Fossil Mobiles: Exploring the Process of Art as Science Inquiry for Elementary Students through a Grounded Theory Study

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Abstract
Arts integration into Science, Technology, Engineering, and Mathematics (STEM) subject areas is currently an important area of investigation. This study developed a grounded theory of how artmaking of a mobile related to fossil life of the Devonian period engendered geoscience inquiry. Data were collected from elementary students entering fourth to sixth grade (7 male, 9 female) attending a week-long summer camp at a Midwestern university. Students engaged in a daily hour-long class creating fossil mobiles and learning geoscience content through illustrated slide shows, form and function sets of materials related to Devonian fossils, fossil books, and a fossil hunter- fossil find matching game. The art fossil mobile was constructed of painted dowel rods suspended from a beaded string with four craft fossils (traced onto clear plastic and back-painted or stenciled onto canvas) attached to the ends of the rods. The grounded theory research design identified seven major repeating interactions among the triad of art, science, and students: (1) art promoting science inquiry, (2) art aspects positively influencing science learning, (3) science learning increasing interest in fossils, (4) science influencing art, (5) student-centered artwork increasing desire for more art knowledge, (6) student-centered art providing connections to science, and (7) student-centered science increasing interest in fossils. Implications for educators include integrating art activities into science lessons, thereby providing engagement and motivation for students, supporting students' fine motor skills development, and building a community of learners. Geoscience educators should consider the positive cyclical effects of art-science-student interactions identified in this study.

Key Words
Grounded theory; art-integration; elementary students; fossils

Introduction

McNiff (2011) defines art-based research as "involving the researcher in some form of direct artmaking as a primary mode of systematic inquiry" (p. 385). McNiff finds that art-based studies are especially useful to therapy and education, two areas that use creative expression as a way of understanding, communicating, and enhancing development. Although both science and the arts have many similarities in modes of investigation, there are strong differences. Science seeks exact replication of results while the arts encourage uniqueness and variation; science investigations are generally structured to test hypotheses, whereas art is often initiated with uncertain premises and outcomes, creating themes and messages through the artistic process. These contrasts point to the value of artistic inquiry in reaching new areas of human understanding.

This study used Glaser's classic grounded theory research design (Glaser & Holton, 2007) to develop a theory of how involvement in art-based research through the making of an artwork related to a geoscience topic affected student inquiry into that topic. In the current study, elementary students at a summer day camp created fossil art mobiles to explore the fossil life of the Devonian Period. In the following literature review, historical and contemporary examples of scientist-artists, the current movement to integrate the arts into science, the contributions of art to science learning and a brief explanation of classic grounded theory applied to the study are examined.

The Historical Combination of Artist and Scientist

Today's scholars are often relegated to either the arts or the sciences, but, historically, the combination of artist-scientist was more common (Root-Bernstein, 2011). Artists often became inventors of scientific devices related to their work, influencing future technologies. The first computers used programmable devices similar to those used by the fiber artist Jacquard who constructed a programmable device to control his tapestry weaving looms. In addition to programming the first "computer," Jacquard also created the first black and white digital image from black and white thread. "In fact, the computer chips that run virtually all our devices today are made using a combination of three classic artistic inventions: etching, silk screen printing, and photolithography" (Root-Bernstein, 2011, para. 2). The medical field has benefitted from needlework artists: surgeons performing heart surgery use the stitching techniques of lace makers (Root-Bernstein, 2011). The musical arts have also made an impact on science and technology. One example is the pacemaker. This device that so rhythmically keeps a human heart beating was derived from a metronome (Gott, 2007). These inventions show how the use of ideas in one domain can provide inspiration for work in another.

Leonardo da Vinci has been well-recognized as a genius artist-scientist, being an "accomplished painter, sculptor, architect, musician, mathematician, engineer, inventor, anatomist, geologist, cartographer, botanist, and writer" (Smith, 2014, p. 58). His success in so many fields may have been due to the relative infancy of these fields and their lack of delineation into separate areas of endeavor (Smith, 2014). Many artists have turned scientists as well as scientists becoming artists. For example, Conrad Dressler was a sculptor working in bronze and marble who began to work in ceramics, eventually inventing in 1912 the first tunnel kiln through which a car of ceramics moved on rails as it was heated, fired, and cooled (Ruark, 2015). This invention allowed the kiln to be continuously used, speeding production of ceramic products. Beatrix Potter, beloved author and illustrator of Peter Rabbit stories, made scientific contributions to the field of mycology (fungi), but was prevented from formally pursuing the field during the nineteenth century because of her gender. She, therefore, focused on study of woodland animals and illustration of children's stories about them (Lear, 2006-2015). A 20th century scientist who pursued art to gain new perspectives was Richard Feynman, the Nobel Prize-winning physicist. He began drawing after he became friends with an artist, offering to trade physics lessons for art lessons. Feynman pursued art as an outlet for expressing his feelings of the beauty of nature, eventually becoming quite accomplished (Feynman, 1985).

Currently, a father and son glassblowing artist and mathematician team, Erik and Martin Demaine, use numbers to create origami sculptures, some of which are contained within glass. "Working closely together, they blend handwork and materials with theory and numbers, in a spirit of discovery and play. Science inspires their art, while art informs their scientific research" (Lovelace & Wolinsky, 2014, para. 2). Erik Demain, a professor of computer science at MIT, launched the field of computational origami, believing that an understanding of how things fold and unfold has practical applications for robotics, medicine, airbags, and other industrial products.

Integrating Arts with Science

In recent years, researchers expanded the field of STEM (Science, Technology, Engineering, and Mathematics) to integrate the arts (represented by the letter "A"), broadening the STEM acronym to STEAM (Daugherty, 2013; Maeda, 2013). Maeda (2013) described the integration of the arts into STEAM as a process of combining forces of convergent (looking for the *one* right answer) and divergent (seeking *multiple* possible correct solutions) thinkers. Storksdieck (2011) claimed that adding the arts to STEM introduces a different way of perceiving, knowing, and interacting with the world, thereby expanding the toolbox of scientists and engineers. Storksdieck also noted that the addition of the arts adds an element of freedom and fun to STEM areas. Integrating the arts into science and engineering may give students who had not considered becoming scientists and engineers the opportunity to use skills from those fields for other projects or learning opportunities (Daugherty, 2013).

