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# Using Asteroid Scale Models in Space Science Education for Blind and Visually Impaired Students

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### Abstract

A major obstacle confronting blind and visually impaired students in their science education is the inaccessibility to graphical materials that are critically instructive and abundantly available to sighted students. The use of three-dimensional models can effectively address this problem. Specifically, this article discusses how scale models of near-Earth asteroids can be used to teach space science to blind and visually impaired students. The models, published in the peer-reviewed literature and in almost every case based on radar observations, are developed with a rapid prototyping process. With these models, many of the recent exciting discoveries about near-Earth asteroids suddenly are directly accessible to blind and visually impaired people. Recent research has shown that many sighted students also learn better when their haptic sense is engaged.

## 1. INTRODUCTION

Blind and visually impaired students are often at a disadvantage when they study science and math because of the ubiquity of important graphical information, which generally is not made available in alternate formats accessible to them. This problem is particularly severe in astronomy and space science because the objects of interest usually cannot be examined in the laboratory, and their properties are difficult to relate to familiar objects on Earth. Like their sighted peers, many blind students in elementary and middle school have a natural interest in space, which can motivate them to learn fundamental quantitative skills. For some, this interest can even present a pathway into careers in science, math, and engineering.

The lack of appropriate K–12 resources makes it difficult for teachers and parents to engage students in science and math, and students are often discouraged from pursuing these fields even if they show interest and talent (Scadden 1996). This lack of resources and encouragement from teachers and parents causes many blind students to ultimately lose interest in science. Although effective strategies and tools exist for making text, math formulas, and graphical information accessible to blind and visually impaired students (e.g., Gardner 2002), and recent technological advances have opened the door for blind and visually impaired scientists and mathematicians to work in these fields, their numbers remain small (Jackson 2002; Sakaran 1995).

# 2. MAKING GRAPHICAL INFORMATION ACCESSIBLE

## 2.1 Two-Dimensional Tactile Graphics

One way to make graphical information accessible to the blind is to convert images into raised line drawings (e.g., Grice 2002; Jaquiss 2003). To avoid clutter, such tactile images usually have to be simplified by eliminating less important elements without compromising those parts that are needed to convey crucial scientific content. Different groups have developed guidelines that can help in the design of tactile graphics (TAEVIS 2002; Edman 1992; American Printinghouse for the Blind 1997; Levi & Rolli 1994; Eriksson 1999).

## 2.2 Three-Dimensional Models

An important drawback of tactile graphics is the fact that many blind students have little experience interpreting two-dimensional renderings of three-dimensional objects. Most sighted children develop these skills effortlessly because they are exposed to pictures, maps, and graphs from an early age. Blind children generally do not have access to the tactile counterparts of such information and therefore do not develop the same spatial skills (Gardner 1996; Lewis & Tolla 2003). Although they may have learned how to interpret simple shapes and spatial relations (a sphere is usually represented by a circle; if two objects have similar shapes, the smaller one is often further away, and so on), it is difficult to include more complicated three-dimensional objects without making the images confusing. This problem is further exacerbated by the fact that the haptic perception of humans is intrinsically less detailed than sight (Gardner 1996).

Some of the drawbacks of two-dimensional tactile graphics can be avoided with three-dimensional models, which allow blind students to perceive spatial structures directly. In recent years, rapid prototyping has become essential in helping mechanical engineers quickly produce prototype physical models of new designs directly from digital data. This process has also been used to fabricate three-dimensional scientific plastic models for blind students (Skawinski et al. 1994; Jones 1998). Recently, accurate scale models of asteroids, including the ones that can make extremely close approaches to Earth, have become available (Design Cast Studios 2000; see Table 1).

