Tactile Earth and Space Science Materials for Students with Visual Impairments: Contours, Craters, Asteroids, and Features of Mars

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ABSTRACT

New tactile curriculum materials for teaching Earth and planetary science lessons on rotation/revolution, silhouettes of objects from different views, contour maps, impact craters, asteroids, and topographic features of Mars to 11 elementary and middle school students with sight impairments at a week-long residential summer camp are presented along with tips for constructing/obtaining the materials. Many of the lessons focused on spatial skills, an important skill area for persons with visual impairments. The pretest-intervention-post-test design study measured both attitude changes and gains in content knowledge. Students reported significant improvements (with large effect sizes) in the frequency of science lessons, the concrete nature of science lessons, the enjoyment these lessons produced, and the amount of participation in the lessons at the summer camp for students with visual disabilities compared to students' regular schools. Students generally showed a lack of knowledge of lesson topics on the pretest; on the post-test, most students were able to articulate basic facts about contour maps, impact crater formation, volcanic rocks, and features of Mars. The materials are recommended for use with sighted students as well as those with visual impairments because of their concrete, tactile nature. © *2011 National Association of Geoscience Teachers*. [DOI: 10.5408/1.3651404]

INTRODUCTION

Zaborowski (2006) lamented a paucity of research-based science education practices for students with visual impairments and a need for more research-based accommodation for these students. After reviewing federal education policy related to students who are visually impaired, Wild and Allen (2009, p. 115) suggested that these research questions be addressed: "What theoretically based teaching and learning practices are beneficial to students with visual impairments?" and "What modifications to the science education curriculum are essential when working with students with visual impairments?"

This study documents the testing of new materials for teaching geoscience concepts to elementary and middle school students who have visual impairments during a week-long summer Space Camp. These materials present Earth and space science concepts of topographic contours, asteroids, and Martian features, such as massive shield volcanoes, Valles Marineris, and impact craters. In this article, I address three objectives: (a) describe effective materials (both commercial and instructor-made) for teaching Earth and space science concepts to students with visual impairments; (b) present theoretically based lessons as learning cycles so that others will have a constructivist model for teaching; and (c) provide my insights in working with elementary and middle school students with blindness or visual impairments.

Science Accommodations in the Literature for Students Who Are Visually Impaired

Students with disabilities frequently miss out on science lessons because many teachers lack the knowledge and skills to make appropriate accommodations in science (Stefanich *et al*., 2005; Yuen *et al*., 2004). Middle and high school science and mathematics teachers, in a study by Rule *et al*. (2011), expressed great concern whether they could meet the needs of their students with visual impairments at the beginning of the school year; however, when provided with adaptive materials, equipment, and ideas for accommodating the disabilities, they became more confident and their students were largely as successful as sighted peers. Therefore, it is important to report effective materials and accommodations for teaching science to students with visual impairments. Science and mathematics have traditionally been difficult subjects for students with visual impairments because they are typically presented in a visual format. Sahin and Yorek (2009) underscored the need for tactile materials for students with visual impairments, suggesting Braille note-taking devices, tactile specimens and models, embossed maps/figures, and audio recordings of lectures and texts. Kumar *et al*. (2001) added that providing course materials in electronic form permits software-generated audio translation, and assistive technologies such as talking thermometers, scales, and calculators, along with rulers and glassware with embossed numbers, allow better participation. Similarly, Supalo (2005, recommended the use of a thermo raised-line pen on special polymer-based paper to produce tactile drawings or a hot glue gun to outline figures on Braille paper so that the student can later label them in Braille.

In the field of geoscience education, Asher (2001) described accommodations she made for a student with visual impairments in a college geology course. These included spelling new terms during lectures, describing visuals in use, specifically referring to right-hand side or left-hand side of a diagram to indicate position (rather than saying "Over here"), explaining visual humor so that everyone understood the joke, providing glued-on foam or cloth textures on block models of structural geology features, and using Braille mineral and rock identification charts.

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Importance of Spatial Skills for Students with Visual Impairments

Spatial awareness skills are crucial for students who are blind or sight impaired. Because vision is so important to a child's early development (Fazzi *et al.*, 2005), children with vision impairments often show significant lags in development as compared to sighted age-mates (Brambring, 2001, 2006) but have the same range of mental abilities as students with sight (Kumar *et al.*, 2001). If students with visual impairments are provided accommodations, they can learn higher-order science concepts like other students (Jones *et al.*, 2006). Kesiktas (2009), after a review of the early childhood literature related to children with vision impairments, concluded that intervention programs for early childhood (birth to age 8) need to focus on all developmental areas, with special emphasis on orientation and mobility skills. Siekierska *et al*. (2003) echoed the importance of orientation and spatial skills, noting that everyday tasks are extremely challenging because most environments are designed for sighted people. They recommended tactile and audio-based maps to aid persons with visual disabilities in navigating their surroundings. Shepherd (2001) listed important visually based skills for geographers and Earth scientists that need to be taught to students with visual impairments in nonvisual ways: map reading, observation and recording, landscape sketching, judging heights and distances, spatial skills, and coordination and balance. In the space science lessons presented here, important spatial skills of recognizing three-dimensional objects by silhouettes from different perspectives and use of contour maps are integrated into the learning of information about asteroids, craters, volcanoes, and other features on planets to help students increase their spatial understandings.

The concepts taught in the lessons presented here address the Earth and space science standards for grades K–4 (properties of earth materials, objects in the sky, changes in Earth and sky) and grades 5–8 (Earth in the solar system) of the National Science Education Standards (National Research Council, 1996, p. 107). Additionally, several of the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 2008) are met by these lessons.