Daugherty (2013) explained that much like the sciences have the scientific method and engineering has the engineering design method, the arts also use a similar process known as studio habits of mind or studio thinking. The steps in the studio thinking heuristic overlap with the steps found in science and technology education. Studio thinking is "an experience-based technique for problem solving, learning, investigation, and discovery" (Daugherty, 2013, p. 12). Engineering and art both include the steps of considering the problem and its challenges, the benefits and shortcomings of different approaches or material choices, the generation of design options, the production of prototypes, and the evaluation of their effectiveness (Bequette & Bequette, 2012). The arts, technology, and sciences work hand-in-hand. Root-Bernstein (2011) explained that "Arts provide innovations through analogies, models, skills, structures, techniques, methods, and knowledge. Arts don't just prettify science or make technology more aesthetic; they often make both possible" (para. 1).

How the Arts Support Science Learning

Using creative arts methods with hands-on activities in science education may retain young people in STEM fields by introducing new perspectives, creativity, and innovation (White, 2011). A study of teachers' views of what art adds to the curriculum (Venäläinen, 2012) determined three main contributions: education concerning aesthetic properties and the creation of art; creativity and self-expression; and meta-cognitive and affective skills. For example, using Southwestern jewelry making to reinforce concepts as part of a geoscience lesson on color, luster, hardness, and other physical properties of minerals provided cross-disciplinary connections among science, social studies, and art, with the opportunity to apply new knowledge through the motivating, real-world activity of making a piece of jewelry (Russell & Tripp, 2010). Another example involved an exploration of marbled art with acid-base indicators and basic solutions, allowing students to learn while viewing chemistry with a new aesthetic perspective (Cil, Çelik, Maçın,T., Demirbaş, & Gökçimen, 2014). In a third study (Olsen, Zhbanova, Parpucu, Alkouri, & Rule, 2013), creation of three-dimensional pop-up pages about environmental issues during a science class were found to increase student motivation, focus, and collaboration, while allowing students to practice fine motor skills, spatial thinking, and paper-engineering concepts.

Arts incorporated in science may help students understand science concepts better. Merten (2011) described a science lesson on wind and the Beaufort wind force scale in which students generated observations of wind such as flags whipping, branches moving, and grass waving before viewing professional artwork depicting wind and then creating art of their own. Observing and classifying the effects of wind helped students learn the concept of the Beaufort scale better. Similarly, a science-focused performing arts project enabled students to gain better understandings of science concepts by script writing, storyboarding, creating clay models, and taking digital images to finally produce an animated presentation (Talib Norishah, & Zulkafly, 2014). Additionally, fifth grade students reported they understood science concepts better through a science e-book project in which they planned, wrote, illustrated with original photographs, and published e-books (Encheff, 2013). Another study detailed how ninth grade students wrote and illustrated picture books about cells for fourth grade students, learning more science content in the process (DeFauw & Saad, 2014).

Many scientists who have been awarded Nobel prizes, such as physicists Luis Alvarez and Albert Einstein, together with chemist Hans von Euler-Chelpin, ascribed their innovative abilities of visualizing science processes and devising pioneering experiments to their work in the arts (Root-Bernstein & Root-Bernstein, 2013). The more arts and crafts that scientists engaged in across their lifespans, the more likely they were to generate important science findings in their fields (Root-Bernstein & Root-Bernstein, 2013). Advanced visual imaging abilities, a major predictor of science success, may be due to observations of nature or experiments made through sketches or paintings (Winner & Casey, 1992). Art, music and dance allow participants to recognize and play with patterns, another important aspect of science thinking. Craft-making exercises fine motor skills essential to laboratory research. Finally, translating scientific concepts into art elements requires reflection and re-organization of the ideas to fit within the work of art, prompting questions and thereby promoting deeper science learning.

Glaser's Grounded Theory Applied to the Study

"[C]lassic GT is simply a set of integrated conceptual hypotheses systematically generated to produce an inductive theory about a substantive area" (Glaser & Holton, 2007, p. 48). "The goal of grounded theory is to generate a conceptual theory that accounts for a pattern of behavior which is relevant and problematic for those involved. The goal is not voluminous description, nor clever verification" (Glaser, 1978, p. 93). The goal of using grounded theory in the current study was to examine the effects on elementary students of involvement in art-based research through the making of an artwork (a mobile) related to the geoscience topic of fossil life.

In accordance with classic grounded theory, hypotheses were not generated in advance and *all* observations were used as data. The classic grounded theory product is not a factual description, but a set of carefully grounded concepts organized around a core category and integrated into hypotheses (Glaser & Holton, 2007). In the current study, the researchers developed concepts about using the arts to learn about science and about elementary students using the project of producing a decorative mobile featuring fossil images during learning about fossil life. The generated grounded theory sought to explain the majority of students' behaviors during this educational experience relevant to the science education researchers.

Method

Participants

Sixteen upper elementary students entering grades 4, 5, and 6 at the end of the summer participated in the study (7 males, 9 females; 13 White, 2 Black, 1 Asian). This study was approved by the Internal Review Board of the overseeing university and was approved by the directors of the summer day camp of which the project was a part. All students and a parent or guardian gave fully-informed, signed consent to participate in the study.

Research Design

This study used grounded theory research design that addressed the process of art as science inquiry or, more specifically, fossil mobile art as leading to or inspiring scientific inquiry into fossils. This study's research design qualifies as a grounded theory approach because it studies the components identified by Creswell (2002, p. 449): (1) a sequence of activities or process (the day camp lessons on making fossil-related art mobiles), (2) actions by people (lessons and examples provided by teachers), and (3) interactions by people (student interactions with art materials, lesson activities or materials, fossil books, each other, and teachers).