# 3. NEAR-EARTH ASTEROIDS

## 3.1 Science and Technology Background

Our planet resides in a swarm of asteroids thought to contain about a thousand asteroids as large as a kilometer, about a hundred thousand as large as a football field, and many millions as large as a house. Most of these near-Earth asteroids (NEAs, defined as objects with perihelia as small as 1.3 AU) probably come from the main belt, but a few might be extinct comet nuclei. Some NEAs might be (or share) the parent bodies of meteorites (Wetherill & Chapman 1988). They hold clues to relationships between those small-body populations, to mechanisms for delivery of material into Earth-crossing orbits (Greenberg & Nolan 1989), and to the nature of terrestrial-planet planetesimals (Weissman et al. 1989). Coincidentally, many NEAs also gain relevance as the cheapest targets of human or robotic exploration beyond the Earth-Moon system (Jones et al. 1994), as sources of minerals with potential commercial value (Hartmann & Sokolov 1994; Lewis, Matthews, & Guerrieri 1993), and as long-term collision hazards (Chapman & Morrison 1994).

Radar is the most powerful Earth-based technique for physical characterization of NEAs (Ostro et al. 2002). Delay-Doppler images (Ostro 1993) provide resolution as fine as a decameter, and a sequence of such images can be inverted (Hudson 1993) to yield accurate physical models. Radar-based reconstruction of asteroid shapes has been applied to objects with diverse sizes, shapes, and rotation states (Hudson & Ostro 1994, 1995, 1999; Hudson et al. 2000; Hudson, Ostro, & Scheeres 2003; Benner et al. 1999; Ostro et al. 1999), and improvements in radar instrumentation are extending this work to main-belt asteroids (Ostro et al. 2000).

Radar-derived shape models of asteroids have opened the door to a variety of theoretical investigations central to a geophysical understanding of these objects. They are relevant for future spacecraft rendezvous and landing missions, and for investigations of the potential effectiveness of nuclear explosions in deflecting or destroying hazardous asteroids.

The radar-derived computer models are polyhedra with enough vertices to accommodate the most detailed structure revealed in the images. Rapid prototyping methods (e.g., Kai, Fai, & Chu-Sing 2003), such as selective laser sintering and stereolithography that add and bond materials in layers to form objects, can fabricate a scale model of an asteroid directly from the computer description of its polyhedron. NASA’s Jet Propulsion Laboratory has produced three-dimensional models of seven asteroids (all reported in the peer-reviewed literature), and Design Cast Studios in Henderson, Kentucky, manufactures and sells copies of these models under a JPL licensing agreement (see Table 1).

**Table 1.** Stereolithographic Scale Models of Near-Earth Asteroids

| Asteroid | Asteroid Length (km) | Model Length (cm) | Scale | Reference |
|---|---|---|---|---|
| **1998 KY26** | 0.03 | 7.5 | 1:400 | Ostro et al. 1999 |
| **CASTALIA** | 1.6 | 8 | 1:20,000 | Hudson & Ostro 1994 |
| **TOUTATIS** | 4.6 | 11.5 | 1:40,000 | Hudson & Ostro 1995; Hudson et al. 2003 |
| **GOLEVKA** | 0.69 | 7.5 | 1:9,000 | Hudson et al. 2000 |
| **KLEOPATRA**[1] | 217 | 7.5 | 1:2,900,000 | Ostro et al. 2000 |
| **GEOGRAPHOS** | 5.1 | 11.5 | 1:44,000 | Hudson & Ostro 1999 |
| **EROS**[2] | 33 | 11.5 | 1:290,000 | Veverka et al. 2000 |
| **BACCHUS** | 1.05 | 8 | 1:13,000 | Benner et al. 1999 |

1 Main Belt Asteroid
2 Produced by the San Diego Supercomputer Center for Cornell University from data collected by the NEAR Shoemaker spacecraft.

