When the Sky is Falling...
Written by: Stephen Edberg, Cassini Outreach Lead

Objective
Impact cratering has shaped planetary surfaces and life on Earth. Students will explore the cratering process and understand the relationship between the projectile, the energy it delivers, and the landform it creates.

Keywords: crater, collision, kinetic energy, mass, volume, meteorite, meteoroid, asteroid, impact

Materials
- Baking pan or shallow cardboard box bottom, at least 7 cm deep (the depth is necessary to avoid bouncing the projectiles off the bottom) to make a portable sandbox.
- Projectiles: BBs and marbles and bearing balls (of various sizes).
- Sand (to fill the pan, available from construction/hardware stores; use plastic or tape to seal the bottom of a box to prevent sand leakage).
- Flour, cocoa, or colored sand (if desired, to provide a thin layer on top of the sand that will better show the effects of the impact; colored sand is available from craft stores).
- Ruler or tape measure
- 3 m of string (may need to be longer depending on your lab situation)
- Heavy washer (tied to end of string to make a plumb bob)
- Cardboard sand surface-smoother
- Magnet (will help retrieve bearing balls that get buried)
- Cooked oatmeal (1 serving, if desired, for experiment extension)

Discussion
Craters are found on every solid body in the solar system except on Jupiter's moon, Io, which continually resurfaces itself with lava flows that cover any craters formed there, and perhaps Saturn's moon, Titan, whose surface we haven't yet seen in detail. Tiny ones are found on moon rocks, they have been seen on asteroids, and they are found on the largest solid planet in the solar system, Earth.

The process of crater formation on planets involves the transformation of the energy of motion of a projectile, a meteoroid or small asteroid, into heat. This heat, in turn, causes an explosion that creates the crater. Crater diameters will typically range from 10 to 20 times greater than the size of the projectile. Large projectiles, on the order of 1 to 15 km in size, can be very destructive. The devastation resulting from the impact, earthquakes, tsunamis, and atmospheric effects can cover state-size territories or even larger and can lead to mass extinctions, such as those of the dinosaurs 65 million years ago.

In the school laboratory, cosmic velocities exceeding 11 km/s cannot be reproduced. Still, cratering by excavation rather than explosion will demonstrate the principles involved.

Procedure
At its simplest, projectiles are dropped from a fixed height into the sandbox one at a time. The diameter of the excavated crater is measured and the data are recorded for further analysis. With a little more effort, additional data can be acquired that will significantly add to the scientific investigation.

Gravity provides a constant, repeatable impact velocity for the different-sized projectiles. For all the projectiles recommended for experimentation here, air resistance is negligible. The projectiles can be dropped from desk height, some shelf or ladder, and if available, from the upper stories of a building. Use the plumb bob to center the sandbox directly under the projectile release point. Smooth the sand before each drop. After impact, gently remove the projectile so as not to damage the crater. Measure the diameter of the crater. (These measurements are more challenging than might first be thought. Deciding where the crater rim peaks is not always easy and individuals will make different choices. Expect experimental variability in these measurements.) Repeat the smooth-drop-measure-record process for each projectile at each of several different heights.

Before the drop tests are made, students should prepare a table of characteristics for the projectiles. Each should be weighed and its diameter measured. The volume and density of each should be computed. The kinetic energy at impact can be calculated from $KE = 1/2(mv^2)$, where m is the measured ("weighed") mass and v is the velocity just before impact. The velocity can be computed from $v = (2gL)^{1/2}$ where g is the gravitational acceleration 9.8 m/s^2 and L is the drop distance.

Once these parameters and crater sizes are known, have students compare various parameters with crater diameter. Diameter and volume will show little relationship to crater size, while mass and kinetic energy will show a strong relationship.

<u>Extensions</u>

An impact has more effects than the excavation of a crater. The initial contact with the surface generates a far-ranging spray of material that can cover an area much larger than the sandbox (one reason to do this activity outdoors; at least warn the custodian if this activity is performed in your room).

As the projectile impacts, the excavation process not only sprays surface material out, but subsurface material may be thrown short distances or overturned to help create the crater rim. These effects can be studied in more detail by using two or more layers of colored sand/flour/cocoa (so that the layers are distinctive). New layers will have to be added after each smoothing if additional drop tests are conducted.