Grounded theory research generally adheres to the following steps (Scott, 2009): (1) identify a process in an area of interest for study [how making a fossil mobile affects science inquiry into fossils]; (2) collect data [observations of students and student responses to questions]; (3) open code the data using the constant comparative method (Dye, Schatz, Rosenberg, & Coleman, 2000) [see analysis section]; (4) write memos throughout the process to record ideas of theory development [these were made during teacher discussions after each class]; (5) conduct selective coding with additional sampling to better define the theory [additional questions for later class periods]; and (6) develop the theoretical categories that best organize the theory [presented in the results section].

The Fossil Class Procedures

The fossil mobiles class was part of a larger annual one-week summer day camp hosted by a university school of music that focused on the creation, rehearsal, and presentation of a themed musical play. The camp director wished to expand student learning into STEM (Science, Technology, Engineering, and Mathematics) areas by combining the Arts with STEM to make STEAM. Therefore, an hour (9:15 to 10:15 AM) was devoted to STEM mini-courses each day. The current fossil mobile project was one choice of these five-part mini courses that was taught for one hour each of the five days of the day camp. The schedule of activities for the course is shown in Table 1.

The fossil mobile craft work involved two art techniques for making the fossil representations and the assembly of painted dowel rods, plastic pony beads, craft fossils, and label cards with cotton string to make the balanced, three-dimensional mobile. The first technique involved back-painting of clear plastic pieces cut from recycled juice bottles. First, students traced using a fine-tipped black permanent marker, the image of the fossil from photographs provided by the teachers or from one located in a fossil book, marking details of features with the permanent marker onto the clear plastic. The fossil outline was cut with scissors. Then students outlined features of the fossil on the back with glitter glue. After the glitter glue had dried, the back was painted with white gesso. The craft fossil was traced on colored felt and its outline was cut with scissors. The ends of a cotton string loop decorated with several pony beads was sandwiched between the glued-on felt backing of the craft fossil and allowed to dry.

For the second technique, students chose a fossil stencil and used a flat-tipped stencil brush to paint the fossil silhouette onto gesso-coated white canvas. The stencil was wiped clean and flipped over to produce the reverse side of the craft fossil on another piece of canvas. After both sides had dried, they were put together and an oval outline was trimmed. The ends of a bead-decorated cotton string loop was embedded between the two halves that were glued together.

Form and function analogy sets of cards and manufactured objects, along with actual fossil specimens and cards showing detailed photographs of fossils, were used in the class. The four sets focused on brachiopods, crinoids, trilobites, and horn corals. The forms (physical characteristics such as shape, color, configuration, texture, mode of movement, etc.) of the fossil organism were underlined to draw attention to them. Similarly, the functions of each organism body part were italicized so that students would easily distinguish function from form. These were compared to analogous manufactured items that exhibited the same forms and functions. During the activity, the student took the twelve manufactured items from the box and arranged them on the table. Then the student took one of the twelve cards (one card corresponded to each of the twelve objects) and read the front of the card. This gave information about the fossil organism's form and function. The student then searched for a manufactured item with the same form and function. The back side of the card showed an image of the manufactured item and explained how its form and function was analogous to the fossil organism for self-checking. See Figure 1 for an example of four cards from the brachiopods box. The left column shows card fronts; the right column shows card backs.

Eleven highly pictorial juvenile and adult books for student fossil research were made available during the class at designated times, but also for students to use independently. This set included the following titles: Trilobite: Eyewitness to evolution (Fortey, 2000); Discovering fossils: How to find and identify remains of the prehistoric past (Garcia and Miller, 1998); Paleontology: The study of prehistoric life. (Gray, 2012); The illustrated handbook of fossils: A practical directory and identification aid to more than 300 plant and animal fossils (Parker, 2014a); The world encyclopedia of fossils and fossil collecting: An illustrated guide to over 375 plant and animal fossils from around the globe and how to identify them, with over 950 photographs and artworks. (Parker, 2014b); Fossil hunting: The expert guide to finding and identifying fossils and creating a collection (Parker, 2012); Fossils: A guide to prehistoric life (Rhodes, Zim, & Shaffer, 2002); Fossils (Squire, 2013); Eyewitness fossil: Discover what fossilized shells, bones, skulls, teeth, and plants tell us about earlier eras (Taylor, 2004); The Audubon Society Field Guide to North American Fossils (Thompson, 1998); and Smithsonian handbooks: Fossils (Walker & Ward, 2002).

A "Fossil Hunters" matching game was created by choosing historically well-known persons (e.g., Mary Anning, Roy Chapman Andrews, Sue Hendrickson, Jose F. Bonaparte) who collected fossils or were paleontologists and the most famous specimens associated with them (e.g., coprolites, dinosaur egg nests, largest Tyrannosaurus Rex, Titanosaur). An image and brief description containing clues of one of the fossil hunters was taped to the front of each of half of the participants, while one of the fossil finds was taped to the front of each of the remaining participants. Participants then tried to determine their corresponding person or fossil discovery.

