more deeply than in past years because of the movements associated with the concepts.
- There are kids for whom lecturing is all it takes. But there are other kids who don't get it yet. They don't see it without moving around and physically acting it out. The more you hear something the more you own it. The more you're comfortable. But if I just repeat the science lesson, the kids stop listening. The arts made it new.
- There's a chant they did about electricity flowing and the circuit being open. The kids are probably going to remember that for many years and will understand it.
- Dance worked best, tying movements to a concept or vocabulary word. It's easier to learn because it's more concrete. They are retaining the information better.

The observations of these teachers were in line with the Dana Consortium finding that an interest in a performing art leads to a high state of motivation, which produces the sustained attention necessary to improve performance (Gazzaniga, 2008). In addition, teacher comments echoed findings from earlier studies that showed arts integration boosted student engagement

(Brouillette, Childress-Evans, Hinga & Farkas, 2014) and supported development of a greater sense of community within the classroom (Brouillette, 2010).

Recognizing a Crucial Dimension of the STEM vs. STEAM Debate

A tug of war is currently looming between proponents of STEM education (science, technology, engineering, and math) and advocates for STEAM lessons, which add art to the mix (Jolly, *Education Week*, November 18, 2014).

Proponents of STEAM point out that, in engineering, product design (a form of art) clearly plays a role. Artists routinely use technology—ranging from a simple paintbrush to digital media—in the creation of art. Scientific drawings and photographs often have great aesthetic appeal. But opponents of the STEAM movement argue that the commonalities between the arts and the STEM disciplines are incidental, either to the application of mathematical and scientific concepts to the expansion human knowledge or to the production of technologies that solve real world problems. Some STEM education advocates argue that attempts to integrate art/design into the teaching of science or math are likely to undermine the rigor of STEM instruction. On the other hand, many arts educators are wary of the instrumental use of the arts, simply to boost achievement in other fields.

The research summarized in this article suggests that such arguments, which tend to focus on older students, miss a key contribution that STEAM can make through boosting the scientific understanding of students in the upper elementary grades. The framework for the *Next Generation Science Standards* (National Academy of Sciences, 2012) is built on the assumption that learning is a developmental progression during which children continually revise their initial conceptions about how the world works. Insights that are developed through arts-based experiences can contribute to this process. Drawing, painting, and sculpting can provide children who are not yet abstract thinkers (Inhelder & Piaget, 1958) with a powerful means of promoting understanding by providing concrete methods for envisioning phenomena that children cannot directly observe. Nor does the potential of STEAM extend only to the visual arts. Dance can effectively represent movement through space and the relationship between moving objects. Music builds an ability to recognize patterns and relationships (Catterall, 2009).

This suggests that the arts, like mathematics, may have a dual role in education. We recognize that mathematics is both an independent scholarly discipline and a crucial tool used in scientific research. Now there is growing recognition that the arts are not only independent disciplines, but effective tools for depicting and understanding the world at large. Just as children learn to count on their fingers before starting school, children routinely learn to sing, dance and engage in dramatic play long before they begin to take formal lessons in the arts.

Arts advocates are understandably wary of suggestions that arts education is valuable *only* to the extent that it promotes broad social and economic goals. Therefore, many feel uncomfortable with discussions of arts integration (STEAM) as *instrumental* in boosting science achievement. They ask: should the *intrinsic* benefits of arts experiences (such as aesthetic pleasure, stimulation, and a sense of meaning) not be given equal emphasis? The final section of this article addresses that question, pointing to a deeper reality beyond the oft-cited instrumental/intrinsic dichotomy.

The Rand report, *Gifts of the Muse: Reframing the Debate about the Benefits of the Arts* (McCarthy, Ondaatje, Zakaras & Brooks, 2005), offers a useful framework for understanding

the complexity of the challenge facing arts advocates. An unfortunate effect of the diminished presence of the arts in U.S. public schools is that, to the extent that the intrinsic benefits of the arts are mentioned in policy discussions, they tend to be seen as having only a private, personal value that is largely irrelevant to objective, quantitative discussions of school policy. But, for the personal benefits students receive from the visual and performing arts to be taken seriously by policymakers, arts educators must show how these private benefits serve the public good.

TAP teachers touched on a key issue when they commented that, during the arts lessons, “students were highly engaged.” There was a “wide awake” quality to the children’s awareness when working with the teaching artists that—along with the concrete nature of the activities—made it easier for children to absorb new concepts and vocabulary. Student interest was awakened by the pleasure they experienced, not just from the possibility of getting higher test scores. Motivation may be the “missing link” that is routinely overlooked by those who assume that “intrinsic” benefits are strictly private. Over time, motivation to participate in STEAM lessons and other kinds of arts integration can lead to growth in individual capacities, such as enhanced powers of observation and an increased understanding of the world. These benefits not only enrich individual lives but also have a spillover component. Increased individual capacity and achievement bring public benefits. Personal benefits are not strictly private.

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