



ACTIVITIES

Feel the Impact

Cratering Research Teacher Guide

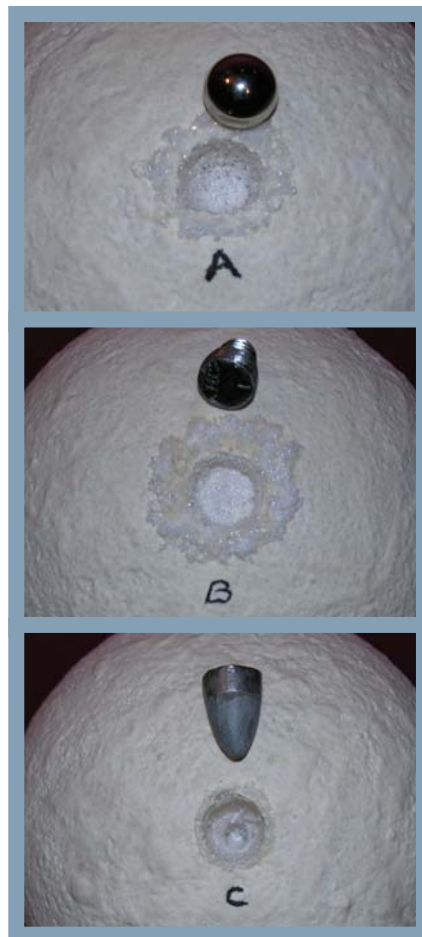
Science Background Information

The National Science Standards place a high value on inquiry in the science classroom. The first content standard for all levels, K-12, is "All students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry." The first science teaching standard begins with "teachers of science plan an inquiry-based science program for their students". Inquiry is often discussed in teacher preparation programs as one of the preferred methods of instruction. Yet, inquiry does not exist in equal prevalence in the classroom. Most science teachers can list reasons for the discrepancy immediately:

- Inquiry takes more classroom time.
- Inquiry is difficult to assess.
- Inquiry creates a heavy planning burden.

It is difficult to operate in an inquiry mode and have a classroom that "looks like" what teachers and administrators often expect a classroom to "look like". This unit has been designed as an example of what inquiry in the classroom might look like.

The ACE and Deep Impact teams believe that the most important item that a NASA mission has to offer the classroom is a look into the process of scientific inquiry in action. As cratering is a favorite topic for space science teaching, this module is designed to give students and teachers a structure for investigating one of the questions that faced Deep Impact's mission design team, "How do you make a crater on a comet?" Using some aspects of the familiar "drop the ball into the flour" cratering activities, this endeavor explores the nature of



ongoing science investigations and strives to develop students' inquiry skills. This unit also takes these explorations a step further by doing some mathematical exercises with the results, and discussing the limitations of low energy classroom impacts as models of high-energy Solar System impacts.

Cratering

Cratering is a phenomenon that students have lots of ideas about. Most have experience with throwing things against each other and the results of those collisions. This module allows students to explore their own ideas about how cratering might work. As they perform the initial experiment they will be looking for patterns in the data and try to reconcile their understanding of what happened with their preconceived ideas about cratering. It is important to note that the designers of this activity believe that the primary goal of this component of the “Feel the Impact Unit” is to teach students methods of science inquiry, rather than develop a full modern understanding of cratering. The students explore and refine their own ideas, rather than “discover” the “correct” answers

The activities in this section are designed to model one path that a scientific inquiry might take. The students will begin by brainstorming what factors might influence crater size and do some initial experimentation and exploration. Next, have the students design their own experiments, testing one of the possible factors. They will then evaluate their suggestions and describe how their initial ideas about cratering matched with what they had come up with in the brainstorming session.

After analyzing the data for patterns that might be used to predict crater size from the initial variables, the students will test those predictions by performing systematic experimentation using a specific set of impactors. Emphasis will be placed on experiment design, limiting the test to one variable, and quantifying the experiment. As students perform the experiments have them think about the advantages and limits of scientific modeling as they compare their own low energy simulations, the work of Deep Impact Science Team cratering experts, and cratering on a Solar System scale to be discussed later in class.

For more details about the NASAS Deep Impact Mission see <http://deepimpact.jpl.nasa.gov>

National Science Education Standards Addressed

Grades 5-8

Science as Inquiry

- Understands about scientific inquiry

Physical Science

- Properties and changes in properties of matter
- Transfer of energy

History and Nature of Science

- Nature of science and scientific knowledge

Grades 9-12

Science as Inquiry

- Understands about scientific inquiry

Physical Science

- Motions and forces
- Interactions of energy and matter

History and Nature of Science

- Nature of science and scientific knowledge

View a full text of the National Science Education Standards

<http://newton.nap.edu/html/nses/6a.html>

Student Objectives for Cratering Research

- Conduct a scientific investigation in low-impact cratering.
- Use technology to improve scientific investigations.
- Use mathematics to analyze the investigation results.
- Discuss the limitations of low energy impacts as models of high-energy Solar System impacts.

