Upper Elementary Students Creatively Learn Scientific Features of Animal Skulls by Making Movable Books

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Introduction

Many countries across the globe (e.g., European nations: Education, Audiovisual and Cultural Executive Agency, 2009; China: Cronenweth, 2012; and South America: Marin, 2001) are implementing standardized testing to decide students' academic futures. In America, elementary school arts and crafts work is being reduced or eliminated from the curriculum in many schools because of the current emphasis on high stakes testing of reading and mathematics (Spohn, 2008). This situation is unfortunate because arts integration across the curriculum, and especially in science, has many benefits, as will be explained in the following sections. The current study focused on form and functions of animal skulls provides a vibrant example of how handcrafts incorporated into science instruction can motivate students and assist in their learning.

Use of Manipulatives and Objects for Learning

Early theorists postulated that as children develop, they are assisted in constructing abstract concepts through the manipulation of concrete objects (Piaget & Szeminska, 1941/1995; Bruner, 1966; Montessori, 1964). Objects that are handled provide an additional learning resource through the tactile modality; connect practical, real-world knowledge to more abstract concepts; and improve memory through physical actions (McNeil & Jarvin, 2009).

Montessori theory recognizes hand motion and tactile manipulation of objects as a key factor in maintaining students' attention through interest and movement (Lilliard, 2005). Repetitive hand motions such as those used in coloring, painting, cutting, and sewing, help to develop attention (Sobe, 2004). Attention serves as a gate for information flow in the brain: selecting salient information and directing cognitive processing of that information (Cohen, Sparling-Cohen, & O'Donnell, 1993). One line of empirical evidence for this assertion is the fact that students with attention deficit disorder exhibit lower academic performance throughout childhood and college than peers without the disorder (Barkley, 2006; DuPaul & Stoner, 2003; Heiligenstein, Guenther, Levy, Savino, & Fulwiler, 1999). Other measured supports for this idea are pretest-posttest, control group-experimental group studies of kindergarten students using tweezers, tongs, and spoons to manipulate small objects during sorting and matching activities, which found that these fine motor skill activities not only increased fine motor skills (Rule & Stewart, 2002), but were effective in increasing female students' attention (Stewart, Rule, & Giordano, 2007).

Interest is central in determining how students select and persist in directing attention to and mentally processing certain kinds of information in preference to others (Hidi, 1990). Interest can be situational (triggered by stimuli from the environment), individual, or a combination of both (Hidi & Renninger, 2002). Individual interest in a topic refers to the relatively enduring predisposition of a person to re-engage in actions associated with that particular topic and consists of two components: stored knowledge and stored value (Renninger, Ewen, & Lasher, 2002). Students in the current study exhibited situational interest when shown the teachers' example movable books and the plastic animal skulls with which they would be working. The movable book pages were fascinating to them (example student comments accompanied by repeated manipulation of the movable pages: "Cool!" "Wow!" "How does that work?") and they expressed a desire to learn how to make them. Students conveyed individual interest in learning more about animals by referring to their love and knowledge of pets or animals encountered in nature and the media.

Importance of Integrating Arts and Crafts with Science

The engaging, high-interest activities of arts and crafts integrated with science motivate students and assist in reaching a larger classroom audience for science (Bull & Barry, 2007; Griffis, Brand, & Shackleford, 2006; Klopp, Rule, Schneider, & Boody, 2013). Arts integration adds depth and personal interpretation to the curriculum, thereby increasing student engagement (Mason, Steedly & Thormann, 2008). This finding connects to the theoretical framework regarding the two components of individual interest of Renninger, et al. (2002). Application of science knowledge recently taught to integrated arts activities allows students to use their stored knowledge; making personal interpretations through art contributes to valuing of the activity.

Arts-integration into the curriculum enhances student science learning, not only through increasing student interest and attention, but through specific skill activities shared by both disciplines: visual imaging, pattern recognition, and fine motor skills. Drawing or painting observations of nature or experimental results practice the science process skill of observation and support visual imaging abilities, which are a predictor of science success (Winner & Casey, 1992). Students recognize, create, and play with patterns when they engage in art, music, and dance. These patterning abilities are another important component of scientific thinking. Through craft-making, students build fine motor manipulative skills needed for laboratory research (Rule & Zhbanova, 2012).

Art integration across the curriculum builds cognitive and behavioral skills while increasing content learning and achievement (Appel, 2006; Deasy, 2002). Catterall (2009) found that students from socioeconomically disadvantaged school districts who engaged in arts instruction made gains on standardized tests even when the tests did not address arts-related material. Allowing students to transform what they know about science into art encourages reorganization of ideas and connections between new and previous knowledge as students convey ideas creatively (Burton, Horowitz, & Abels, 1999; Eisner, 2002). Student appreciation and understanding of science is often deepened through making illustrations or replicas of systems (Bull & Barry, 2007; Dickenson & Jackson, 2008; Finnerty, 2006). Klopp and colleagues (2013) found that student craft projects addressed more science content than technology-rich science products, indicating that hands-on craft work motivated students to dig deeper into the content.

Diverse groups of students benefit from science-arts integration. Assessments based on science craft project work can bridge language barriers for English language learners or for students struggling with written language (Gooden, 2005). By making images and models of the science concepts, students have the opportunity to show their knowledge. Similarly, students with vision impairments and their typically-sighted peers learned science concepts better when they made and explored tactile models of the concepts (Rule, 2011; Rule, Stefanich, Boody, & Peiffer , 2011). Concrete representations of science concepts such as hand-made models help elucidate difficult science concepts (Gooden, 2005; Finnerty, 2006).

Recent research into the effects of arts and crafts participation on scientists has a compelling message for involving students in science craft projects. Root-Bernstein and colleagues (2008) found that scientists as a group engaged in more arts and crafts work than the general population; also, top-performing scientists were more involved with arts than peers. Root-Bernstein and Root-Bernstein (2013) established that the more arts and crafts in which scientists participated over the life span, the greater the likelihood of these scientists generating important findings for their fields. Physicists Luis Alvarez and Albert Einstein, along with chemist von Euler-Chelpin attributed their ground-breaking abilities of visualizing science processes and experiments that led to their Nobel prizes to their arts instruction (Root-Bernstein & Root Bernstein, 2013).