METHOD

Student Participants

Twelve students (3 females, 9 males) in grades 2–8 attended the six day residential summer Space Camp held on the campus of a state K–12 facility. Because blindness and significant sight impairment occur in a small percentage of the school population, students in general are isolated in different districts, making it difficult to conduct classroom studies of exclusively this population. This summer camp offered the valuable opportunity to observe the reactions of many students to the new curriculum materials in a group setting. In this case, the sample size of 11 students and the intense residential nature of the camp can be considered a rich setting for data collection.

All students had significant visual impairments with three students being completely blind and two more with extremely limited vision. Students' visual impairments were caused by conditions associated with albinism, brain tumor, degenerative disease, or other medical conditions. Three students who had significant cognitive impairments associated with their medical conditions that adversely affected their short-term memories were not able to retain much information from the lessons, although they participated completely and visibly enjoyed the activities. Eleven of the 12 students participated in all lessons. The exception was a young student, emotionally upset with homesickness, who stayed with the nurse during some activities and refused to participate in others, although physically attending. The responses of this student were not used in the data.

Human subject participation in this study was approved by the Internal Review Board of the University of Northern Iowa (IRB#-09-0001) and the Iowa Braille and Sight-Saving School. The students and their parents gave written permission for the study to take place, including allowing photography of students during activities.

Experimental Set-Up and Instrumentation

I used a simple pretest-intervention-post-test design study to validate the efficacy of a set of new curriculum materials for teaching Earth and space concepts to elementary and middle school students with visual impairments. Both attitudes and content knowledge were addressed, respectively, by two surveys given on the first day of Space Camp and again on the last day. I administered all surveys orally in private. I set the students at ease by telling them that this was just a way to determine what they thought or knew so that the lessons could be tailored to their needs (pretest) or improved for future students (post-test). Responses were accepted without judgment, probing for further details occurred when students made general statements. Because this was a "fun" summer camp with no grades administered, students did not feel a pressure to perform well on the surveys. Students did not study the concepts outside of the lessons presented; therefore, any gains can be attributed to the lessons.

The attitude survey consisted of six questions that I modeled after questions in Rogers' "Attitudes about school and learning" survey (2002). The questions, which addressed important issues of liking for the educational setting and for science lessons, along with participation in and perceived understanding of science, have content validity. These items attend to important affective aspects of science and the current critical issue of nonparticipation of students with disabilities in science classes. In the tradition of Lawshe (1975), the questions were evaluated by three experts in the field of science education and determined to all represent essential information for the main constructs of the study. Cronbach's alpha (Cronbach, 1951; Cronbach and Shavelson, 2004), a commonly used measure of internal consistency of test scores, was 0.84, indicating reasonably strong reliability. The questions were answered by choosing one of these responses: "yes," "mostly," "sometimes," "a little," and "no." They were scored by assigning a score of "5" to "yes," a score of "4" to "mostly," a score of "3" to "sometimes," a score of "2" to "a little," and a score of "1" to "no." The means, along with standard deviations, were calculated for each question and a paired t-test was used to determine statistical significance from pretest to post-test. Effect sizes were calculated using Cohen's d (Cohen, 1988) and pooled standard deviations (Dunlop *et al.*, 1996) for statistically significant items.

The content survey consisted of five questions:

1. "Tell what you know about contour maps;"
2. "Tell what you know about craters;"
3. "Tell what you know about volcanic rocks;"
4. "Tell what you know about volcanoes on Mars;" and
5. "Tell what you know about Valles Marineris on Mars."

These questions are criterion-referenced and directly addressed the objectives of each lesson. The questions were open-ended so that students had to construct answers. I recorded their responses in writing. Each response was divided into separate ideas that were coded into inductively created categories in a qualitative analysis. The number of responses in each category was tabulated to more quantitatively show what concepts were learned from pretest to post-test. Two other science educators reviewed and agreed with the categorization of the responses.

Additionally, responses from students to lesson activities were recorded, and students were asked to tell ways the lessons could be improved or what aspects they most enjoyed at the close of several lessons. This qualitative information was used to triangulate and enhance the more formally collected pretest–post-test data.

Lessons and Curriculum Materials

The lessons described in this study were conducted by the author with small groups of four students at a time. One of several paraprofessionals assisted the author with students during each lesson. Generally, each lesson lasted about 45 min with the next group of students following a few minutes afterward. Although four complete learning cycle lessons are presented here, they actually stretched over 5 days with two activities, the contour map drawing and the plaster crater model, taking place during an additional lesson period. Groups of students rotated among three different structured activities during the morning, each taught by a different teacher.

In the afternoons, all students, teachers, and paraprofessionals participated in various activities including investigating a model of the solar system with scaled models of planets located at measured distances along a rope, visiting two museums (an aerospace museum and a natural history museum), working as three teams to assemble microgravity sleds made of PVC pipe and plastic connectors on dry land and underwater in the shallow water of a swimming pool (NASA, 2007), watching/listening to a descriptive NOVA video about Mars (Davis, 2004) and a descriptive version of the movie Apollo 13 (Broyles and Reinert, 1995), free play in the swimming pool, and practicing the script for an Apollo13 reader's theater play (Scholastic Action, 2005).