The general strategy of a radar observation is to transmit modulated waveforms toward the asteroids and process the echoes into images. Thus, in contrast with "passive" astronomical observations that rely on natural electromagnetic emissions or reflections, radar astronomers provide their own personally tailored illumination. Interestingly, this parallels the process by which blind people form mental images of three-dimensional objects: instead of detecting the light emitted by these objects with their eyes, they analyze the tactile feedback from the surface of the object to their hands (see Figure 1). Similarly, radar astronomers analyze the electromagnetic feedback from the surfaces of the asteroids via radar waves sent and felt by their radio telescopes.

## 3.2 Asteroid Activities for Blind Students

NEAs naturally lend themselves to teaching fundamental standards-aligned science concepts in middle school and high school. In an effort to help teachers incorporate three-dimensional models and recent astronomical discoveries, and to actively engage blind students in scientific inquiry, we have developed four prototype activities for blind students. These activities are based on the asteroid scale models, tactile orbit diagrams of asteroids and planets, and a tactile map of the surface of the Moon (Edinboro University of Pennsylvania Planetarium and Tactile Lab 2002). We tested them with students at the Wisconsin Center for the Blind and Visually Impaired (WCBVI) and at a workshop during the 2003 convention of the National Federation of the Blind. In both cases, students worked in small groups under the guidance of an experienced teacher from the WCBVI.

**Figure 1.** A 12th-grade student from the Wisconsin Center for the Blind and Visually Impaired examines a model of near-Earth asteroid Toutatis.

In the first activity, students tactually explore the asteroid models and match them to descriptions of the asteroids in Braille and large print. Students learn that, along with the planets, smaller objects with varying shapes, sizes, orbits, rotation periods, and compositions orbit the Sun.

In the second activity, the students estimate how long it would take them to walk all the way around the asteroids. The activity is designed to give the students an intuitive sense of the asteroids' sizes. Advanced students with good problem-solving and mechanical skills can find the answer independently, using a Braille meter tape (see Note 1), string, and information about the scale of each model. Alternatively, instructors can provide the time estimates in the form of Braille and large print cards, which the students then match to the models.

In the third activity, students discover that asteroids exert gravitational forces on objects on or near their surfaces and that the magnitude of these forces depends on the sizes and masses of the asteroids. To start the activity, one might ask the students to guess what familiar objects would have the same weight on the asteroids as one of the asteroid models has on Earth. Students can then collaboratively develop a solution to this question using the asteroid models. This may, for example, involve an experimental determination of the volume of the models using water and a Braille measuring cup (see Note 1), which, together with an estimate of the density of the asteroids and information about the scale of the models, allows them to calculate the average gravitational acceleration at the surface. If this is too difficult or time consuming, instructors can do these calculations for the students, who then discover the relationship between mass and gravitational force by matching the objects to the asteroids.

In the fourth activity, students analyze tactile diagrams depicting the orbits of the asteroids and the planets. They discover that some asteroids have elongated orbits, which periodically take them very close to Earth's orbit. They discuss the consequences that asteroid impacts might have on Earth, and how they have affected Earth throughout its history. Finally, they study a tactile map of the Moon, discover the ubiquity of impact craters, and discuss why there are fewer impact craters on Earth.

Although the activities described above were primarily designed for blind students, sighted students can benefit from multisensory approaches to learning as well. To explore objects in their environment, young children have a natural instinct to touch. Even though visual and auditory learning become dominant as the child matures, haptic learning experiences can still benefit students of any age (Treviranus 1999).

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## Notes

**Note 1:** Braille meter tapes, measuring cups, and other measuring equipment are available, for example, from the Lawrence Hall of Science (http://www.lhs.berkeley.edu/cml/saviselph/)

**Note 2:** Asteroid orbit diagrams constructed using the JPL Horizons On-Line Solar System Data and Ephemeris Computation Service (http://ssd.jpl.nasa.gov/horizons.html) are available on the Web at http://analyzer.depaul.edu/SEE_Project/. Tactile versions can be created from these diagrams with thermal expansion machines (Jaquiss 2003).

## References

American Printinghouse for the Blind. 1997, Guidelines for Design of Tactile Graphics, http://www.aph.org/edresearch/guides.htm.