Paper Engineering of Movable Books

The paper engineering techniques used in this animal skull science project were examples of movable book pages: pages that have mechanical motion when opened or when a flap is lifted or a wheel turned. Movable books have a long history: volvelles, or revolving disks, were used with handmade books before printing presses were invented. “Lift-the-flap” pages were in use during the fourteenth century as scientific illustrations. Similar books designed for children’s enjoyment appeared in the 1820’s (University of North Texas Library, 2013). Pop-ups, illustrations that stand up vertically when the page is opened, were developed by British publisher S. Louis Giraud in 1929. He created a series of well-liked, beautifully-illustrated books, calling his pop-up scenes “living models” (Montanero, 2005). Pop-ups and other movable books remain popular today with many new titles being added annually. Children enjoy these books and are highly motivated to make them, as will be seen in the current study.

Many paper engineering principles applicable to other real-world enterprises are encountered as elementary students engage in making movable books. Spatial reasoning concepts emerge as a flat, folded page is transformed into a three-dimensional pop-up scene by opening the page. These two- to three- dimensional translations skills are accessed by professionals reading blueprints or floor plans, creating dress patterns or altering clothing, assembling furniture or providing diagrams for machine set-up, and interpreting maps or cross-sections. Planning skills are implemented as students assemble the books step-by-step. Design principles of symmetry, balance, color, line, texture, and spatial arrangement of shapes are applied as students create pop-up displays on the pages. These ideas are used by artists, product engineers, and software designers. Logic and the effects of rotational angles are practiced in determining how elements drawn on a wheel behind a page come into view through cut-out windows as the wheel is turned. Reasoning and precision in gluing are necessary to successfully attach a page of opened flaps on top of a sheet containing illustrations or words so that each will occur beneath its respective flap. These skills will assist students in many homeowner tasks such as wallpapering, painting, or repairing loose items. Essential paper characteristics such as stiffness, tensile strength, tearing, and adhesion properties become kinesthetically understood as students work with the materials (Hendrix & Eisenberg, 2006). This knowledge supports future paper or cardboard-based projects and builds a foundation for understanding properties of other materials.

Example movable book pages related to animal skulls from the current study are shown in Figure 1. Figure 1a shows a pop-up page of descriptive terms applied to a bobcat skull including crest, suture, nasal cavity, auditory bulla, foremen magnum, and orbit. Another page, not shown, required students to identify bones of several different animal skulls. Figure 1b is a lift-the-flap page featuring animal skulls on top of the flaps and clip art images of the corresponding animals beneath each flap. Figure 1c presents a rotating wheel behind the page that can be turned from the edge of the page. The four teeth types, their names and functions on the wheel show through cut-out areas on the page. Figure 1d is another pop-up page on which animals are classified as predators or prey according to eye positions.

The instructional activities of the animal skulls unit engaged students in examining plastic replicas of skulls, sorting or matching cards that featured images of animal skulls and explanations of skull features, making movable books that illustrated important science concepts about skulls, and learning about the Mexican cultural event Day of the Dead during which decorative human, and sometimes animal, skulls are displayed. Table 1 shows the main instructional activities, the integrated arts components, the visual arts standards addressed, the science learning components of this arts-integrated unit, and specific ways arts-integration supported science learning.

Figure 1. Example pop-up and movable book pages

Table 1. Connections between activities, arts actions, visual arts standards (National Art Education Association, 1994), science concepts/skills, and how arts-integration supports science.

Part of Movable Book Project	Arts-Related Actions	National Visual Arts Content Standard	Science Concepts and Process Skills	Arts-Integration Support of Science
Book cover with animal skulls made from reverse-painted, recycled plastic along with discussion of skull parts. Viewing /discussing photographic slide show on Mexican Day of the Dead.	Tracing with permanent marker skull outline and features from a photograph onto curved transparent plastic to simulate the 3-D skull; using technique of reverse-painting; decorating skull in style of Day of the Dead.	1. Understanding and applying media, techniques, and processes 4. Understanding the visual arts in relation to history and cultures	Observing locations and shapes of holes and protuberances of the skull, reviewing their functions in supporting and protecting organs of the head for animal survival.	Tracing and shading work required students to focus attention on skull shapes and features, allowing them to notice different parts.
Lift-the-flap page with images of animal skulls and the corresponding animal's head under the flap.	Creating flaps and aligning the image underneath with the opened flap; applying glue strategically so the flaps work.	1. Understanding and applying media, techniques, and processes	Making observations of key skull features and inferring how the fleshed-out animal appears.	Choosing the images of the animal heads required students to make connections between the skull and overlying flesh.
Turning wheel of tooth types, shapes, and functions. Identification of different tooth types on images of animal skulls.	Aligning rotation of a wheel behind the page to bring new images or words into view in openings cut through the page.	1. Understanding and applying media, techniques, and processes	Relating the form/shape of the tooth to its function and what this indicates about the diet and lifestyle of the animal.	Making sure the correct images and words were arranged to be visible through the openings required review of tooth concepts.
Pop-up page with animal skulls sorted into two groups by eye positions on front of head or on the sides.	Cutting and bending tabs on the fold of the page to make pop-up; arranging skull images effectively.	1. Understanding and applying media, techniques, and processes 2. Using knowledge of structures and functions	Sorting skull photos according to the binocular vision (predators) and the peripheral vision (prey).	Arranging the skull images required application of science concepts regarding eye positions.
Adding lines and shading to a given figure to transform it into an object or scene related to the animal skull unit.	Envisioning possible images related to the animal skulls science unit that can be made with the figure.	6. Making connections between visual arts and other disciplines	Reviewing and making connections to the science content that was studied.	Choosing the image for transforming the figure required review of science concepts and activities.
Creating an animal skull with found objects or materials; presenting it to the class, telling reasons for choice of materials or style; and responding to the work of classmates.	Finding items suitable for the project and deciding the pose or aspects of the skull to portray; explaining choices; telling the effective aspects of classmates' work.	3. Choosing and evaluating a range of subject matter, symbols, and ideas 5. Reflecting upon and assessing the characteristics and merits of their work and the work of others	Inventing an animal skull from found materials; use of creative thinking with concepts of design and material properties.	Creation and presentation of the skull required students to identify skull bones, features, and their shapes.