Table 1. *Fossil Mobiles Activity Schedule*

Day	Activity	Minutes	Materials
Day 1	Slideshow on geologic time	10	Color images from Internet
	Slideshow on crinoids and horn corals of the Devonian	10	
	View example fossil mobiles made by the teachers and discuss goals of project	10	Example mobiles
	Rotate the four groups of 4 students each through center activities.	25	Analogy cards and manufactured objects set assembled by teacher; specimens
	Center 1: Form and function analogy learning materials for crinoids with fossil specimens of crinoids to examine.		
	Center 2: Form and function analogy learning materials for horn corals with fossil specimens of horn corals to examine.		
	Center 3: Paint the two wooden dowel rods that will support the mobile.		Dowel rods (approximately 30 cm long); acrylic paint, brushes, drop cloths, paint shirts
	Center 4: Trace fossil from photograph onto clear plastic with black permanent marker and apply glitter glue highlights.		Clear plastic pieces cut from recycled bottles, scissors, markers, glitter glue
	Respond to first three items of questionnaire: 1. What are the first things you are thinking about when you are deciding how to make your fossil mobile? 2. What do you want to find out about fossils? 3. What kind of scientific information do you want to show with your mobile?	5	Paper, pencils
Day 2	Famous Fossil Hunters Game: Tape images of various paleontologists or fossil-related people on shirt fronts of half of class; tape image of most important finds on remaining students. Students must find their corresponding person or fossil find.	10	Images, names, and brief descriptions of fossil hunters and famous finds
	Slide show on Devonian brachiopods and trilobites.	10	Images from Internet
	Centers 1-4 as on previous day. Individual students did not experience all centers on the previous day.	35	As previous day
	Center 5: Examine fossil books. May choose to trace a fossil from the fossil books.		Assorted pictorial fossil books
	Respond to next three items of questionnaire: 4. What information about fossils do you want to research to make your mobile better? 5. What shape or decoration aspects did you consider when choosing fossils for your mobile? 6. Is there a theme to your mobile? What is it and why did you decide to use that theme?	15	Paper, pencils
Day 3	Famous Fossil Hunters Game: Repeat game, giving students different people or fossil finds.	10	As previous day
	Slideshow on Devonian armored fish, eurypterids, and cephalopods.	10	Images from Internet
	Center 1: Form and function analogy learning materials for brachiopods with fossil specimens of brachiopods to examine.	30	Analogy cards and manufactured objects set assembled by teacher; specimens
	Center 2: Form and function analogy learning materials trilobites with fossil specimens of trilobites to examine.		
	Centers 3 and 4: Stencil a fossil of choice onto small canvas piece with acrylic paint. Flip stencil and create mirror image on another canvas piece.		Plastic stencils prepared by teacher, cut from flat plastic from cat litter jugs
	Center 5: Examine Fossil Books		As previous
	Respond to three more items of questionnaire: 7. Does this art project inspire you to learn more about science? If so, how? 8. How does your choice of the type of craft materials support what you want to show about fossils? 9. Why did you choose a particular fossil? What do you know about this fossil now that you didn't know at the beginning? How can you find out more? Will you?	5	Paper, pencils
	Choose a fossil horn coral to keep from set provided by teacher.	5	Teacher-collected specimens
	Because of time limitations, after class, teachers applied gesso to backs of plastic fossils, paired the stenciled backs with fronts and cut them together in an oval shape. Teachers prepared strings for mobiles by dipping string ends in gesso so that they hardened like a shoelace tip for stringing beads.	After class	White acrylic gesso, brushes, drop cloth, scissors

Table 1 Continued. *Fossil Mobiles Activity Schedule*

Day	Activity	Minutes	Materials
Day 4	Slideshow on Devonian gastropods and colonial corals	10	Images from Internet
	Centers 1-3 as on previous day.	40	As previous
	Center 4: Trace around plastic fossil on felt; cut out. Fold over cotton string and tie small loop to be slipped onto dowel rod; add four pony beads and knot string. Coat back of gesso-covered plastic fossil with white craft glue; sandwich the string ends between the glue-coated surface and felt to provide a means of hanging the fossil after the glue dries.		Markers; craft felt in many colors; white craft glue; pony beads in many colors; cotton string, scissors
	Students list the names of the craft fossils that were made for their mobiles.	5	Paper, pencils
	Respond to next item of questionnaire: 10. Describe three new things you have learned this week in our class.	5	
	Teacher prepared fossil names for attachment to mobile to identify craft fossils.	After class	Cotton string, gesso, drop cloth; computer, printer, card stock paper for printing business cards
Day 5	Assembly of Mobiles. Students follow a diagram of making a loop, adding beads, and tying knots around dowel rods to create the mobile. The four craft fossils are hung on the dowel rods and glued in place. The dowel rods are adjusted to balance the mobile and then the main string is glued in place.	40	Teacher-drawn diagram; strings, pony beads, painted dowel rods, craft fossils, printed business card labels
	Students receive a card with four small Devonian fossil brachiopods from a local quarry glued to it. They add it to the bottom of the mobile. They add the fossil name cards to label their craft fossils.	5	Teacher-collected fossils, printed business card stock
	Fossil mobiles are photographed.	5	Camera, white table
	Students respond to one more question of questionnaire: 11. Did making a mobile art project inspire you to learn more science information about fossils? If so, how?	5	Paper, pencils
	Mobiles are displayed, hanging from a portable coat rack for the final parent presentations of the camp later that day. Then, students take them home.	Teachers after class	Coat rack

Brachiopods have two **flat or cup-shaped shells connected by a hinge** so that the ***shell may open or close tightly***.

Mirror or Make-up Compact

A compact is made of **two somewhat flat and cup-shaped pieces that are held together by a hinge**, ***allowing*** the compact ***to open or close***. Similarly, a brachiopod's **two shells were held together by the hinge** so that the shells ***could open or close***.

Brachiopod shells have **strong muscles attached** to the inside of the shell that ***keep the shell tightly closed.*** The muscles **have to be compressed** to ***open*** the shell.

Spring-loaded Binder Clip

A black metal binder clip has two steel arms **attached to** the edge of the black clip mouth that are very strong. One must **compress the arms** *to* ***open*** the clip. In a similar way, brachiopods have **strong muscles attached** to their shells that **must be compressed** ***to open*** the shell.

Brachiopods **open their shells a crack** to allow in seawater containing food so they can filter feed while still ***remaining mostly protected***.

Public Mailbox

A mailbox has a **narrow slot** or chute for mail. In this way, the mail inside ***remains safe, protected by the hard*** mailbox ***structure***. Similarly, a brachiopod **opens its shell just a crack** to receive food through seawater while ***allowing its shell to protect*** its soft body.