Benner, L. A. M., et al. 1999, Radar Observations of Asteroid 2063 Bacchus, *Icarus*, 139, 309.

Chapman, C. R., & Morrison, D. 1994, Impacts on the Earth by Asteroids and Comets, *Nature* , 367, 33.

Design Cast Studios 2000, http://dcstudios.com/.

Edinboro University of Pennsylvania Planetarium and Tactile Lab 2002, http://www.edinboro.edu/cwis/planetarium/web/home.htm.

Edman, P. K. 1992, *Tactile Graphics*, New York: American Foundation for the Blind.

Eriksson, Y. 1999, How to Make Tactile Pictures Understandable to the Blind Reader, in *Proceedings of the 65th International Federation of Library Associations Annual Conference*, http://www.ifla.org/IV/ifla65/65ye-e.htm.

Gardner, J. 2002, Science Educational Information and Students with Print Disabilities, http://dots.physics.orst.edu/~gardner/ScienceEd.html.

Gardner, J. 1996, Tactile Graphics: An Overview and Resource Guide, *Journal of Information Technology and Disabilities*, 3(4), http://www.rit.edu/~easi/itd/itdv03n4/article2.html.

Greenberg, R., & Nolan, M. C. 1989, Delivery of Asteroids and Meteorites to the Inner Solar System, in *Asteroids II*, R. P. Binzel, T. Gehrels, & M. S. Matthews (Editors), Tucson: University of Arizona Press, 778.

Grice, N. 2002, *Touch the Universe—A NASA Braille Book of Astronomy*, Washington: National Academy Press.

Hartmann, W. K., & Sokolov, A. 1994, Evaluating Space Resources in the Context of Earth Impact Hazards: Asteroid Threat or Asteroid Opportunity?, in *Hazards Due to Comets and Asteroids*, T. Gehrels (Editor), Tucson: University of Arizona Press, 1213.

Hudson, R. S. 1993, Three-Dimensional Reconstruction of Asteroids from Radar Observations, *Remote Sensing Reviews*, 8, 195.

Hudson, R. S., & Ostro, S. J. 1999, Physical Model of Asteroid 1620 Geographos from Radar and Optical Data, *Icarus*, 140, 369.

Hudson, R. S., & Ostro, S. J. 1994, Shape of Asteroid 4769 Castalia (1989 PB) from Inversion of Radar Images, *Science*, 263, 940.

Hudson, R. S., & Ostro, S. J. 1995, Shape and Non-Principal-Axis Spin State of Asteroid 4179 Toutatis from Radar Images, *Science*, 270, 84.

Hudson, R. S., et al. 2000, Radar Observations and Physical Modeling of Asteroid 6489 Golevka, *Icarus*, 148, 37.

Hudson, R. S., Ostro, S. J., & Scheeres, D. J. 2003, High-Resolution Model of Asteroid 4179 Toutatis, *Icarus*, 161, 346.

Jackson, A. 2002, The World of Blind Mathematicians, *Notices of the American Mathematical Society*, 49(10), http://www.ams.org/notices/200210/comm-morin.pdf.

Jaquiss, R. S. 2003, Tactile Images and You: A Comparison of Thermal Expansion Machines, *Braille Monitor*, 46(5), http://www.nfb.org/bm/bm03/bm0305/bm030507.htm.

Jones, R. R. 1998, Scientific Visualization Through Tactile Feedback for Visually Impaired Students, in *Proceedings of the 13th Technology and Persons with Disabilities Conference*, http://www.csun.edu/cod/conf/1998/proceedings/csun98_170.htm.

Jones, T. D., Eppler, D. B., Davis, D. R., Friedlander, A. L., McAdams, J., & Krikalev, S. 1994, Human Exploration of Near-Earth Asteroids, in *Hazards Due to Comets and Asteroids*, T. Gehrels (Editor), Tucson: University of Arizona Press, 683.