Incorporating Creativity

Besides reinforcing cognitive and motivational skills as just described, arts and crafts work supports creativity and curiosity, an important science attitude motivating students to learn more (Appel, 2006). Creativity is one of the 21st century skills (Ministry of Education, 2002; Partnership for 21st Century Skills, 2011) that will ready global citizens for a rapidly changing world. Traditional science lessons have not prepared students to think creatively (National Research Council, 1996); science teachers need to enrich their teaching pedagogy with more innovative techniques and approaches (Hickey & Zuiker, 2003). The following paragraphs describe three examples of how inventive activities increased creativity in the animal skulls science unit.

Additional craftwork (beyond the movable book pages) and social studies content were incorporated into the project through three-dimensional cover art related to the Mexican Day of the Dead. In Mexico, deceased relatives are thought to visit the living on November first. Families picnic in cemeteries and set up altars at home with food, flowers, and decorated skulls. Sometimes pets are commemorated with flower-decorated skulls. This rich folk practice was depicted on the book covers with skulls made by tracing outlines and features of animal skulls from photographs in black marker on the reverse side of recycled pieces of clear plastic bottles and then cutting them with scissors to the appropriate shapes. Flowers and designs were applied with glitter glue to the back side of the plastic and eventually painted with white paint after the glitter glue dried. Holes were drilled and wire or thread was used to attach the colorful skulls to the cover. Figure 2 presents four example book covers with the animal skulls labeled by name.

Figure 2. Animal Skull Book Covers with Skulls Made from Pieces of Plastic Bottles

Creativity skill exercises were also incorporated into one of the book pages by providing a series of boxes in which a squiggle or simple geometric figure had been drawn. Students were asked to transform each figure into a picture of something related to the animal skull lessons by adding lines or colored shading. Similar figural transformations have been used in creativity tests such as the Torrance Test of Creative Thinking (Torrance, Ball, & Safter, 2008). Students exhibit creativity as they produce original ideas, add elaborate details, use humor or puns, and make their drawings tell a story, among many other possible creative traits.

Another way creativity was integrated into the project was through an optional homework assignment of making an animal skull model from household or discarded materials (another type of creative transformation). The teachers showed a slide show they had compiled of images from a blog (Scalin, 2008) in which the author challenged himself to construct or find a human skull image in a new material every day for a year. For instance, skulls were made of twisted bed sheets, arranged hair clippings, a carved avocado, photographed in cloud patterns, and made with an Etch A Sketch®. Students were encouraged to use found materials such as junk or product packaging for their work.

Science Content and Standards Addressed

The science lessons conducted in this project support the Next Generation Science Standards (Achieve Inc., 2013, p. 33) for fourth grade students: "4-LS1-1 Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction." Instruction focused on: 1) the form and function of bones and openings in the skull; 2) function of binocular eye positions of predators for accurate location of prey or eyes on the sides of the head in prey to facilitate wide peripheral vision for noticing predators; 3) relative eye socket to skull size as an indicator of nocturnal lifestyle (e.g., very large eye sockets in deer and owls) or tunnel-dwelling (e.g., tiny eye sockets for moles); and, 4) types of teeth, their form and functions (snipping, ripping, tearing, shredding, and grinding) and what these signify about diet and lifestyle. Sets of teacher-made illustrated cards were used to introduce each of the topics. All cards had correct answers and explanations printed on the reverse side for self-checking. For example, the card sets for bones of the skull featured two types of cards: the first kind had a bone name followed by a description and photo of an animal skull with the bone highlighted in color; the second type showed a new animal skull with a highlighted bone. Students, then, sorted the second type of skull cards using the identified bone cards as group headers. Similarly, the predator-prey set had two heading cards explaining typical eye positions of predators and prey; additional cards featured animal skull pictures with additional images of the living animal's head for sorting into the two groups of predator or prey using inferences from eye positions. Card decks were also made for distinguishing skulls of tunnel-dwellers from nocturnal animals, for identifying openings in the skull, and for differentiating types of teeth. The following section explains the design of the study and more about lesson delivery.

Method

Participants and Setting

The study included 9 students (6 female, 3 male) age 9 – 12, entering fourth, fifth, or sixth grades. Additional elementary students participated in the lessons and had similar reactions and knowledge gains, but only data from those who provided signed consent are reported here. This study was approved by the researchers' university committee on human research subjects.

A science education professor and graduated or current doctoral students in curriculum and instruction collaborated as researchers and authors in this project. The study was conducted during a week-long summer day-camp for elementary and middle school students at a local university. The students met for approximately 75 minutes each day for a week to work on the animal skulls unit. The students were divided into small groups with each assigned a teacher from the research team. At other times during the week, students attended other day-camp activities unrelated to animal skulls.

Materials and Lesson Procedures

The hands-on science lesson materials included realistic plastic skull models of many animals and cards with information about the forms and functions of the animal skulls to be sorted or matched as explained earlier. Materials for the movable books consisted of colored cardstock, pages printed with photographs of skulls, glue, paper fasteners (for the turning wheel behind the page) and scissors. Items required to make the artsy covers were clear plastic pieces from recycled juice bottles, permanent black markers, glitter glue, white acrylic paint, felt, fabric flowers, needle and thread or wire, cardstock, and a drill for making holes in the plastic.

There were four main science topics for the unit into which the instructional materials (animal skull models, appropriate card sets, movable book page examples, and materials needed to make the student pages) were divided: 1) teeth, 2) bones of the skull, 3) openings in the skull, and 4) eye size and position on the skull. Teachers with their student groups rotated the sets of materials each day so that all groups had access to all sets. When time permitted, students worked on the cover and figural transformation pages. The professor presented the Day of the Dead slideshow to all groups for a few minutes on the first day. The first few minutes of class were used for other special whole group lessons such as the slideshow of skulls made from various items. The last class meeting on Friday of the week-long day camp was used to assemble the books and share the animal skulls created with found materials by the students.