Table 1 shows a description of the curriculum materials used. The lessons will be described in detail in the results section so that student reactions to the lessons may be discussed after the lesson is described to avoid unnecessary repetition of information. All lessons were presented as learning cycles to promote inquiry (Everett and Moyer, 2007) and to help students examine their previous ideas and adopt improvements (Brown and Abell, 2007). Each lesson began with hands-on exploration of materials to capture student attention and engage them in learning. This is often called the "Exploration Phase" of the lesson. A key question related to the lesson topic was used to help students activate their prior thinking about the concept. Sometimes, students had initial difficulty answering the question and experienced disequilibrium. This cognitive state pushed students to learn more. As students responded to the key question, the teacher became aware of students' understandings of the concepts, allowing the teacher to better tailor the lesson to their needs. During the "Explanation" or "Concept Development Phase," the teacher provided examples and explanations that helped students to understand the concept and return to a state of equilibrium. The teacher checked for closure at the end of this phase, asking students to explain the new ideas in their own words. In the last phase of the lesson, the "Expansion" or "Elaboration Phase," the recent learning was applied to a new situation, providing additional mental connections and further practice so that students would be able to easily access the information. At the end of (or during) the lesson, students were evaluated with performance-based assessments in which they demonstrated their new knowledge.

RESULTS

Attitude Survey

In general, student attitudes related to Space Camp were more positive than those associated with the public schools students attended. This would be expected as this was a free-choice summer camp. The majority of students clearly enjoyed their regular schools and all reported that they thoroughly enjoyed Space Camp. There was a statistically significant difference in student perception that there were more science lessons at Space Camp than in their school (Table 2). When asked if there were a lot of hands-on science lessons (question 3), several students stated that most science lessons at school involved watching films or reading textbooks with few concrete experiences. "It's all visual," remarked one student, while another commented, "It's so boring – it's mostly reading." On the post-test, students recognized that Space Camp teachers had provided many rich science experiences for them that they appreciated. The pretest and post-test scores here were significantly different.

Students reported a statistically significant higher level of enjoyment for their participation in science lessons at Space Camp compared to those in their schools (Table 3, question 4).

Students with vision disabilities perceived that they were not having the same chances for participation as other students at their schools (question 5): "I enjoy science, but I don't get to go much because I have to go to another class," and "We do partners and my partner gets to do it all." On the post-test, almost all students agreed that they were able to participate as much as others, creating a statistically significant difference from pretest scores.

Finally, students' responses to the question of how well science lessons at school and Space Camp helped students' understanding of science showed no statistical difference. One factor keeping this score depressed was the responses of the three students with cognitive impairments who realized that they had not retained much information or understanding: "I know we talked about things, but I can't remember. I wish I knew more."

TABLE 1: Curriculum materials used in lessons.

Concepts and specific materials	**Ways the items were produced or obtained**
Lesson 1. Motions of bodies in space and silhouettes from different views	
Toys showing rotation, revolution	Toys were collected by visiting dollar stores, thrift shops, and garage sales. Many cat toys and toys from fast food restaurants often exhibit these motions.
Silhouettes of toys	Twelve relatively small, simple toys were photographed along three orthogonal axes to produce silhouettes from different viewpoints. These outlines were used to produce three thick mat board silhouettes that were glued to a mat board base (one for each toy) along with the name of the toy in Braille. Three additional silhouettes that fit into the hand were made with two thicknesses of mat board and attached by a cord to the mat board base. The reverse side of the mat board base showed the three photographs of the object with its printed name.
Lesson 2. Topographic contour maps	
Layered models of hilly landscapes	Cut layers of colored craft sheet foam (usually about a dollar a sheet) and glue onto a mat board base. Mat board is colored cardboard used to frame pictures (usually $5–10 for a sheet 80 × 100 cm).
Tactile contour maps of hilly landscapes	Cut identical shapes of black sheet foam to match models, and then trim to a 3 mm-wide outlines. Glue to mat board base to duplicate arrangement seen in model.
Layered models showing depressions	Cut rectangular layers of sheet foam to match size of mat board base, then cut holes so that lower layer has small hole that shows through larger hole in upper layer
Tactile contour maps with hachured lines	Cut black sheet foam shapes to match the contours of holes in above models, trim to 5 mm wide, and then cut out rectangular teeth to make the line hachured.
Foam layered contour maps of specific craters on Moon's surface	Use geologic maps of Moon from Internet (Lunar and Planetary Institute, 2009). Although these are not contour maps, contours can be inferred. Trace inferred contours electronically with drawing tools in PowerPoint or other drawing software. Print out contours. Use these as patterns for cutting foam layers.
Tactile contour map of Moon craters	Use the black and white computer-made drawing of contours used for the foam model. Print on special heat-sensitive paper—thermal expansion paper—with black ink on an ink jet printer. Run paper through a thermal expansion machine ($400 and up) so that the black lines "grow" and are raised. See Jaquiss (2003) for more discussion of this technology and comparison of various venders.
Student-made model and contour map	Cut three templates for a layered hill from a stiff plastic placemat. Student rolls out air-dry clay and uses a plastic knife to cut around each of these templates to produce three clay layers of graduated sizes. After these have dried, glue together to make a hill. The templates were traced on film using a Draftsman Tactile Drawing Board (American Printing House for the Blind, 2009) (currently $177) to produce a tactile contour map with layers oriented as in the clay model.
Lesson 3. Near-earth asteroids and the process of large crater formation	
Models showing six steps occurring during impact	Use air-dry clay, papier-mâché, and/or craft foam cut-outs applied to a mat board rectangular base to show the relevant items in each step. Rounded cobbles (in our case of iron slag) were used to model the asteroid before impact.
Pictures and descriptions for each step	Visuals help those students who have sight. Braille descriptions were provided for Braille-readers along with print for those who were sighted.
Meteorite specimens	Obtained from a rock and mineral shop and an online science specimen supply house

