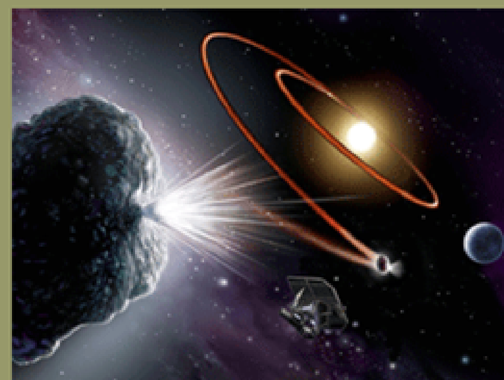
**Designing Craters:
Creating a Deep Impact**

Thinking about Cratering

TEACHER GUIDE

BACKGROUND INFORMATION



This lesson introduces both the Deep Impact mission and the concept of cratering to your students. For more information about the mission, visit the Web site at http://deepimpact.jpl.nasa.gov You can find a brief summary of our modern understanding of cratering in Appendix B.

In this section, students will have the opportunity to freely explore different factors about cratering. Additionally, they will begin to form ideas about what sorts of tests can be conducted and what the results of these cratering tests might be. These exploration activities will help prepare students for the next section of this module in which they will design and conduct a formal experiment that focuses on just one of the contributing factors to comet size.

From these initial explorations, your students will see that dropping objects or impactors from greater heights produces deeper and larger craters; compacting the surface makes for smaller craters; and the heavier an object is, the deeper the crater will be. Some students in the pilot test also noticed that impactor mass was more important that impactor diameter when it comes to determining crater depth, but that crater diameter was driven by impactor diameter for the most part. This is an important observation that will become significant when we look at the differences between the low speed impacts we create in the classroom and the high speed impacts that take place on a Solar System scale in a later module section, "Cratering in the Classroom, the Lab and the Solar System."

NATIONAL SCIENCE EDUCATION STANDARDS ADDRESSED

(View a full text of the National Science Education Standards.)

Grades 5-8

Science as Inquiry

Abilities necessary to do scientific inquiry

- Identify questions that can be answered through scientific investigations.

Understandings about scientific inquiry

- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- Scientific investigations sometimes result in new ideas and phenomena for study.

Earth and Space Science

Earth's History

- ...Earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet.

Grades 9-12

Science as Inquiry

Abilities necessary to do scientific inquiry

- Identify questions and concepts that guide scientific investigations.

Understandings about scientific inquiry

- Scientists usually inquire about how physical, living, or designed systems function.
- Scientists rely on technology to enhance the gathering and manipulation of data.
- Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists.

MATERIALS

For each student:

- Letter from the Deep Impact Science Team
- Cratering in the Solar System: Images - found in Appendix A
- Student Handouts: Exploring Cratering and Comet Research
- Student Journal: Assignments #1 and #2 - found in Appendix D
- Basic Cratering Experiment Supplies:
  - Trays (tin foil baking pans or other such containers -- the deeper the better)
  - Flour, sugar or sand
  - Meter sticks
  - Balances
  - Collection of objects to use as projectiles - ball bearings, styrofoam balls, Superballs, clay, etc.

Alternate Strategy Tip

Another way to engage students in the study of cratering is to provide the "big picture" explanation with compelling reasons for studying craters.

Have students read the text, "The Importance of Cratering in the Solar System." Then have a discussion about the kind of information that craters give scientists.

PROCEDURE

Day 1 (Hook)

1. Engage students in the excitement of the Deep Impact mission by showing the Pumice Impact test at:
   http://deepimpact.jpl.nasa.gov/gallery/mpeg4.html
   (You may want to download this animation to a computer and show to your class using a projector or television using the full screen mode.)

   Ask students what comes to mind when they think about an impact. Students may talk about asteroids or comets hitting the Earth or relate a movie that they have seen about the topic.

2. Continue by showing Encounter Animation 1 located at:
   http://deepimpact.jpl.nasa.gov/gallery/mov1.html
   (You may want to download this animation to a computer and show to your class using a projector or television using the full screen mode.)

   Explain to students that this animation shows an artist's conception of what the encounter will look like between the Deep Impact Spacecraft and Comet Tempel 1. Tell students that they will view the animation several times. The first time they should just watch it without writing anything.

   After the first viewing, ask students questions similar to the following:

   a) What do you think the goal is of the Deep Impact mission? What do the scientists want to study? (Students should suggest that scientists want to learn more about the inside of a comet.)
   b) How are the scientists going to learn more about the comet? (Students might suggest that in order to study the inside of a comet, they are going to send a spacecraft and make a crater on its surface.)