The following main activities occurred with students each day. The lesson began with the teacher of each group of students asking students to tell what they knew about the science topic for the day. For example, the teacher might ask students to tell what they currently know about types of teeth. Afterward, the teacher briefly explained the science concepts being addressed in the day's lesson, acknowledging students' existing knowledge and adding new science concepts. Next, students used a set of cards featuring photographs of animal skulls and sorted them according to the bone, structure, or tooth that was highlighted in color, the skull opening that was circled, or the skull's relative orbital size or position. The teacher then assisted students in checking their work and discussed difficult aspects of the work. Students examined the animal skull replicas and applied the concepts that had been taught to these models. Animal skulls included: beaver, bobcat, cougar, coyote, gray fox, muskrat, porcupine, rabbit, raccoon, skunk, squirrel, turkey, and white-tailed deer. Finally, with demonstration, explanation, and assistance as needed from the teacher, students made a page for their books that highlighted their learning such as a pop-up construction, a page with cut-out areas showing images and words on a turning wheel behind, or a lift-the-flap page. As time permitted, students also worked on the cover art and the page of figural transformations. The animal skull made from found household items was completed as homework.

Research Design, Instrumentation, and Data Analysis

The research study design was pretest-intervention-posttest with the intervention consisting of the five lessons of the animal skulls unit and related activities. The pretest and posttest were identical instruments administered at the very beginning of the unit on Monday and at the end of the week-long unit on Friday. This science content instrument was criterion referenced to the content being taught during the unit and consisted of six questions that are shown with their point values in the two leftmost columns of Table 2.

Identical attitude surveys were administered three times during the animal skulls unit: at the end of lesson 3, lesson 4, and lesson 5. The instrument consisted of five items. The first item asked the student to "Please circle a number to indicate on a scale of 1-10, how creative the arts-related product you made today was." The "1" on the scale was labeled "not creative at all" and the "10" was labeled "very creative." The second item asked the student to "Specifically tell how you were creative in today's activity." The third item asked the student to "Please circle a number on the scale of 1 to 10 to indicate how much you enjoyed the science animal skull lesson and creative activity today." The "1" was labeled "not enjoyable at all" and the "10" was labeled "very enjoyable." The fourth item asked the student to tell "what motivated you during the lesson?" The fifth item asked the student to tell "What aspects of the lesson were most interesting?"

All pretests and posttests were scored by one researcher with data being entered into a spreadsheet for analysis. Means, standard deviations, *t*-tests, and Cohen's *d* effect sizes (Cohen, 1988) were calculated using spreadsheet functions. The numerical results of the attitude surveys (the circled rating numbers) were also entered onto a spreadsheet for analysis with means and standard deviations being calculated for each lesson and overall. The student-written responses to items 2, 4, and 5 were copied into cells on different pages of the spreadsheet. Sorting functions were used to assist in the analysis which was conducted through the constant comparison method (Dye, Schatz, Rosenberg, & Coleman, 2000). This approach combines inductive category coding with a simultaneous comparison of all student responses to the same prompt. Categories were refined as each new student response was considered until satisfactory categories for the data set had been developed.

Table 2. Pretest and Posttest Mean Scores

Item	Maximum Possible Points	Example Correct Responses	Pretest Mean Score	Posttest Mean Score
1. Name different kinds of teeth and their purposes. (1 point each tooth type and 1 point each correct function)	8	Incisors: gnawing, snipping; canines: ripping, tearing, stabbing; premolars: shredding, chewing; molars: grinding, crunching; canine: stabbing, gripping.	1.4 (2.1)	3.3 (2.5)
2. Some animals have large or small eyes compared to head size. What does this indicate? (1 point each correct function)	2	Small eyes: tunnel dweller; large eyes nocturnal or underwater.	0.0 (0.0)	0.8 (0.7)
3. Draw arrows and identify the names of the bones of this skull on the photo provided. (1 point each correctly labeled bone)	8	Possible bones: mandible, maxilla, nasal, frontal, zygomatic (arch), occipital, parietal, auditory bulla	0.4 (0.7)	4.5 (2.3)
4. Tell what the position of eyes on an animal skull means about the animal's lifestyle. (1 point for each type vision and 1 point each corresponding lifestyle)	4	Eyes facing forward for binocular vision: predator; eyes on the sides for peripheral vision: prey.	0.1 (0.3)	1.2 (1.5)
5. Draw arrows to identify different holes or parts of the skull (not bone names) on the photo provided. (1 point each correctly labeled part)	5	Possible terms: foramen, orbital or eye socket, nasal cavity, foramen magnum, crest	0.2 (0.4)	1.9 (1.8)
6. Tell anything else you know related to animal skulls. (1 point each correct idea that did not appear elsewhere on test)	3	Examples: information about day of the dead, sketches of specific animal skulls, teeth of specific animals	0.0 (0.0)	1.8 (1.0)
Total Score	30		2.0 (1.8)	11.8 (6.4)

Note: Standard deviations in parentheses

Results and Discussion

Overall, the lessons were a large success with students eagerly approaching the activities and staying on task (both noted through teacher observation); learning many concepts as shown through performance on the posttest; and expressing their enjoyment verbally during class and on the attitude surveys. These lines of evidence indicate positive student interest, attention and science learning. The well-completed movable books with exciting cover art and figural transformations, along with the student-made animal skulls, showed that students had completed activities supporting several visual arts standards, most notably Standard 1 of the National Visual Arts Content Standards (National Art Education Association, 1994): "Understanding and applying media, techniques, and processes." The following sections provide evidence of these assertions.

Learning Gains

Table 2 presents mean pretest and posttest scores of students. A paired t-test showed a significant difference between the pretest and posttest scores with a very large effect size ($p < 0.00002$; Cohen's $d = 2.1$), indicating that students learned a considerable amount from the one-week experience. Because students did not have the opportunity to study the science content outside of class, these performance scores are quite good.