TABLE 1: *Continued*

Concepts and specific materials	Ways the items were produced or obtained
Plaster model of cratered moon surface	Plastic cereal bowl filled with wet plaster of Paris ($5–10 for 2 kg). Students held rocks at waist-height and dropped them to produce craters (rocks were then removed before plaster set). Plastic toy astronaut with oiled feet was "walked" across the surface to produce footprints.
Model of asteroid belt in solar system	Mat board model with foam rings with beads or buttons to represent the planets in their orbits. The asteroid belt was shown as a circular band of glitter between Mars and Jupiter.
Asteroid Models	Potato-sized models of near-Earth asteroids licensed under authority of NASA and the Jet Propulsion Laboratory were purchased from Serra Designs (2009). Currently approximately $180 for a set of 13 asteroid models.
Silhouettes of asteroid models	Photograph models from along three orthogonal axes. Use photographs to produce mat board silhouettes in the same way as described for the toys. Mount on mat board and produce hand-held silhouettes of double thickness attached by cord. Provide information on each asteroid in Braille and print on the reverse.
Lesson 4. Topographic features of Mars	
Volcanic rock specimens	Collected on various vacations and field trips; often volcanic rocks are sold for barbeque pits; they may also be obtained from online science supply outlets such as Ward's Natural Science (2009).
Small plastic model of erupting volcano	This toy was "Pocket Volcano" produced by American Science and Surplus (approximately $4). Models were purchased at a Midwest craft store called "Hobby Lobby;" this item is also available through Amazon.com.
Raised relief map of Mars	This is a commercially available item that shows the polar regions and the equatorial region of Mars (approximately $35).
Contour model of Olympus Mons	A model was made of securely-glued sheet foam layers cut along topographic contours. A topographic map is provided in Wu *et al.* (1981) and also in James and Leon (n.d.).
Contour model of Valles Marineris	This was a commercially available kit called "Expedition to Mars: Planet Mars three-dimensional model Valles Marineris surface topographical map" that I altered by mounting each contour layer on craft sheet foam to produce a solid block model. The kit (approximately $25) is sold online by Cool Stuff Express (2009).

The statistical analysis indicates that there were large effects at Space Camp for the perception of the frequency of science lessons, the concrete nature of science lessons, the enjoyment these lessons produced, and the amount of participation in the lessons for students with visual disabilities. There was not a statistically significantly difference between students' overall enjoyment of school versus Space Camp or student perception of their relative knowledge retention between the two environments. Overall, this attitude survey indicates that Space Camp was a positive and effective experience for students.

Lesson 1: Motions of Bodies in Space and Silhouettes from Different Views

Some basic motions of bodies in space are rotation (spinning on an axis) and revolution (following a circular or elliptical path around another object(s). In the Exploration Phase, students told what they knew about these terms to activate their prior knowledge and to allow the teachers to see their current understandings. Then, during the Explanation Phase, they acted them out correctly with guidance by standing and slowly turning around in the same place to simulate rotation and then moving in a circle around a cane or chair to simulate revolution. For additional practice, students examined a set of toys to determine which type or types of motion they exhibited. For example, students spun tops, felt how a cat-toy ball traveled in a circular tunnel-groove around a central pillar, or blew on a pinwheel and touched it to observe its motion (Fig. 1). As we reached closure for this phase of the lesson, students suggested other objects in their experience that exhibited rotation (i.e., a rolling tire, a ballerina), along

TABLE 2: Results of the pretest–post-test attitude survey with 11 students responding. Students' responses and assigned points: yes (5 points), mostly (4); sometimes (3); a little (2), and no (1).

Pretest question	Mean (SD)	Post-test question	Mean (SD)	T-test results show statistically different?	Cohen's *d* effect size calculated for significantly different differences
1. Do you enjoy going to school?	4.6 (0.8)	1. Did you enjoy going to Space Camp?	5.0 (0.0)	No; $p = 0.08$; one tailed	—
2. Are there many science lessons taught for your class at school?	3.2 (1.8)	2. Were there many science lessons for the students at space camp?	4.8 (0.6)	Yes; $p = 0.009$; two tailed	$d = 1.2$ large effect
3. Are there a lot of hands-on science lessons that you participate in at school?	2.8 (1.7)	3. Were there a lot of hands-on science lessons that you participated in at space camp?	4.8 (0.6)	Yes; $p = 0.003$; two tailed	$d = 1.6$ large effect
4. Do you enjoy the science lessons you do at your school?	3.5 (1.9)	4. Did you enjoy the science lessons you did at space camp?	5.0 (0.0)	Yes; $p = 0.01$; one tailed	$d = 1.1$ large effect
5. Do you get to participate as much as other students in the science lessons you do at school?	2.9 (1.9)	5. Did you get to participate as much as the other students in the science lessons you did at space camp?	4.6 (0.7)	Yes; $p = 0.008$; two tailed	$d = 1.2$ large effect
6. Do the science lessons at school help you to deeply understand science?	3.5 (1.8)	6. Did the science lessons at space camp help you to deeply understand science?	4.4 (1.2)	No; $p = 0.22$; two tailed	—

with those showing revolution (i.e., a tethered ball, cars on a racetrack). They also named items showing both rotation and revolution: A rolling coin moving in circles in a giant funnel for donating to charity and the Earth moving around the Sun.

To apply the above concepts further during the Expansion Phase, I told students that many objects in space appear as silhouettes—dark filled-in outlines; their three-dimensional shape is determined by observing them from different positions as they either rotate or as we revolve to different viewpoints. A silhouette is a projection of points from an object onto a plane. Although these points on the object may not lie in a plane, this idea provided a foundation for exploring three-dimensional shapes in another way

TABLE 3: Student pre- and post-test responses to, "Tell what you know about contour maps." Eleven students responded.