Teacher Tip

Use this assignment as a way to assess your students' prior knowledge about comets and the Deep Impact mission. Students may want to refer to the Mission Fact Sheet to have additional information as they develop their scripts.

c) What questions would you have if you were on the science team? (Students might be interested to know about what makes up the interior of a comet. Others might be interested to learn how information about the inside of comets will help us better understand our Solar System. Others may be interested in the likelihood of a comet impact on Earth.)

3. In subsequent viewings, ask students to write down a script that could be used to accompany the animation. Tell students to be creative in how they write the script, but it should be written such that it follows the sequence of the animation provided. As an extension, students could be encouraged to provide a soundtrack that incorporates their script along with music and/or sound effects.

Day 2

4. Hand out the Deep Impact invitation letter to the students and read through it together as a class.

5. Present any additional information from the Deep Impact Mission Fact Sheet you judge to be interesting and relevant. Use the Deep Impact links below to present current mission timeline and information to aid this presentation.

6. Explain that, as stated in the letter, the students will be focusing on the problem of creating a crater on a comet.

7. Talk about cratering as a regular phenomenon in the Solar System. Show evidence of cratering on various planets, moons, and the Earth itself (see Cratering in the Solar System: Images in Appendix A). Discuss the idea that there are different types of craters (created by volcanoes, etc.) but that the focus of this unit will be on those caused by impacts.

8. Explain to the students that in order to make predictions about crater size, the class first needs to determine what factors influence cratering and how. Engage the class in a brainstorming session. Your role as facilitator is to record all student ideas without rewording, revising or evaluating them and to encourage students to contribute any ideas they might have. Set up ground rules for brainstorming. You may want to record the student ideas on an overhead so that each class' ideas can be saved and displayed again the next day. *See the "Student Anticipations" section of the next activity for expected student responses and factors to add to the list if not generated by the class.*

Suggested ground rules for brainstorming:

- All ideas will be written.
- Ideas are not evaluated during brainstorming session. (Setting this rule means that students are more likely to give ideas than if they are evaluated and discussed either by the teacher or the other students during the listing process).
- Anything that you (the students) think could be a factor should be mentioned.

9. When the brainstorming session winds down, assign the Student Handout "Comet Research," which is the long term homework assignment for the unit. This assignment has the students collect information about comets such as composition, size, shape, etc. Set the due date for approximately when you think you will reach the final section of the module – "Cratering on the Comet."

10. Talk about the Student Journal Assignments (see teacher directions with Teacher's List of Journal Prompts in Appendix D: Deep Impact Project Journal). Assign Journal Assignment #1 as homework.

Day 3

11. Review the list of possible factors influencing cratering generated in class during Day 2. Inform students that the next step will be to explore these ideas and factors. Hand out the Student Activity "Exploring Cratering" and give any group structure, clean up, and work area instructions you feel would be helpful.
12. Students work on "Exploring Cratering."

13. Stop the class for clean up with enough time to allow you a 10-minute discussion at the end of class.

14. Review the list of factors that might influence crater size with the class. Now that the students have done some initial exploring, ask them to consider the following questions: Which factors seem like they would be the most important? Are there ways to categorize these ideas? Which ones are feasible for testing in the classroom? Do some factors need to be broken into more specific parts ("How big" to mass, density, diameter, etc.)? *See the "Student Anticipations" section for more information about what answers to expect from your students and suggestions on how to select factors for investigation.*

Student Anticipations

Brainstorming Factors Influencing Crater Size

Interestingly enough, in initial interviews with students, all of the factors listed by students actually do contribute to determination of final crater size and shape to varying degrees. Most of the ideas from your students will fall into three basic categories: (1) how "big" the impactor is, (2) how "hard" it hits the surface, and (3) what the surface is like. Here are example comments that illustrate each category.

"Little impactors would make little holes"

"If it hits with a big impact, big smash, it will make a bigger crater"

"….the dust is so soft, it would make a smaller hole because the dust is going to cushion the fall"

15. Now, during the follow-up discussion at the end of this class, your role as facilitator shifts from encouraging any and all ideas to encouraging the students to break down factors such as “the size of the impactor” or how “big” into more precise and measurable quantities such as mass, diameter, or density, etc. **It is very important to keep in mind that what your students mean by a term can sometimes be very different than what you mean by a term.** When drawing out student ideas, take care to have them thoroughly explain what *they* mean by hard, or big, or the other terms listed. If you simply jump to the terms used on the chart, you and your students may be using the same words to mean different things. Remember that you are interested in helping your students test their own ideas about cratering.

Possibilities to Consider:

For example, one group during the pilot testing used the term "impact." Their idea was that the larger the "impact" the larger the crater. When the students were asked how they intended to create larger and smaller "impacts," they replied "We'll just drop one (ball), and then we'll throw the others at different speeds." This group was actually interested in looking at the impact speed. Meanwhile, another group using the term "force" wanted to change both the velocity of impact and the mass of the object. See the chart on the next page for possible student ideas, suggestions for refinements, and some experimental design ideas for the next activity.