Student Attitudes

Motivation and enjoyment of the lessons. Table 3 shows student attitudes measured at intervals during the unit. Students were enthusiastic throughout the lessons reporting high rates of enjoyment. Student excitement was shown by the response to the optional homework assignment of creating an animal skull from items found at home. All students participated and some brought multiple projects they had completed. Figure 3 shows four student-made examples. Figure3a shows a beaver skull made from cantaloupe and carrot sticks. The student captured the shape of the skull and angles of the animal's iron oxide-coated orange teeth with the inserted carrots. Figure 3b depicts a drawing of a wolf, colored with glitter glue, showing a prominent canine tooth and decorated in the style of Mexican Day of the Dead. Figure 3c was made by unbending paper clips to outline major skull features such as ridge and zygomatic arches. Figure 3d shows Styrofoam insulation carved to represent an animal skull with nasal cavity and orbits.

Table 3. Student Attitude Ratings

Attitude	Third Day	Fourth Day	Last Day	Mean
Student's rating of own creativity	8.2 (2.4)	9.5 (0.9)	8.9 (2.1)	8.9 (1.9)
Student's rating of enjoyment of the lesson	8.4 (2.8)	9.2 (1.6)	8.8 (1.9)	8.8 (2.1)

Note: Standard deviations in parentheses

Figure 4 shows additional student and teacher-made skulls. Figure 4a represents a student-made beaver skull created with duct tape-covered items. The prominent incisor teeth and zygomatic arches are visible. Figure 4b was created entirely from one fast food drink tray that was cut and reassembled with glue. The model shows eye sockets, nasal cavity and maxilla with teeth. Figures 4c and 4e, were made by a teacher. Figure 4c features the underside aspects of a skull including the foreman magnum and auditory bulla, while Figure 4e, made of discarded cardboard, emphasized suture lines on the top of the skull. Figure 4d shows puzzle pieces that can be assembled to form a cow skull. The teacher who designed this game wrote a clever introduction containing word play: "Can you put the *cow*lection of puzzle pieces together to form an animal skull? I *dairy* you. This is an *udderly* fun activity. I would not *steer* you wrong! If you have *herd* enough, please cut, *moove*, and join the puzzle pieces if you *cud* figure out what kind of animal skull this is. *Milk* this activity for all it is worth!"