Spirifer brachiopods often have wide wing-shaped shells. The tentacle-bearing lophophore **is spirally coiled** to ***fit into the narrow space*** of the shell wings.

Thread on a Spool

Thread on a spool is **coiled in a spiral** around the spool *to* ***fit neatly into the small space*** of the spool surface. Similarly, the tentacle-bearing lophophore of the brachiopod is **arranged in a spiral coil** ***to fit into the small space*** of the narrow wings of the shell.

Figure 1. Example form and function analogy cards for the brachiopod set.

Data Collection

Data were collected throughout the five days of the fossil mobile class by the five teachers who collaborated on this project. Teacher observations of students, student comments to peers and teachers, student reflection responses on an eleven-item questionnaire, and teacher reflections were used in the data collection. All data statements were entered onto a spreadsheet for sorting and analysis. The questionnaire items are shown in Table 1, embedded in the fossil mobiles activity schedule.

Data Analysis

The constant comparison method, in which each data statement is compared to the other data statements to develop categories which evolve as all of the data are coded (Dye et al., 2000), was used to code a total of 520 data statements into 56 initial categories. These were then combined into 9 major themes. The nine themes with the corresponding initial categories listed in brackets follow: (**1) connecting fossils to myself and what I know** [ancient Iowa sea; connecting fossils to something else; from our area in Iowa; prior familiarity]; (**2) craft skills learned** [craft learning, creativity in crafts; fine motor skills; intense focus and interest]; (**3) desire to find out more about fossils** [book interest; finding or owning fossils; Internet research planned; making a fossil sparks interest in researching information; slide show generates interest; want to learn about fossils]; (**4) fun aspects** [enjoyable activity; humor important; name is intriguing; usefulness of fossils]; (**5) role models** [fossil hunters; matching game]; (**6) scientific information about fossils** [ammonites; armored fish; brachiopod; cephalopod; crinoid, gastropod; horn coral; how animal lives; can identify a fossil; informative; learning about fossils sparked interest in craft; location in ancient times; origin or formation of fossils; reading about fossils prompts more interest; realistic; taking notes; time period or fossil age; trilobites]; (**7) sense of wonder** [facts of interest learned; interest in specific fossil; size of fossils important; specific body part of armor plating or boney plates for teeth or eyes or mouth or legs or lobes or tentacles; uniqueness]; (**8) understanding ancient life and how it evolved and connects to life today** [diversity of fossil life; evolution; relationships to other animal groups; still living or extinct]; and (**9) visual aesthetics** [three-dimensionality; aesthetics important; color important; detail is interesting; pattern; shape; symmetry; visual aspects].

After the sorting into themes, the researchers met and summarized one or more main findings for each initial category, recording it on the spreadsheet as a "memo". These were later refined into the grounded theory narrative presented in the results section. Additionally, researchers placed a shortened version of each statement on a diagram that had areas for interactions between the student, the mobile art project, and the fossil science content learning. The diagram soon became quite crowded and was refined into a more simplified theory diagram.

The Resulting Student Products

All of the students successfully completed their mobiles during the course. Figure 2 shows a representative sample of eight of the student products. They were photographed flat on a table, but the two dowel rods tend to be at right angles to each other in a hanging mobile, giving the mobile a three-dimensional quality, while the delicate balance of the craft fossils suspended from the dowel rods lends movement. Student pride in the fossil mobiles was particularly evident at the end of the course as students brought their work for photographing and as they collected their mobiles from the coat rack display after the musical presentation later that afternoon. Discussion about the project occurred between family members and the student as they examined the mobile. These conversations created a bridge between school and home experiences.

Figure 2. Example Student-Made Fossil Mobiles.

The Resulting Research-Grounded Theory

Figure 3 shows a simplified model of the art, science, and student interactions during the fossil mobile class observed through the grounded theory data analysis. The dynamic, cyclic process began with students who had little familiarity or interest in Devonian fossil life, but who developed knowledge and curiosity as they created craft fossils for their mobiles and were introduced to information through pictorial slide shows with artists' renderings of Devonian sea life. The intense observation required while tracing or stenciling the craft fossils, along with students' valuing of realistic fossil mobiles, drove interest in learning more about these Devonian fossils. The attractive aspects of the colorful and glittery craft materials provided a positive tone to the study of long-dead remains. More knowledge through subsequent slide shows, book-reading, or other learning activities drove greater fossil interest and the desire to depict this knowledge on the fossil mobiles. A large factor in the model is the importance of student-centered instruction during the project. The ability to *personalize* and create *unique* mobiles through color and fossil choices increased motivation to produce and experiment with art. Comparisons of Devonian fossils to manufactured items and to present-day organisms *familiar to students* increased science understanding. *Ownership* of fossils through creation of craft fossils and work within the *class community of craft and science learners* promoted intense involvement in the project. The following sections explain these interactions in detail.