General category of idea or concept	Frequency of response	
	Pre-test	Post-test
A contour map shows where high and low spots are and how land is laid out	0	6
NASA, scientists, hikers, and boy scouts use these maps	0	3
Uses lines to show the shape of hills or mountains	0	3
A flat map that represents something that is three dimensional	0	3
Shows the shape of levels or layers of the land	0	2
Hachured lines show the low spots or holes	0	2
Shows the elevation of hills and other landforms	0	2
Tells the number of feet in thickness of each layer	0	1
Used to show surface of planet or moon	0	1
Incorrect statement	0	1
No knowledge	11	3

FIGURE 1: (Color online) Example toys showing rotation and revolution.

through contours in the next lesson. To better understand the concept of silhouettes, students explored silhouettes of various toys (Fig. 2). As described in Table 1, each toy had a corresponding board with tactile silhouettes from different orthogonal directions. Students were each given three toys and three silhouette boards to touch and match. The table was covered with a white sheet to enhance contrast with the brown silhouette shapes for those with limited sight. After students had matched the toys to silhouettes, the sets were passed around the table.

Evaluation of the lesson occurred as students told their strategies for determining which object went with which silhouette. A student with a narrow range of vision suggested, "Pick up the object and look at it. Put the silhouette against the object and see if it covers it up all the way and fits perfect." Another student with no vision told his strategy: "Feel your object and feel your silhouette… Figure out the bumps and what sticks out and match them." Students were surprised by some of the silhouettes for common items viewed in uncommon ways and benefitted by participating in a discussion of what the different parts of the silhouette represented.

One of the paraeducators who was blind suggested that those students with some vision be blindfolded to force them to use their sense of touch during the exercise so that they would hone their tactile skills. Another idea suggested by the camp director was for students to make their own silhouettes of other objects by placing the object on a sheet of paper, using wax-covered yarn sticks called Wikki Stix® (2009) to outline it, and then removing the object to feel the raised outline of the silhouette. This would work well for objects shaped like thick slices but not with objects that have appendages in different planes. Objects could also be pushed into dough or modeling clay to produce a tactile silhouette.

Lesson 2: Topographic Contour Maps

The pretest showed that students knew very little about contours maps. I began the Exploration Phase of the lesson by giving each student a tactile contour map and its corresponding hilly model, both oriented in the same way, to explore (Fig. 3). Although stereoscopic views of a landscape or shading help sighted students better interpret contour maps (Rapp *et al.*, 2007), these techniques are not available to students who are blind. Instead, students need tactile three-dimensional models to help them make sense of two dimensional maps. I asked students to tell me what they knew to be true about contour maps from their tactile (and for some, visual) investigations. Students were able to tell that the shapes were the same and that nested sets of lines indicated hills. In the Explanation Phase, I defined a contour as a closed line that shows the shape of the land at some level. We noted how the lines were closed, like ropes with the ends tied together. Lines inside of lines on the models with which we worked indicated that the land was getting higher. Lines close together showed steep slopes, while lines spaced farther apart indicated gentle slopes or flat areas. We also discussed how the lines connected points that were at the same elevation or height and that each layer on the models was the same thickness, corresponding to the "contour interval."

After this discussion of basic concepts, students were given three models and one map (or three maps and one model) and asked to pair a map with and its corresponding model. Students with some sight had a distinct advantage in this activity. I found that reducing the choices from three to two prevented students without vision who struggled

FIGURE 2: (Color online) Example toy sea lion with silhouettes and board with Braille label, "sea lion."

FIGURE 3: (Color online) Example contour model of hill and map.

FIGURE 4: (Color online) Student determining the correct model for a contour map of a depression.

FIGURE 5: (Color online) Student examining the tactile foam model of moon craters.

from becoming frustrated. However, even struggling students seemed to be thoroughly engrossed in the activity.

Students were introduced to hachured contour lines of depressions in a similar way. I asked them how someone might show that there was a hole or depression on the land such as a quarry, sinkhole, pond, bomb crater, or mining pit. This puzzled students—no one could think of a suggestion. This reaction is actually beneficial because it is an indication that students were in a state of disequilibrium and were readying their minds for new information and connections. Then, I gave them matched pairs of a model showing one or more depressions and its corresponding tactile contour map. After examining the two items, students were able to state that this line texture indicated a drop in elevation (Fig. 4). Again, as before, students were then given a contour map to match to one of three models.

One of the paraprofessionals led the students in an imaginary tour across the landscape of the depressions, describing how the land sloped and what type of a pit they were delving into as they moved their fingers across the landscape. Students enjoyed this fantasy excursion, which helped these young students with visual impairments mentally visualize the landscape from the model.

During the Expansion Phase, foam models of cratered landscapes based on NASA geologic maps of the moon's surface were passed to each student. As students moved their fingers across the surfaces of the models, they identified depressions that were impact craters (Fig. 5). I explained how a meteorite or asteroid strikes the surface of the Moon, blasting a deep hole and sending material high above the surface, only to have it fall back into the crater moments later. Therefore, many large craters have rings of mountains around them and relatively flat debris-filled floors, often covered with lava flows of rock melted by shockwaves generated by the impact. Some large craters have uplift in the centers. Not all craters are negative features: many are depressions perched on raised features and larger craters often are surrounded by sloping aprons of ejected materials.

After students had explored the models, I gave them each the corresponding contour map. These models were created by printing on special heat-sensitive paper—thermal expansion paper—with black ink on an ink jet printer. The printed paper was then run through a thermal expansion machine so that the black lines "grow" to form a raised feature detectible with fingertips (Jaquiss and May, 2003). This map was a much finer-detailed map than the foam maps we had used previously. I asked students to locate a crater on the model and then on the contour map and to identify the hachured lines. I indicated that this map was much closer to the maps that geologists, hikers, and scientists use. Finally, I gave students much more complex contour maps and corresponding models of parts of the moon's surface. Students tried to find as many craters as possible, and we discussed other features such as small craters on top of larger ones. As a lesson evaluation, students summarized what they had learned.