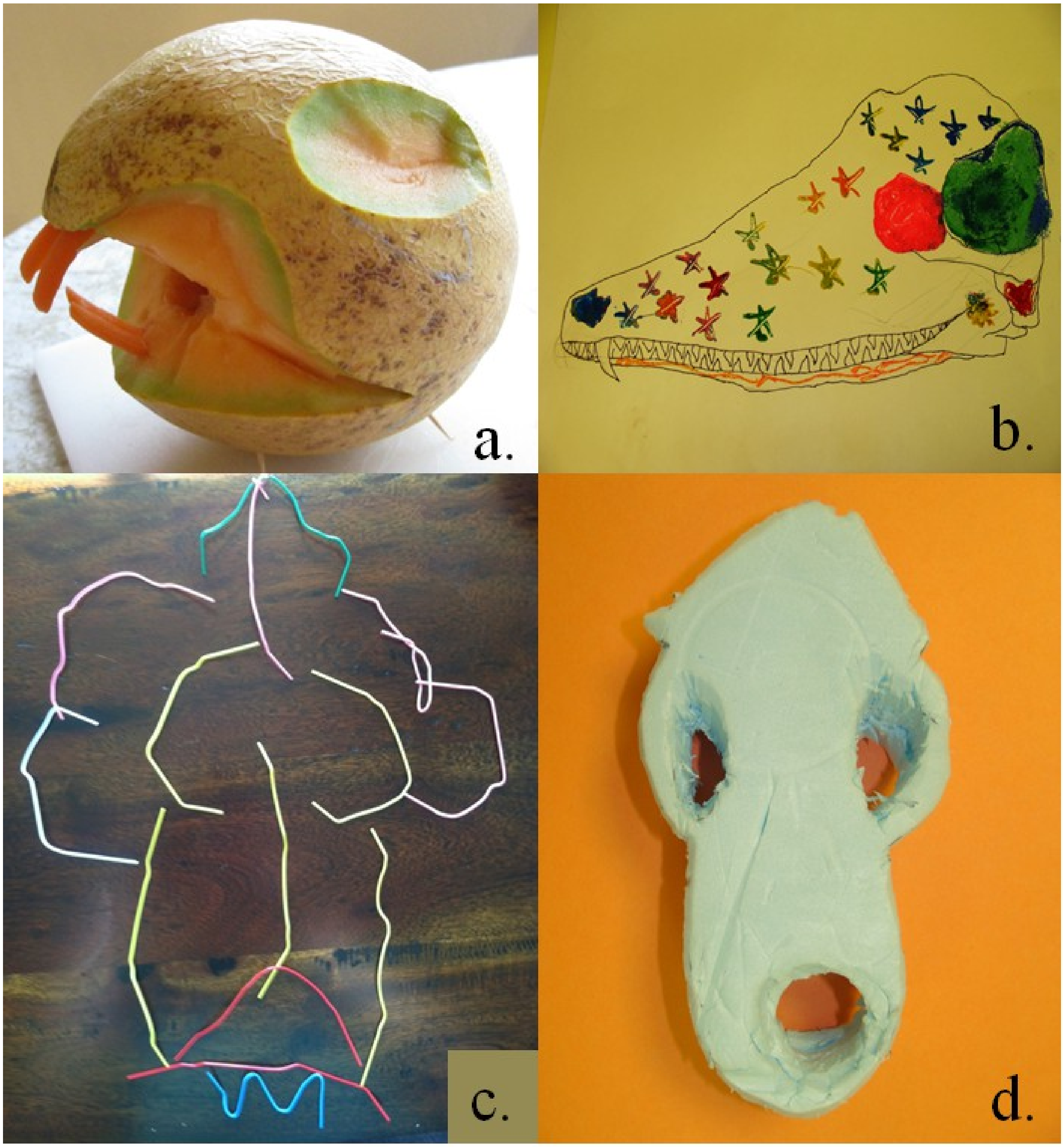

Figure 3. Creative Skulls Made from Found Materials

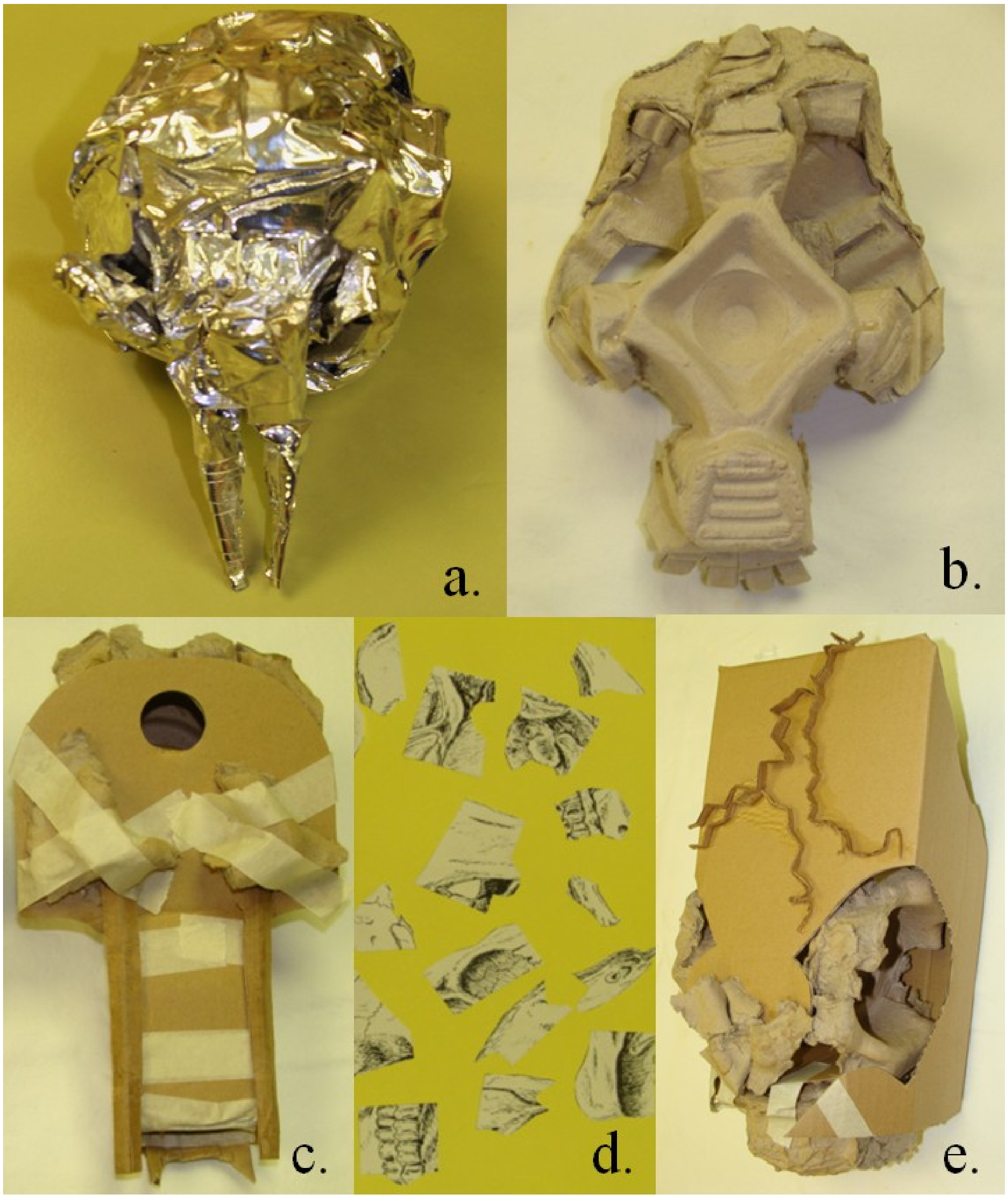

Figure 4. Additional Creative Skulls Made from Found Materials

Table 4 shows reasons students gave for motivation during the lessons. The arts and crafts were cited most frequently as factors contributing to student motivation. Students also mentioned teacher help and general enjoyment of the lessons.

Table 4. Reasons Students Gave for Motivation during the Lessons (combined from three days of surveys; some students provided multiple reasons)

Frequency	Reason student gave for being motivated
9	Doing the arts and crafts was fun
7	The teacher motivated me by helping me and explaining it well
7	General statement of the fun and excitement of the lessons
6	Information about animal skulls and bones was very interesting to learn
5	Making the book - seeing how it would turn out when everything was in it.
4	Creative home project of making a skull from household items was fun and challenging

Many students remarked that they found the animal skull lessons interesting even though they did not usually like science (See Table 5). Arts, crafts, and working with glue in particular were reported as high-interest activities. Many students remarked in class that such activities were absent form their elementary education. They were very eager to engage in cutting, folding, drawing, painting, and gluing during the animal skull lessons. The three-dimensional nature of pop-up constructions fascinated students who were accustomed to working in two dimensions. The curved, three-dimensional surface of the animal skulls on the book's cover made from the shoulders of clear plastic bottles was exciting. Being able to exercise creativity by creating animal skulls from found objects or discarded materials at home (e.g., the skull cut from a cantaloupe or outlined by unbent paper clips) was motivating.

Teacher observations supported high levels of student motivation. Students studied the card sets on their own without being prompted or specifically encouraged. Many students asked to see the animal skull models used in previous lessons so that they could review concepts. A couple of students spontaneously brought in animal skulls they had found in the woods or their parents had produced as a result of hunting.

Table 5. Most Interesting Aspects of the Lessons as Identified by Students (combined from three days of surveys; some students provided more than one highlight)

Frequency	Most Interesting Aspects of the Lessons
5	Learning about the animal skulls when I don't always like science
5	Doing arts and crafts
4	Gluing everything together was fun.
3	The slide show about Mexican Day of the Dead
3	The contest of making a skull at home of household materials
3	Drawing the pictures for the figural transformations
2	Making the wheel of teeth
2	Making the pop-ups
2	Learning about types of teeth
1	Getting to learn, then do something fun with what we learned.

Perceived and evidenced creativity. Table 3 indicates that students perceived themselves as being highly creative (ratings of 8.2-9.5 on a 10-point scale). Ratings dipped slightly on the last day of the unit because students were assembling their books rather than creating new items. The reasons students gave for creativity are shown in Table 6. Pride in the final elaborate product, resourcefulness in designing a skull from household items, and success at drawing many figural transformations were cited most frequently.