16. Assign Journal Assignment # 2 in Appendix D.

Possible Student Responses	Possible Scientific or More Specific Terms	Possible Experiments
Size of impactor (How "big" is it)	mass diameter density	Objects of different masses but same diameter and shape are dropped. Objects of same mass but different diameter are dropped — could be done with a mass of clay that is reshaped to give different impacting diameters. Same-sized object, different mass.
How "hard" it hits Impact momentum+ Force+ of impact	mass velocity acceleration	See above. Dropping the ball from different heights gives you an impact velocity that can be calculated from the formula v^2=2gd, with d=height in meters above ground from which ball dropped and g=9.8 m/s^2 for acceleration due to gravity. Avoid this one - difficult to vary acceleration in easily measurable way and doesn't give you much useful information. Velocity is the key in this section.
How hard or soft the surface is	density connectivity of surface materials (tightly bound like metal or loosely packed like sand) compressibility	Adding more flour and compacting to the same level in the pan or using different materials. Using a variety of different surface materials in the pan (dirt, mud, cake, jello,) or try a variety of surfaces outside - mud, sand, concrete, etc. Use different surface materials (see above).
Does the surface "bounce back"	elasticity	Use different surface materials (see above).
State of matter of surface	is the target a solid, liquid, or gas	Use different surface materials (see above).
How "hard" or "soft" the impactor is	compressibility elasticity	Use objects that maintain rigid shape and objects that can easily deform. Soft impactors will deform and produce a different crater than a rigid impactor.
Shape of impacting body		Use impacting bodies of different shapes. Using a particular mass of clay and reshaping it may be the best way to test for shape.
Angle of impact		Roll impactor down a ramp at different angles.
Temperature of target or impactor		Non-flammable materials for surface or impactor either on hot plate or microwaved.
Presence or absence of atmosphere on target body		Dropping objects into the sand at the base of a water-filled fish tank.

+ It is easier, for experiment design purposes, to break the terms "force" and "momentum" into their components: mass, velocity, and acceleration.

TEACHER RESOURCES

Publications
Beatty, J. K. & Chaikin, A. (Eds.). (1990) third edition. (1999) fourth edition. The New Solar System. Cambridge, MA: Cambridge University Press. [One of the most current coverage of solar theory and technological data; each chapter is written by an authority on the topic, so there are differences in the reading/technical levels between the chapters.]

Booth, N. (1995). Exploring the Solar System. Cambridge: Cambridge University Press.

Encrenaz, T., Bibring, J. P., & Blanc, M. (1990). The Solar System. New York: Springer-Verlag.

Melosh, H. J. (1989). Impact Cratering: A Geologic Process. New York: Oxford University Press.

Shirley, J. H. & Fairbridge, R. W. (Eds.). (1997). Encyclopedia of Planetary Sciences. London: Chapman Hall.

Smoluchowski, R. (1983). The Solar System. New York: Scientific American Library, An imprint of Scientific American Books, Inc. Taylor, S. R. (1992) Solar System Evolution: A New Perspective. Cambridge, MA: Cambridge University Press.

Web sites
http://deepimpact.jpl.nasa.gov/gallery/mov1.html
Deep Impact encounter animation.

http://deepimpact.jpl.nasa.gov/gallery/mpeg4.html
Pumice Impact Test animation

http://deepimpact.jpl.nasa.gov/mission/factsheet.html
Deep Impact mission fact sheet.

http://deepimpact.jpl.nasa.gov/mission/index.html
Deep Impact Web site mission section.

http://deepimpact.jpl.nasa.gov/mission/timeline.html
Deep Impact mission timeline.

http://nssdc.gsfc.nasa.gov/planetary/mission/near/near_eros_approach.html
NEAR Encounter with Asteroid 433 Eros.

http://pds.jpl.nasa.gov/planets/welcome.htm
A collection of some of the best images from NASA's planetary exploration program. Includes informative captions; examples of impact cratering, volcanism, and tectonism; as well as information for ordering the complete collection in the *Welcome to the Planets* CD-ROM.

http://spacelink.nasa.gov/products/Exploring.Meteorite.Mysteries/
Exploring Meteorite Mysteries: This educator guide provides information and activities related to meteorites and their origins, for Mars, asteroids, and the Moon.

http://www.cas.usf.edu/~jryan/craters.html
Craters and Cratering, What Can they Tell Us? An Internet Search Activity from the University of South Florida.

http://www.lpl.arizona.edu/SIC/impact_cratering/intro/
Terrestrial Impact Cratering and their Environmental Effects.

http://www.lpi.usra.edu/lpi/resources.shtml
Resources from the Lunar and Planetary Institute.