To reinforce this lesson, students made their own layered hills of clay and a corresponding contour map. I had cut out three different-sized and shaped templates for each student before the lesson. Now, each student was given a fist-sized portion of natural air-dry clay to roll out about 1 cm thick on a plastic mat. Then, using a plastic knife, the students cut around the templates to make the three layers of his/her hill. These were set aside to dry in the sun. Later, they were glued together to form a hill, and the templates were traced to make the corresponding contour map on a tactile film (the Draftsman tactile drawing board) that produced a raised line when scribed with a ball-point pen. Each student named his/her mountain, made a map key, and devised a contour interval (Fig. 6).

The majority of students retained the general ideas of contour maps as representation of the shape of the land with many students telling multiple facts (Table 3).

Lesson 3: Near-Earth Asteroids and the Process of Large Crater Formation

An analysis of pretest information (Table 4) showed that five of the 11 students had no knowledge of craters, while a few had a general idea that craters were round holes or depressions and two knew they were caused by impacts of a meteorite or asteroid. In the previous lesson, students had, however, been introduced to the concept of

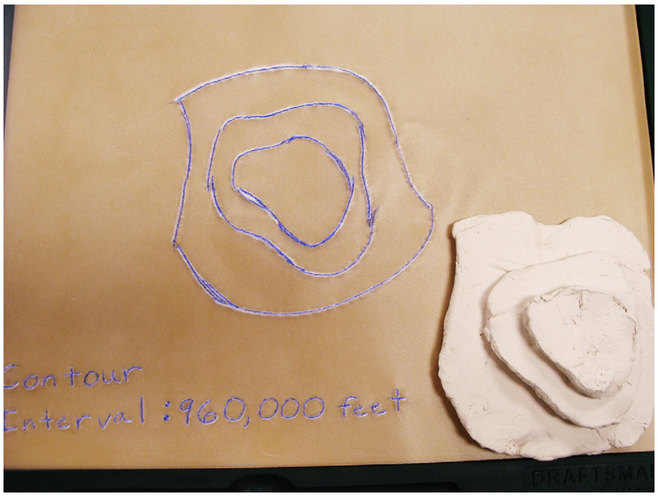

FIGURE 6: (Color online) Example student-made clay hill model and contour map on film.

craters being formed by impacts of space bodies on a surface, so by the time this lesson was taught, all students had a general idea of how craters form.

In the Exploration Phase of the lesson, students elaborated on the process of large crater formation. Each student was given a set of six tactile models, each showing one of six steps in large crater formation, placed in random order. Students were told to touch each of the objects and suggest what each might represent as a part of the crater-forming process. Figure 7 shows the six models in correct time order, based on information in French (1998). The first model shows an asteroid coming close enough to a planet or other body to be drawn into its gravitational field. The second model shows the asteroid falling through the atmosphere at about 20–25 km/s or greater. The third model shows compression of the surface immediately upon impact. During the next step, a shock wave moves out from the point of impact and returns to vaporize the asteroid and cause melting of surrounding rock. The fifth model shows a tremendous fountain of material thrown high as the shock wave moves outward and bounces back.

TABLE 4: Student pre- and post-test responses to, "Tell what you know about craters." Eleven students responded.

General category of idea or concept	Frequency of response	
	Pre-test	Post-test
Depression or hole on surface	3	9
Caused by asteroids or meteorites	2	7
Hole is big	3	6
Circular in shape	2	4
Material thrown high collapses into hole	0	4
Impacts surface	0	4
Form on planets, moon, asteroids	1	4
Shockwave generated after impact	0	3
Extensive ring of material throw high in air	0	3
Dangerous-destroys and kills	0	3
Rock travels through space, then atmosphere	1	2
Melting of material by heat	1	2
Vaporization of rock that impacted	0	1
Shockwaves travel from point of impact and make the crater circular	0	1
Shockwave travels faster than sound	0	1
Hole increases in size after impact	0	1
Gravity pulls the meteor or asteroid in	0	1
Formed in four seconds or less	0	1
Crater may have flat bottom so space ships can land	0	1
Atmosphere might be dark for a long time	0	1
Asteroid/meteorite travels at high speed	0	1
Made of rock	2	0
Size depends on the meteorite	1	0
Small meteorites burn up in atmosphere	1	0
Black and brown colored	1	0
No knowledge	5	1
Incorrect statement given	3	0

FIGURE 7: (Color online) Six models of steps of large impact crater formation.

The last step, just seconds later, involves collapse of material to fill much of the crater.

After students had expressed their ideas and made guesses as to what the models portrayed, the Explanation Phase began. I took each model one at a time in random order and explained what it portrayed. As I spoke, I asked students to touch the model that I was describing. Then, I asked students to try to put the six models in logical time order. After students had taken the opportunity to tell which one was first, second, and so forth, I began with the first one and explained why it occurred at the beginning. I continued through the sequence, asking students to put their models in correct order as I spoke. Then, students were given the cards with explanations of the six steps in pictures, print, and Braille. They matched these to the models and put them in order.

Near the end of this phase of the lesson, students hefted genuine iron–nickel meteorite specimens as they were passed around to gauge their high density. I explained that these were from a site in Argentina and resulted from a meteorite that was smaller than the ones that create the very large craters we had just discussed. Because it was smaller, it had not been vaporized just after impact as bodies about a half kilometer or larger would. However, it is likely that some of those larger bodies would have an iron–nickel composition as these specimens do. As closure, I asked students to review the steps in large crater formation.