Table 6. Reasons Students Gave for Creativity Ratings (combined from three days of surveys; some students provided more than one reason)

Frequency	Reason student gave for creativity rating
5	Putting the final animal skull books together in an attractive way.
5	Original in making a skull from household items
5	Clever or fluent in making many figural transformations
3	Skillful sketch of an animal skull
3	Appealing, colorful decorated skulls made for Mexican Day of the Dead cover of the book
3	General statement about being creative
3	Able to make a pop-up or wheel behind the page that worked well
2	Elaboration in adding details
3	Did not think I was creative today

Figure 5 shows student drawings made on the various given simple figures (bolder lines) that were chosen to illustrate creative skills of the students. Figure 5a shows many creative traits including humorous motion of skulls bouncing down a staircase while a skeleton listens to the ruckus below the stairs (creative skill of storytelling articulateness). Figure 5b shows a turkey skeleton choosing acorns from an oak tree. This was a topic that no one else used for this given figure (originality). Figure 5c depicts a side view of a baboon skull showing the creative skill of taking an unusual perspective. Figure 5d shows a Cheshire cat with a partly invisible body (imagination) and highlights the jaw bones of maxilla and mandible (science content). Figure 5e shows the occipital bone (science content) of an emotionally expressive skull (a creative trait), while Figure 5f shows a colorful rendition of a pirate flag with skull and crossed bones. Use of color shows originality and elaboration, both creative traits.

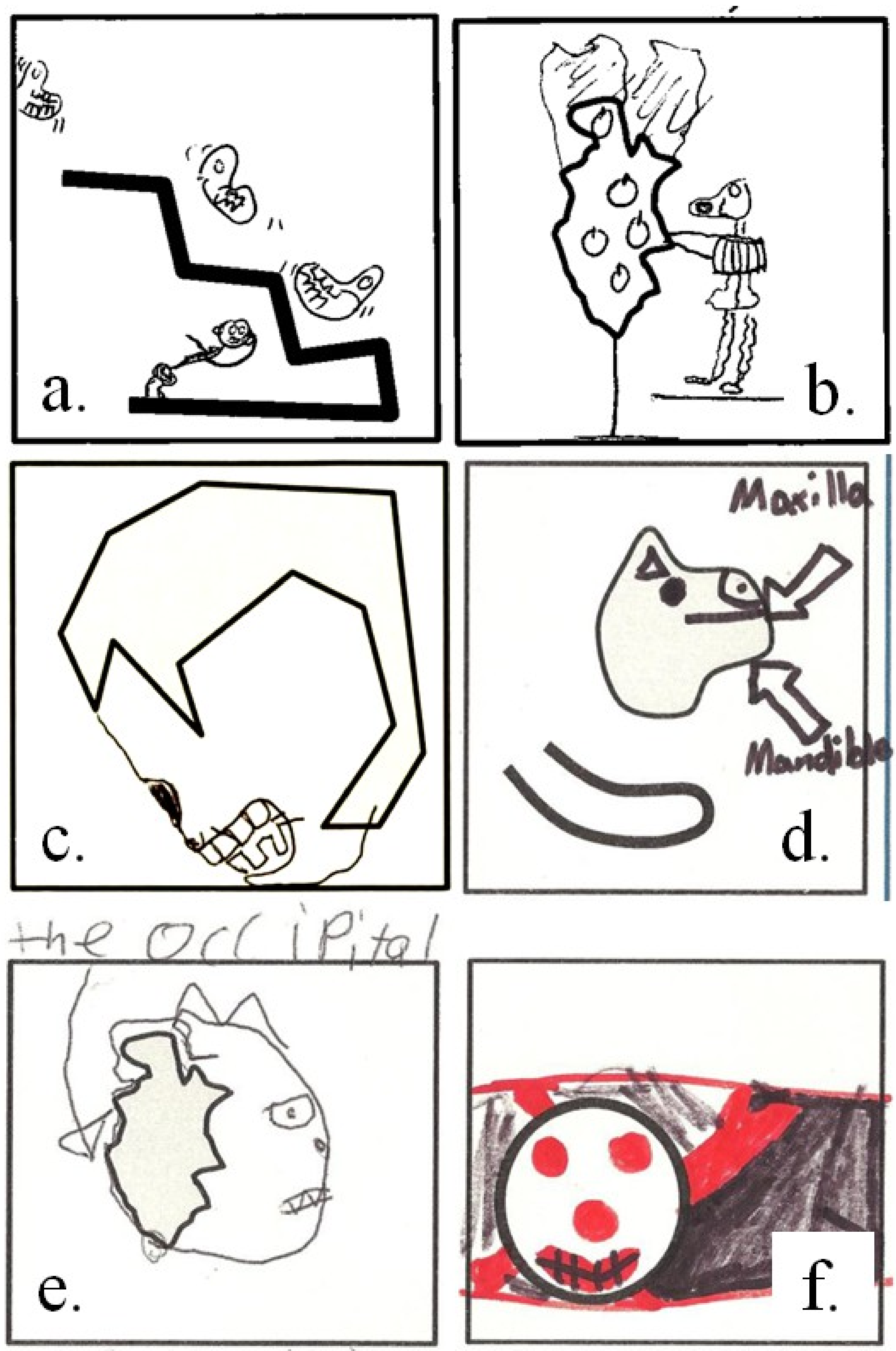

Figure 5. Assorted Figural Transformations Made by Students

Figure 6 shows four different students' approaches to the same given figure. Part of the teacher-given instructions for this activity were to try to think of something no one else in the class would make that still related to the animal skulls theme. Figure 6a depicts a cartoonish cat with identified canine teeth. Figure 6b shows a cat head with exaggerated whiskers. Figure 6c depicts the Pac Man character from early video games with the skull bones drawn inside and canine teeth added, titled, "Pac Man's a predator." This related to the work students did in sorting skulls by eye socket positions as predators or prey. The final image in Figure 6d has been made into the letter "B" to write the word "Bite," referring to student interest in teeth.