This analogy to impact cratering in the solar system suffers from a serious deficiency: the projectiles remain whole after impact, something that is uncommon except for small meteoroids striking Earth. Most large cosmic projectiles will explode on impact with the surface. In order to observe this effect in these classroom scale experiments, drop individual spoonfuls of cooked oatmeal from various heights. The oatmeal has enough tensile strength to hold together as it falls (large water droplets will break up and gelatin holds together on impact) but will "shatter" on impact with the sandbox, sending oatmeal and sand over a fairly wide area. Use food coloring in the oatmeal to help distinguish it from sand after impact. Note that experiments with oatmeal are messy enough that they should be conducted outdoors.

Craters on real worlds often have central peaks caused by the rebound of subsurface material at the end of the collision process. Do classroom craters develop central peaks? Why or why not?

Numerous challenges to the students can be made for measuring the drop distance. While a tape measure is the obvious solution and measuring the length of the plumb line is easy, other physics can be used. For example, a precision barometer can be used as an altimeter.

The height can be measured by timing the duration of the fall: $s = 1/2(gt^2)$. A stopwatch is a necessity, and experimental error due to reaction time will be notable and variable among students.

A stopwatch can also be used to measure the period of a pendulum extending from the drop point to the top of the sand (move the sandbox out of the way so the pendulum can swing freely). The length L = drop height can be determined by timing the period of the pendulum, $T = 2\pi(L/g)^{1/2}$. Experimental error will creep in with the timing; compare the period measured for a single swing back & forth with the period determined by measuring the duration of 5 and 10 swings and computing the average period.
Compare the potential energy of the projectiles, PE = mgL with their kinetic energy.

Standards
A visit to the URL http://www.mcrel.org yielded the following standards and included benchmarks that may be applicable to this activity.

Level III Middle School (6-8) Science Standard 3. *Understands essential ideas about the composition and structure of the universe and the Earth's place in it.*
Knows characteristics and movement patterns of asteroids, comets, and meteors.

Level I Lower Elementary (K-2) Science Standard 12. Understands motion and the principles that explain it.
Knows that the position of an object can be described by locating it relative to another object or the background.

Level II Upper Elementary (3-5) Science Standard 12. Understands motion and the principles that explain it.
Knows that an object's motion can be described by tracing and measuring its position over time.

Level I Lower Elementary (K-2) Science Standard 15. *Understands the nature of scientific inquiry*.
Knows that learning can come from careful observations and simple experiments.

NOTE: This activity is currently posted to the Cassini web site as a field-test version. Educators who use this activity for classroom demonstration purposes are encouraged to submit comments to the Cassini Education Outreach Coordinator. We are dedicated to providing high-quality activities for classroom use and welcome your suggestions.

Cratering Activity Student Sheet

Provide a description of the type of sand surface into which the projectiles will be dropped.

Prior to drop tests
Drop Distance (L) that will be used: _______________

For each projectile that will be used, measure mass, and diameter and calculate volume, density, velocity, and kinetic energy. Record the data in the table.

Projectile Type	**Mass (g)**	**Diameter (cm)**	**Volume (cm^3)**	**Density (g/cm^3)**	**Velocity (cm/sec)**	**Kinetic Energy ($g\text{-}cm^2/sec^2$)**

Required Equations

Density = mass/volume

Kinetic Energy (KE) = $1/2(m*v^2)$
Velocity, $v = (2*g*L)^{1/2}$
Where g = acceleration due to gravity = 9.8 m/s^2

Volume = $4/3(pi*r^3)$
Where pi = 3.14159
R = radius = 1/2(diameter)

Experimental results from drop tests
For each projectile dropped, measure and record the diameter of the crater that was made.

Projectile Type	**Diameter of Crater**

Plot 4 graphs:
- Graph #1 is crater diameter versus projectile mass
- Graph #2 is crater diameter versus projectile volume
- Graph #3 is crater diameter versus projectile diameter
- Graph #4 is crater diameter versus kinetic energy

Using the graphs, determine which characteristics show a strong relationship to crater size?