The Expansion Phase of the lesson involved an examination of approximately potato-sized models of larger near-Earth asteroids—asteroids that in Earth's distant past have collided with our planet, producing huge craters. In fact, the tremendous number of extinctions at the end of the Cretaceous is thought to be caused by such an asteroid impact. These asteroids with paths that cross Earth's orbit have the potential to impact Earth again and are being closely tracked by astronomers.

I began by giving each student a tactile model of the solar system showing the orbits of Mercury, Venus, Earth, Mars, and Jupiter around the sun as foam circles glued to cardboard with sewn-on buttons representing the planets. Between Mars and Jupiter, I showed the broad band of asteroids as a sand-covered ring. Students located the planets and the asteroid belt. Then, I explained that some asteroids' paths follow an elliptical path around the sun that crosses the orbits of Earth and Mars. These asteroids have the potential of colliding with the Earth.

I collected the solar system models and gave each student a board that showed three tactile silhouettes of an asteroid and an identical set of silhouettes attached by cord so that they might be cupped in the hand. Students also received three different asteroid models to compare to the silhouettes. See Fig. 8 for a photograph of a student working with the materials. I asked students to determine which asteroid model corresponded to their silhouettes. Information about each asteroid (such things as the origin of its name, how it had acquired its shape, how close it had come to Earth and when) was presented in both Braille and print on the reverse side of the board. Students then took turns reading out loud the information about the asteroids they identified. Students were fascinated with the information.

As a culminating activity for this lesson, students each dropped rocks from waist-height into a plastic bowl of wet plaster to create permanent craters (I removed the rocks) that they could tactilely explore the next day. We also used a plastic toy astronaut to impress footprints on the surface just as astronauts have left on the moon. Students later took these lunar-surfaced "doorstops" or "paper-weights" home.

Lesson 4: Topographic Features of Mars

The preceding lessons on topographic contours, the solar system, craters, and asteroids provided a foundation for learning about major topographic features of Mars, including Olympus Mons, the tallest and most voluminous volcano in the solar system (Bleacher *et al.*, 2007; Helgason, 1999) along with other raised volcanic areas such as the Tharsis region (Hyneck *et al.*, 2003), Valles Marineris, a 4000-km long canyon that is 7 km deep in some parts, tremendous impact craters, and polar ice caps that contain water ice (Christensen *et al.*, 2008).

I began with a focus on volcanism and started the Exploration Phase of the lesson by passing around several large volcanic rocks with golf-ball sized vesicles, ropy pahoehoe textured pieces, lightweight pumice, and dense basalt. I told students these were some volcanic rocks from

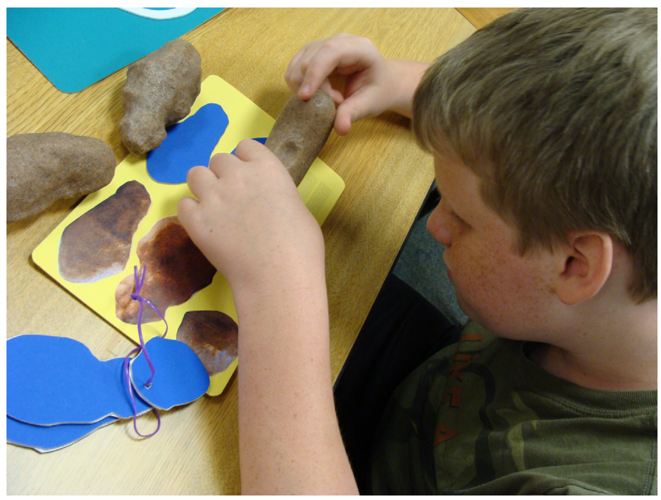

FIGURE 8: (Color online) Photograph of student matching asteroid model to silhouettes.

several different places and asked them to describe the features they noticed and to attempt to explain them. Students were fascinated with the voids and the light-weight pumice but could not explain these features.

Students observed a demonstration during the Explanation Phase that helped them understand the air bubbles. Each student was given a small 6-cm-high plastic model of a volcano filled with baking soda. A few spoonfuls of vinegar were then poured into the volcano's vent and the student placed his/her hand over the vent to feel the frothing fountain, a simulation of the gas-filled lava released during a shield volcano eruption. Then, I explained how some lavas cool, trapping these air bubbles and resulting in the holes in the rocks they were examining. I also discussed other features of volcanic rocks such as "aa" and "pahoehoe" textures. Many students remembered the air vesicles and recognized the presence of gas in the baking soda models (Table 5).

Next, in the Expansion Phase of the lesson, we examined two identical large raised-relief maps of Mars. Students located the polar ice caps, large volcanoes, craters, and a long crack called Valles Marineris. I passed around a foam topographic model of Martian Olympus Mons, the largest volcano in our solar system. Next to it was the diminutive foam model of Mount Saint Helens, a familiar Earth volcano, presented at the same scale. Students were very impressed with the size of Olympus Mons and wanted to know why it was so much larger than Earth volcanoes. To answer that question, we determined the features that were on the other side of the planet from these volcanoes. Students located some large craters. Drawing on students' new knowledge of asteroid impacts, I explained that some scientists hypothesize that several asteroids hit one side of Mars with such force that the core was pushed against causing lavas from far below the crust on the opposite side to rise (e.g., Weber *et al.*, 2008). These lavas resulted in tremendous volcanism. Table 6 summarizes the information students retained from this part of the lesson: the large size of Martian volcanoes, their hypothesized origin, and the gas content of lavas.

Next, we examined a topographic contour model of Valles Marineris (Fig. 9). Students were interested to feel its contours. They hypothesized that the canyon formed by being directly struck by an asteroid. I reminded them that a large impact causes circular shock waves, resulting in a round crater, not a crack. But scientists hypothesize that the crack may be indirectly caused by the same asteroid impacts that generated the tremendous bulge of volcanics. This bulge pulled on and ripped the crust, causing this large canyon. Table 7 shows the information students retained from this lesson.