Conclusion

Overall, students evidenced large gains in knowledge about animal skulls (with a very large effect size), reported high enjoyment and motivation during the lessons, and demonstrated creative ideas while recognizing their own creativity. The paper engineering and creative art activities stimulated students into a near-frenzy of excitement over making the movable books and learning more about animal skulls. Many students expressed that they enjoyed the creative lessons so much because they had not had previous opportunities in their school experiences to engage in craft-making or creative thinking. As one student remarked, "The best part was learning about skulls and I do not like science, but this is fun!" Several students commented that they liked learning the skull information because they were able to immediately apply their learning to the movable book pages. Not only did students evidence pride in their craft work by showing the completed books to family members and other peers not involved in the classes, but they remarked how the books would remain keepsakes to remind them of their learning and assist in reviewing the skull information in the future.

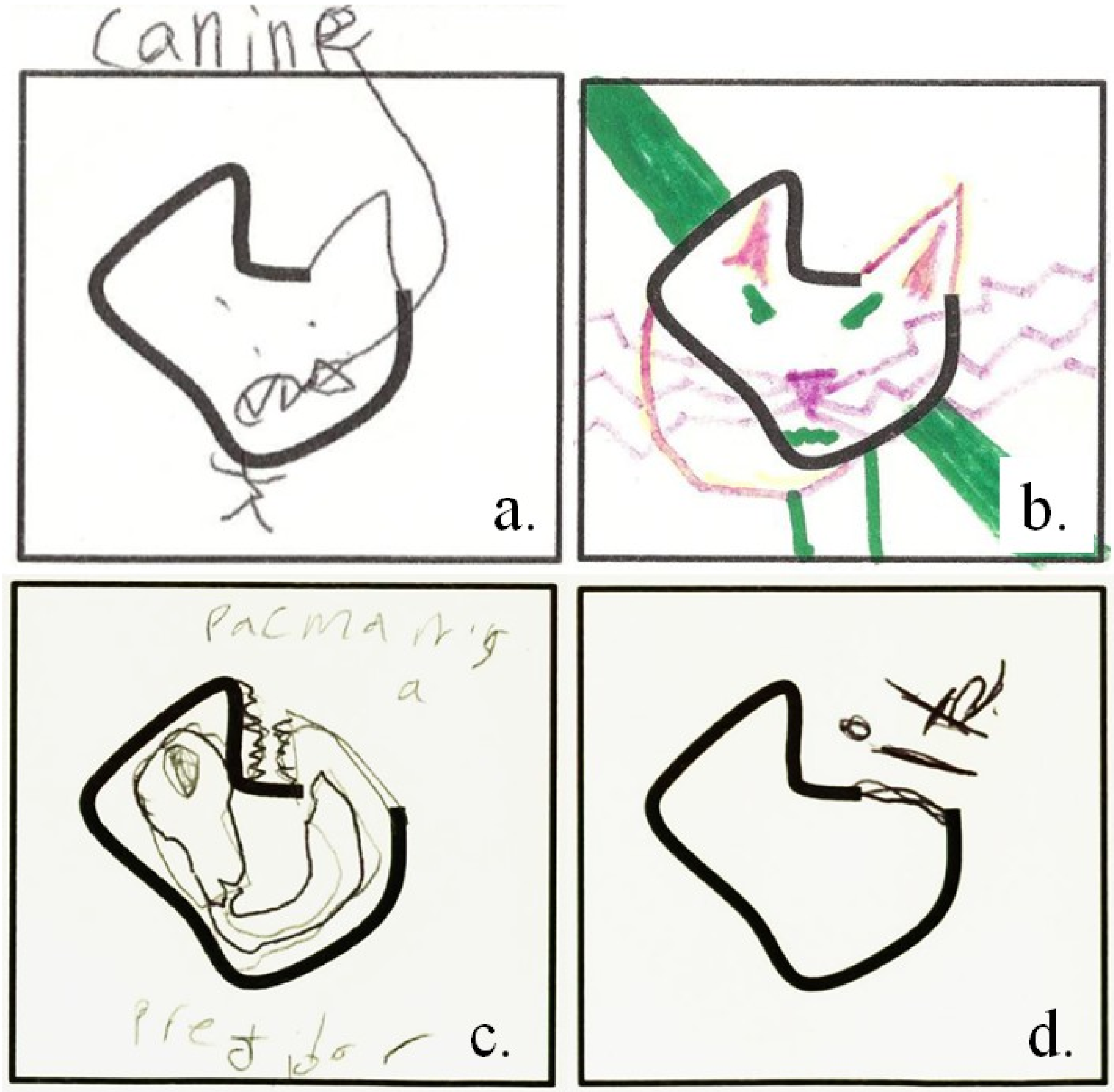

Figure 6. Figural Transformations of the B-Shaped Image

We recommend that science teachers consider including similar lesson approaches that include craft-making in their science pedagogy. Our findings related to high motivation and strong retention of science content are similar to that of Klopp, et al. (2013) who found that elementary and middle school students preferred crafts to technology-rich science projects and evidenced more science content in craft projects. Our study showed that art integration with science built student motivational and creative skills while increasing learning of science information similar to the work of Appel (2006) and Deasy (2002). The hands-on and manipulative nature of the craftwork such as cutting, folding, positioning pieces of paper, spreading glue, drawing, and painting allowed students to practice fine motor skills which maintained attention on the task and the content (Lilliard, 2005; Sobe, 2004).

These activities could be adapted to other science topics. Any concepts that can be sorted into two groups could be substituted for the pop-up page of predator versus prey. Any science topic that has three or four types of specimens such as types of rock (e.g., igneous, sedimentary, metamorphic) could be used with the wheel behind the page that we utilized for types of teeth. A lift-the-flap page is effective for presenting science trivia, facts about animals, or identifying contributions of famous inventors. The figural transformation page of simple geometric forms or squiggles is easily adapted to any science topic.

An advantage of frequently making movable books or art-integrated projects is that students will eventually be able to design their own projects without teacher guidance. This can lead to students going beyond books to create an apparatus, device, or other invention to demonstrate their learning of science concepts. Certainly, our students expressed the intention to continue to make movable books on their own for school projects and to create visual images related to their favorite topics as we had done in making animal skulls of found materials. The ability to problem-solve and generate creative solutions is needed in the constantly evolving environment of today's world.

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