Materials:

Student Handouts for Cratering Research

Make copies of each of these student texts and handouts in the most appropriate form—screen reader, low-vision or Braille versions. Click on the title you wish to access.

- [Student Text Exploring Cratering](#)
- [Exploring Cratering Student Activity](#)
- [Student Data Sheet A Exploring Cratering Activity](#)
- [Student Time Trial Data Sheet](#)
- [Student Data Sheet B Exploring Cratering Activity](#)
- [Student Data Sheet Factors that Influenced Cratering](#)

Experimental equipment

The following list includes a large variety of items that may be used. The level of visual impairment of your students and how sophisticated you wish to make the experiment to will be the determining factors for determining which items and set-up that will be best suited for your class. Instructions for making the adapted devices shown in the pictures may be found by following the appropriate links provided with the pictures.

Containers for surface materials: If you are going to use your cratering activity repeatedly, it is advisable to use sealable plastic 2–4 quart containers. These are easily stacked for storage and keeping the lids on until being used can avoid unpleasant spills. If you are going to prepare tactile crater models of actual impacts, aluminum roaster or lasagna pans that are 3–4 inches deep work very well. These items can be obtained from a Family Store™ or Dollar Store™ inexpensively. If you have access to large, shallow containers, these are excellent for keeping the fine grain ejecta materials from spreading all over.

Crater mediums: Flour is an outstanding medium, is inexpensive and can be packed down to provide a different firmness. Plaster of Paris is an excellent medium for cratering; however, if used in its dry state it tends to fly everywhere and you need to be sure that students do not inhale it. This will be difficult with VI students who will need to get quite close to the surface material to see the resulting crater, ejecta and ray patterns. On the other hand, Plaster of Paris works very well mixed with water to form a thick paste to create hard models for the blind students to feel. Other materials for mediums include: sand, colored aquarium gravel, different grades of cat litter, potting soil both dry and dampened, sugar, and dry mortar cement. The dry mortar cement gives excellent ejecta patterns but has the same drawbacks as Plaster of Paris. Sugar gives a great ejecta pattern but does not allow for a well-defined crater wall.

Colored medium to coat the surface: For the white substances, the standard cocoa powder can be used. An alternative is to use table salt and food coloring. This is much cheaper than buying colored sugar. For dark surfaces like the cement, flour can be used. Salt shakers or small holed strainers work very well for spreading the colored substances over the cratering materials. For the colored aquarium gravel, the same size gravel to use as a cover medium can be obtained from large anthills

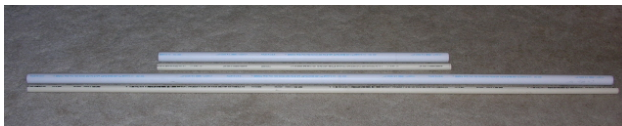


Objects to use as impactors: There are a variety of items that can be used as impactors from glass marbles, steel balls, old computer mouse balls, plastic, Styrofoam and rubber balls, and blocks of wood as well as irregular objects such as metal bolts. Since this activity will be looking at what impactor factors produce the desired crating effects the adapting author chose to use two sets of three different shapes: a ball, a bullet design, and a blunt headed impactor all made of steel. Both sets have the same shaped objects but the second set has twice the diameter and four times the mass of the smaller set. Click [here](#) for instructions to create the impactors used in this experiment.

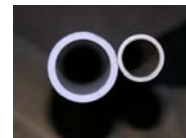


Experimental Apparatus

Apparatus for determining height and angle of drop: Cut a 1x2 inch wood strip into a 2-meter length, mark and notch it at the halfway point for 1-meter drops. This can be hung above the impact containers to insure consistent dropping heights.



A set of PVC pipes in 1 and 2 meter lengths with $\frac{1}{2}$ and 1 inch diameters allow impactors to not



only be dropped at consistent heights but also allow for directing impacts at different measured angles.



Another advantage of using the pipes is that they keep the impactor from tumbling, allowing you to insure that the desired impactor face is what strikes the surface medium. Click [here](#) for PVC Impactor Guide construction directions.



Measuring devices:

- You will need a small scale or pan balance to obtain the mass of the impactors.
- To measure the diameter of the round objects have two small wooden blocks and a ruler. Slide the wooden blocks flush with the ruler, place the object to be measured in between the blocks and take your reading. The ruler will also be used to measure the length of the crater rays. A set of vernier calipers will give a more precise measurement. Braille rulers come with slides that allow them to act the same as Vernier calipers.
- To measure the depth of the crater, use a piece of uncooked pasta inserted into the crater, mark it with a felt pen or break it off where it meets the



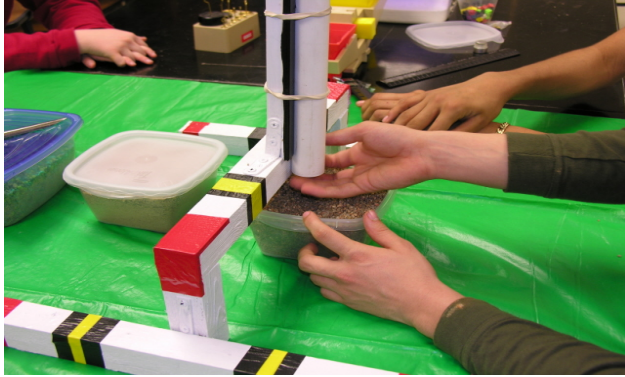
surface and measure. A thin piece of wire may be used as well by simply bending the wire at the surface and measure.