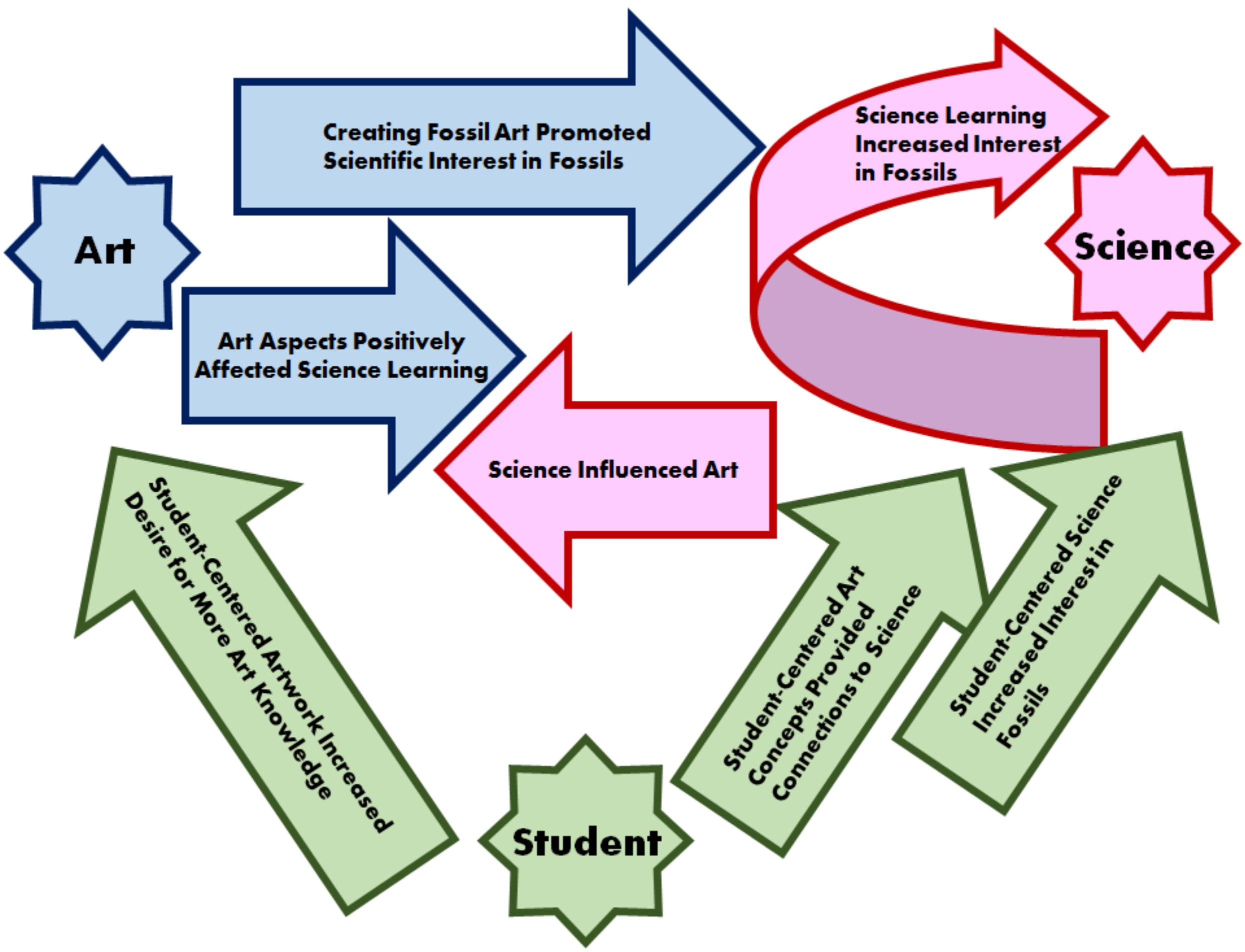

Figure 3. Simplified grounded theory model of interactions between art, science, and students during the fossil mobile project

Creating Fossil Art Promoted Scientific Interest in Fossils

The intense fine-motor skill activities of tracing or stenciling a fossil image required focused eye-hand coordination. This work allowed students to notice and become interested in the details of the fossils. Students reported that seeing and constructing attractive mobiles with craft fossils increased their interest in learning more about the fossil organisms. Students' desire to make realistic craft fossils drove interest in understanding their features. Students wanted to learn more about the animal, its lifestyle, and what the various body parts do to help the animal survive. Several students expressed that they wanted their fossil mobiles to not only be "realistic," but also "colorful and showy" with "very detailed, cool fossils." Students wanted to understand how the fossil organisms lived so that they could point out features on their craft fossils and talk about them when displaying the mobile. For example, a participant commented, "I learned about megalodon, the giant shark, because I made shark teeth. Megalodon was 59 feet long!"

Students were very interested in color, making paint, felt, bead, and glitter hue choices for their mobiles carefully. Individual color selections were a way of showing ownership of the mobiles. Students wanted to find out why authentic fossils occurred in different colors. They noticed that some fossils matched the color of the rock matrix or were somewhat lighter or darker, but some were black, while others showed the rainbow colors of mother of pearl. One student wrote, "Trilobites are pretty because they are black. I like the ones with the spikes and thorns. They eat with their legs." In this statement, the student combined an affinity for the color black with intrigue regarding how the trilobite legs' medial surfaces were jagged to process and move food (often worms), a fact discussed during one of the slide shows.

Students sought science information to make their fossils more realistic. They chose to read science information about their chosen craft fossils in the fossil books that were provided. A highly motivated and articulate student wrote on the questionnaire, "From the Illustrated Handbook of Fossils by Steve Parker, I learned trilobites were not named for the three parts of their body which include the head, middle, and tail, but they were named for the three lobes seen from side to side (p. 56)." Students conveyed that the craft activities allowed them to make fossils themselves and thereby "own" fossils. Aesthetically pleasing, interesting-looking fossils prompted their scientific interest. Students often chose to reproduce a fossil from a book or a stencil because of its interesting appearance. Students wrote that good feelings about the creativity engendered by the craft work motivated students to learn about fossils. Students felt that making the craft taught them science in a more interesting way that allowed them to be creative and contribute something of themselves to the project. This creative aspect inspired them to want to learn more about fossils.

The slideshow had a variety of artists' drawings of different life communities of the Devonian Seas, which students enjoyed. This sparked a lot of interest in fossils because students could see what the living animals and communities looked like rather than just view the fossil remains, although those were also shown in the slideshow. During the slide shows, which featured artists' paintings or drawings of colorful scenes of underwater life during the Devonian period, students made appreciative comments and remarked on the beauty of the organisms. They often pointed out predators and prey or unusual shapes of shells.

Art Aspects Positively Affected Science Learning

A student remarked, "Glitter glue transformed the tone of fossils from scary to interesting," showing the effect of art on human emotions and readiness for science learning. Another student commented, "Creativity helps students make cool connections to the past," indicating that students appreciated the opportunity to apply their originality and elaboration to the art projects. Students noted that accomplishing the finished product and synthesizing ideas gave them positive feelings that promoted the desire to learn more about fossils and life of the past.