DISCUSSION AND CONCLUSION

Summary of Findings

The curriculum materials and lessons presented in this article formed a major and integral part of the science teaching at Space Camp. Their efficacy has been established by positive student attitudes toward the camp program and large effect sizes when compared to regular school experiences. Additionally, post-test results showed that most students retained key information about the new concepts taught.

Many teachers do not make accommodations for students with vision impairments because of a lack of knowledge of general methods of teaching students with visual impairments, lack of knowledge of how to make or acquire tactile materials, and lack of knowledge of or access to assistive technology. There is a strong need for science lesson accommodations to be described in the literature to build a knowledge base and bank of resources. This small study provides both quantitative and qualitative data indicating the efficacy of these tactile materials.

TABLE 5: Student pre- and post-test responses to, "Tell what you know about volcanic rocks." Eleven students responded.

General category of idea or concept	Frequency of response	
	Pre-test	Post-test
Many volcanic rocks have air bubbles or vesicles	0	8
Many volcanic rocks are sharp and pointy	0	5
They form from molten lava that cools	7	4
Some are lightweight and some are heavy or dense	0	3
The molten rock was hotter than a kiln	0	1
May have aa or ropy textures	0	1
Rocks may be small or big	1	1
Rocks vary depending upon composition and texture	0	1
Rocks can be black	1	1
Hot lava can kill people	0	1
Can turn into metamorphic rocks through heat and pressure	1	0
Sometimes you can tell the bottom from the top of a volcanic rock from a lava flow because the top is a different color and texture	0	1
Rocks can pile up to form mountains	1	0
Rocks can fall from a volcanic cloud	1	0
No knowledge	1	0

TABLE 6: Student pre- and post-test responses to, "Tell what you know about volcanoes on Mars." Eleven students responded.

General category of idea or concept	Frequency of response	
	Pre-test	Post-test
Huge volcanoes – larger than Earth volcanoes	0	6
Caused in theory by large asteroid impacts on other side of planet that pushed on core and caused hot lava to erupt at surface	0	4
Erupt from a vent bubbling out hot lava and gases	1	4
Rocks are thrown out during eruption and these build the mountain	0	1
These volcanoes do not erupt any more	0	1
Some of the volcanoes have craters on top	0	1
The large bulge of volcanoes and lava on the planet tore the Valles Marineris	0	1
No knowledge	10	1

Insights from Working with Students with Visual Impairments

The lessons in this study proved to be interesting and effective for students. The students with visual impairments, in general, were not much different from other elementary or middle school students. One difference was that they usually waited for instructions before exploring the materials. Part of this was that those who were blind could not see what had been laid out in front of them and they did not want to accidently knock anything over. Sahin and Yorek (2009) also noted that students who have sight impairments tended not to explore their surroundings and often preferred for others to go and get things for them rather than finding the items themselves. Another difference I recognized was that students who were visually impaired were quite candid with facial expressions and comments, exhibiting less concern than sighted students with the opinions of other students. They often genuinely exhibited their joy in discovering and understanding new concepts. However, guiding students who are blind in using complex materials is intensive. I taught four students at a time with the help of a paraprofessional and both of us were kept very busy.

Fraser (2008) noted that her high school students with visual impairments benefitted greatly from working with a Woods Hole scientist who was legally blind herself. Role models for students provide important motivation and reality to students' goals of learning science and considering careers in science, technology, engineering, and mathematics areas. In the summer Space Camp my students attended, two of the paraprofessionals working with students had sensory disabilities themselves: one was blind and the other was partially deaf. Working with these thriving adults helped my students envision a successful future for them and provided the opportunity for students to ask how their disabilities affected their lives and work, easing anxieties.

One of the key components of lessons for students with visual disabilities is practice in spatial awareness skills. Sighted students have a great advantage in that they can look around and immediately sense the spatial arrangement of the objects surrounding them. Students with little or no vision, however, must touch their surroundings or gather information from diagrams or descriptions of others to form mental images to make sense of the world. Therefore, the lessons included in this article that addressed matching objects to silhouettes from different viewpoints or using contour maps to understand the shapes of landscapes help students to practice important spatial skills of mental visualization.

Asher (2001) noted the large amount of preparation necessary to successfully make accommodations for students with visual impairments. I found this to be true: I spent several weeks making materials for Space Camp so that all of my lessons would involve tactile components. This is a reason to share effective ideas through the professional literature so that others will have a head start in making accommodations.

Application of these Materials to Sighted Students

Use of the materials described here should not be limited to students with visual impairments or to summer camp activities; they have been used successfully in a nonresearch classroom setting by sighted students who found them appealing. Presenting lessons through materials accessible by all students supports the concept of universal design. The tactile, concrete nature of the materials helped students focus their attention and become more engaged

FIGURE 9: (Color online) Photograph of students tactilely examining the contour map of Vales Marineris, the Martian canyon.

TABLE 7: Student pre- and post-test responses to, "Tell what you know about Valles Marineris on Mars." Eleven students responded.

General category of idea or concept	Frequency of response	
	Pre-test	Post-test
A huge crack on surface of Mars	0	6
Formation related in theory to asteroid impacts that caused tremendous volcanism on other side of planet, bulging crust and tearing crack	0	5
The canyon is so large it could stretch from the US east to west coasts	0	3
Four miles deep in places	0	2
No knowledge	11	3

with the activities. In another study, Rule *et al*. (2011) found that middle and high school teachers reported accommodations and tactile materials they provided in science and mathematics for students with visual impairments were appreciated by and effective for their sighted peers. Therefore, I recommend that all instructors teaching these topics consider use of the materials described here.

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