Kai, C. C., Fai, L. K., & Chu-Sing, L. 2003, *Rapid Prototyping: Principles and Applications (2nd edition)*, Singapore: World Scientific Publishing.

Levi, F., & Rolli, R. 1994, Manual of Tactile Graphics, Torino, Italy: Zamorani, http://www.arpnet.it/tactile/Uk/manual.htm.

Lewis, J. S., Matthews, M. S., & Guerrieri, M. L. (Editors). 1993, *Resources of Near- Earth Space*, Tucson: University of Arizona Press.

Lewis, S. & Tolla, J. 2003, Creating and Using Tactile Experience Books for Young Children with Visual Impairments, *Teaching Exceptional Children*, 35(3), 22, http://journals.cec.sped.org/EC/Archive_Articles/VOL.35NO.3JANFEB2003_TEC_Article%203.pdf.

Ostro S. J. 1993, Planetary Radar Astronomy, *Rev. Mod. Physics*, 65, 1235.

Ostro, S. J., et al. 1999, Radar and Optical Observations of Asteroid 1998 KY26, *Science*, 285, 557.

Ostro, S. J., et al. 2000, Radar Observations of Asteroid 216 Kleopatra, *Science* , 288, 836.

Ostro, S. J., Hudson, R. S., Benner, L. A. M., Giorgini, J. D., Magri, C., Margot, J. L., & Nolan, M. C. 2002, Asteroid Radar Astronomy, in *Asteroids III*, W. Bottke, A. Cellino, P. Paolicchi, & R. P. Binzel (Editors), Tucson: University of Arizona Press, 151.

Sakaran, N. 1995, Scientists with Disabilities Must Confront Societal As Well As Physical Challenges, *The Scientist*, 9(2):1, http://www.the-scientist.com/yr1995/jan/sankaran_p1_950123.html.

Scadden, L. A. 1996, Making Mathematics and Science Accessible to Blind Students through Technology, in *Proceedings of the RESNA '96 Annual Conference*, E. Langton (Editor), Arlington, VA: RESNA Press, http://www.dinf.ne.jp/doc/english/Us_Eu/conf/resna96/page51.htm.

Schleppenbach, D. 1996, Teaching Science to the Visually Impaired: Purdue University Visions Lab, *Journal Information Technology and Disabilities*, http://www.rit.edu/~easi/itd/itdv03n4/article1.html.

Skawinski, W. J., Busanic, T. J., Ofsievich, A. D., Luzhkov, V. B., Venanzi, C. A., & Venanzi, T. J. 1994, The Use of Laser Stereolithography to Produce Three-Dimensional Tactile Molecular Models for Blind and Visually Impaired Scientists and Students, *Journal of Information Technology and Disabilities*, 1(4), http://www.rit.edu/~easi/itd/itdv01n4/article6.html.

Tactile Access to Education for Visually Impaired students (TAEVIS). 2002, *Tactile Diagram Manual*, http://www.taevisonline.purdue.edu/.

Treviranus, J. 1999, Adding Feeling, Sound and Equal Access to Distance Education, in *Proceedings of the 14th Technology and Persons with Disabilities Conference*, http://www.dinf.ne.jp/doc/english/Us_Eu/conf/csun_99/session0112.html.

Veverka J., et al. 2000, NEAR at Eros: Imaging and Spectral Results, *Science*, 289, 2088.

Weissman, P. R., A'Hearn, M. F., McFadden, L. A., & Rickman, H. 1989, Evolution of Comets into Asteroids, in *Asteroids II*, R. P. Binzel, T. Gehrels, & M. S. Matthews (Editors), Tucson: University of Arizona Press, 880.

Wetherill, G. W., & Chapman, C. R. 1988, Asteroids and Meteorites, in *Meteorites and the Early Solar System*, J. F. Kerridge & M. S. Matthews (Editors), Tucson: University of Arizona Press, 35.

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