Noticing art shapes, lines, and details on fossils while tracing them is actually making science observations; therefore, participating fully in the art allowed students to concurrently participate in science process skills. The three-dimensional aspects of the crafts provided realism. For example, a student stated, "… choosing plastics that aren't flat supports that I want my mobile to look almost realistic but showy and cool." Another remarked, concerning the traced and back-painted plastic fossils, that this craft technique "shows the details on top of it, not just the outline. The glitter glue helped cover my mistakes in tracing. I really liked how some of the plastic was flat, some popped out, and some [pieces] were bent."

A lot of students learned about craft materials such as glitter glue and how one might make a mobile out of craft and recycled items that really showed what fossils looked like. Tracing the fossils helped students practice and develop fine motor skills because these activities are seldom done in school with the high-stakes testing pressures on classroom time. These fine motor skills are needed for science laboratory work and investigations. Many students evidenced metacognition as they explained criteria for choosing fossils to trace. If the student did not have adequate fine motor skills, the student purposely chose fossils that were easy to trace. Some students had a lot of difficulty with tracing and cutting and so felt a great sense of accomplishment in successfully completing the mobile.

Student-Centered Art Concepts Provided Connections to Science

Students connected fossils to manufactured items and living animals they individually knew based on shape. These personal connections helped them interpret the fossils' lifestyles and become more involved in their learning. Patterns and decorative details of the fossils influenced individual artistic and fossil choices for mobiles. Most students were intent on choosing animals with unique characteristics so their individual mobiles would be unique: "I want my work to be attractive and appreciated by others; therefore, the beauty and science information needs to be right."

Science Learning Increased Interest in Fossils

Learning an interesting fact about a Devonian life form sparked more interest in these fossils. The project gave students more experience and familiarity with fossils, which motivated them to learn more. Many students started with only a small interest in the Devonian because they knew little about the life of this time period. At the beginning of the project, some students expressed disappointment that we weren't covering dinosaurs of the Jurassic (especially because of a dinosaur movie currently in theatres). However, as they learned about the animals of the Devonian, they became very excited and interested. After learning about many unique features of trilobites such as defensive spikes, one student expressed that he wanted his entire mobile to feature trilobites. He said he wanted to get his "mobile framed because it has extinct animals," indicating the value he now put on trilobites because of his increased knowledge.

Students expressed a sense of wonder about specific fossil organism body parts and their functions. A student remarked, "The big fish Dunklosteus - I was liking it because it had armor under its skin and I wanted to learn about it because the coelacanth is alive." Another student observed, "I learned that horn corals are long and have tentacle-looking things on them" to grab food out of the water. When students learned how the fossil animals' body parts worked to help them live, their focus of interest shifted from the Jurassic to the Devonian Period.

Students made connections between fossils and living animals, prompting questions and research. For example, students noted that land snails were gastropods, but wondered if gastropods still lived in the oceans today. A student also commented, "I want to learn if the cephalopods/ammonites still live." Information from slide shows about Iowa fossils (the state in which the study was conducted) sparked more interest in past geologic history of Earth. The fact that they received a Devonian horn coral fossil from a nearby quarry in Iowa made students more interested because of its proximity to them.

Students' knowledge of evolution also grew through this project. Many students remarked on the immense diversity of fossil life. One student commented, "I think I have more of an interest, now, in geology and paleontology; also, it helps me realize how far we've come in this world." Students wanted to know fossil growth patterns and the evolution of fossils through geologic time. A student stated, "[The class activities] inspire me to learn more about the size of fossils and if they were always that size and if not then why did they evolve to that size." Students were particularly interested in a slide show portraying some evolutionary advantages of coiled shells versus cone-shaped shells in cephalopods. A student wrote on the daily questionnaire, "I didn't know cephalopods with long cone shells evolved into coiled shells."

The meaning and pronunciation of scientific names of fossils was intriguing to students and encouraged more interest in the fossil. One participant remarked, "I was just shown a picture of a trilobite. I had no idea what they were. I used my knowledge of language to hypothesize that a trilobite has three of something, and I was right!" Several students took notes on fossil names and their meanings. Students also took notes during the slideshows to use later showing that information continued their interest in fossils. Additionally, students actively asked and answered questions during the slideshow, evidence of a true learning community. Students asked questions about fossil's habitat, food, life span, relatives, sturdiness, geographical place, geologic time, living descendants, and evolution.

The matching game sparked interest in finding out about people related to paleontology. A student observed, "Learning about fossil hunters made me want to know more." One student wrote that she wanted to know more about the scientists that experimented on and studied fossils.

There were eleven highly pictorial books available to students and time designated for browsing through them. Students searched in the books about the fossils they were making and became excited about the pictures that showed details of the fossils. One student noted that a particular book had "some pages on sea urchins (echinoderms-echinoids) that looked really detailed and interesting to me, especially the bald tiara and leech tiara." The pictures motivated students to read more; the task of writing a fact about the fossils on the mobile also prompted them to read. Information about fossil body parts and images of fossils in their natural environment caused students to ask questions and seek more information. Looking in books led students to want to find more in websites and to visit the library. Several students spontaneously mentioned that they wanted to find out more about fossils and would research them on the Internet.

Student-Centered Science Increased Interest in Fossils

Individual students were fascinated with very old fossils because of their remoteness in time and rarity. Students asked many questions about how old the various fossils were. Teachers played on this interest by pointing out fossils that were particularly old or from a time period in which students had interest, thereby personalizing the class. Learning about specific fossil hunters or paleontologists whom students viewed as role models made the science seem more real and exciting. Personal connections through prior individual experience with knowing about or owning fossils prompted the desire to learn more. Learning about local Iowa fossils was interesting to students. We compared the fossils to everyday objects with which students were familiar; according to a student, this strategy made "fossils less complicated and more interesting." Many students commented that they now wanted to find and own some of these fossils. This indicates their strong liking for fossils and the desire to have the fossil available so they can make observations at their convenience.

Science Influenced Art

Intricate details influenced choice of fossils to illustrate. One student wrote, "I wanted to learn how detailed the fossil was and how the details evolved." Fossil research through the form and function analogy sets or the fossil books provided specifics for mobiles. Students expressed many times that their mobiles had more value to them when realistic and informative. For example, a student expressed this idea: "I wanted it to be colorful and pretty to look at (so people will stop and look at it) but informative (to prove that I learned), plus, no one wants just facts and no one wants just colors."

Students were fascinated about the variety of sizes of fossils and portrayed the sizes in their art. One student commented, "I chose my fossil because it was the largest fish in the world, which I didn't know before." Another remarked, "I may emphasize fossil sizes as they are varied, huge or small." Several students wanted to show evolution of particular fossils through their mobiles. Liking a particular fossil because of its features or lifestyle caused the student to choose to put it on the mobile. A student remarked that the "best experiences combine learning science and making something artistic."

Student-Centered Artwork Increased Desire for More Art Knowledge

Students' preferences of colors were shown on their mobiles, personalizing them and making the students feel more ownership of the project. As the work unfolded, students began experimenting with the materials and with adding more decoration or embellishments. There was a community of crafting in which students began to support each other with compliments and suggestions. Students were intensely focused and engaged with almost no misbehaviors or off- task activities.

Discussion

The current study indicates that integration of science and art is an effective way for students to learn as demonstrated by student engagement in all aspects of the project. This supports the assertion by White (2011) that the arts increase interest and thereby appeal to young people. Art and science were blended well because the teachers provided many resources, allowing students to investigate on their own without direction. Multiple science sources in different media (books, hands-on items and cards, slide shows) and complementary information about scientists through the fossil hunters' game, fossil specimens, a historical perspective of fossil life, and information about organism life styles supported the project, along with different art techniques being used. Storksdieck (2011) noted that examination of science through art provided different modes of perceiving, knowing, and interacting with nature, giving scientists more tools. This fossil mobile project was student-centered with much choice involved. Students, without prompting, chose to look through books or to use the learning materials on form and function. Autonomy gave students ownership of what they created and therefore more personal engagement. Ownership of real fossils (gifts from the teacher) and the self-made craft fossils impacted students individually by increasing interest in fossils, the people who study them, and their physical ties to the past. Additionally, students made strong connections to fossils being from their area in Iowa. Students evidenced metacognition in choosing fossil craft activities that matched their fine motor skill levels and in researching aspects of fossils for which they wanted additional knowledge. During transitions, students only talked about fossils and behaved like a community of learners by making suggestions to each other and recognizing the achievements of others. These aspects, student choice, metacognition, and discourse among a community of learners, along with the real-world aspects of creating a work of art through examination of real fossils, qualify this fossil mobile project as an authentic learning experience (Rule, 2006).

The lack of art or arts-integrated activities in the public schools (Grey, 2009) causes concern and evidenced itself in students' general lack of familiarity with tracing, cutting, gluing, and painting. Many students lacked fine motor skills to cut the traced outline on clear plastic, to cut felt, and to string the beads. Some students seemed to ask for help too often with their first comment being, "I can't do this." Lack of experience in arts and crafts projects led to their lack of confidence. This situation does not support students' overall development well and hinders their ability to excel in science, as spatial thinking skills, fine motor skills, pattern recognition, and observation skills are developed in the arts and necessary for science success (Root-Bernstein & Root-Bernstein, 2013).

The art-science interaction is complex. Some students were more focused on art driving science, although, others seemed to exhibit science inspiring art. Some students were very engaged with the actual fossil specimens, while others were interested more in the form and function sets and working with the analogous objects. However, through this project, all students seemed to increase their knowledge of and liking for fossils. Students wrote many statements that expressed a wish to know more and the desire to further their learning about fossils. Several students said they were considering being a paleontologist as a result of the project. This result confirms the ideas of Daugherty (2013) that integrating the arts into science provides students who had not previously considered becoming scientists the chance to consider science from a new viewpoint.

Conclusion

The current study indicates that science combined with art produces great student interest and motivation to learn science content, initiating a cycle of art, science, and student interactions that result in learning in both domains. The indication of a *cyclical nature* to these art-science-student interactions appears to be a new finding as one-way relationships were shown in previous work. In light of the current national commitment to STEM education (Reeve, 2015) and the global rise of standardized testing (Smith, 2014), the authors recommend teachers combine the arts with science learning in a student-centered environment to improve motivation, interest, and content learning. Such integration promotes students' desire for science information while allowing science inspiration to be expressed through art.

Activities within the current study that mixed art with science increased student engagement, allowed practice of fine motor skills, exercised observation skills, and built a community of learners through student interactions regarding their science findings and art creations. Authentic learning (Rule, 2006) occurred as students experienced real world art and science problems with related professional skills of scientists and artists, made choices, and engaged in discourse among a community of science and art learners. Additionally, combining art and science improved meaningful student connections to both of these domains.

The fossil-related activities in this project support the Next Generation Science Standards (Achieve Inc., 2013) for third, fourth, fifth grades, and middle school earth and space sciences. In third grade, a main topic is inheritance and variation of traits including the crosscutting concept of cause and effect as well as the disciplinary core idea of natural selection. One of the fourth grade topics is structure, function, and information processing with the disciplinary core idea of structure (form) and function. A major fifth grade topic is matter and energy in organisms and ecosystems, which includes the disciplinary core idea of interdependent relationships in ecosystems and the crosscutting concepts of systems and system models. In addition to teaching concepts from the upper elementary curriculum, these fossil concepts support the middle school Earth and space sciences storyline related to the history of Earth. Although these activities were conducted with upper elementary students, they likely have implications for paleontology lessons at the high school and university levels. Future studies may investigate this possibility.

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