Impactor extractors: Using extractors will help maintain the integrity of the craters for comparisons of similar characteristics. Magnets the same diameter of the metal impactors will help keep the crater intact while removing an impactor from a firm surface. Thin wire forceps work well for gripping objects from loose, soft surfaces. However, due to the fact that the crater will collapse in type of surface as the impactor is extracted, I recommend that if measurements are being made to determine the depth of the crater, that the distance between the surface and the top of the impactor. Add the diameter or length of the impactor to this measurement to find the depth of the crater.

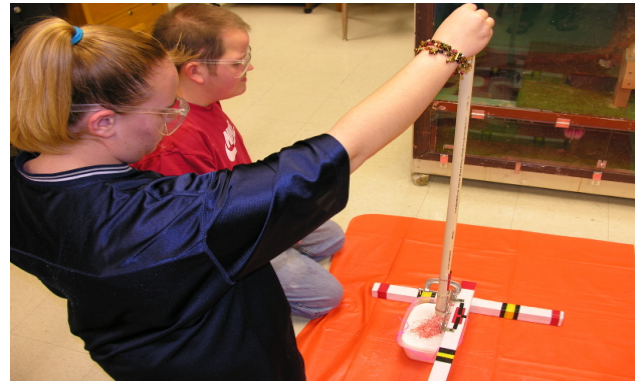


Drop cloths: Inexpensive plastic tablecloths can be purchased at a Family Store™ or Dollar Store™. Newspapers can be used but they do not provide a good surface to observe ejecta rays, especially for students with visual impairments. Damp cloth towels are also a wonderful asset for the material that escapes off of the drop cloths.

Cratering Research During Pilot Testing



Feeling the Impact



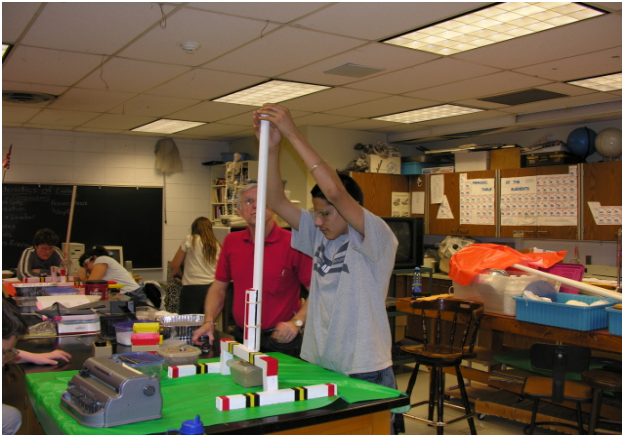
Drop Trial #1



Feeling the Release



Timing the Drop



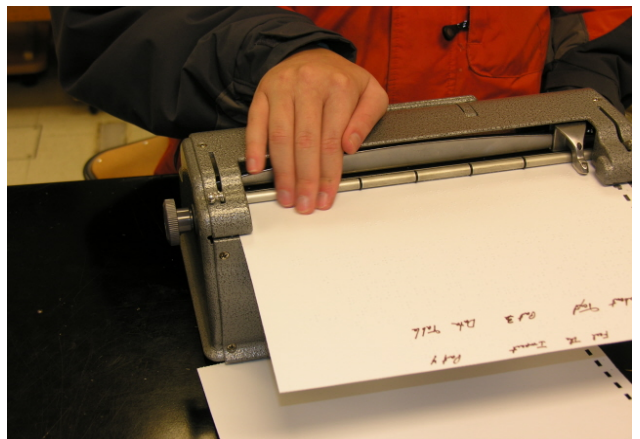
Dropping Trials at 90°



Dropping Trials at 45°



Discussing "What Happened?"



Recording experimental results in Braille Table

Procedures for Conducting Cratering Research

Section 1. Unstructured Testing of Impact Factors

Materials Needed:

- Pan of impact material
- Two or three different objects to act as impactors from items supplied by your teacher
- Ruler, string, thin piece of wire or piece of spaghetti pasta to make measurements
- A 2-meter long wood strip marked and notched at 50 centimeter intervals.
- Safety glasses
- Small scale (pan scale with weights or electric scale)
- Drop cloth
- Student Data Sheet A

Variables to be considered:

- Drop objects from different heights
 - Drop objects of different masses
 - Drop objects of different shapes
 - Is the surface material packed down or loose
1. For this activity you will be looking at differently shaped objects to determine which will produce a crater pattern that provides adequate ejecta material to determine what is below the regolith or surface material.
 2. Distribute the "Exploring Cratering" Student Text in the form most appropriate for your students. Allow sufficient time for them to read the text. Review with students "The Process of Crater Formation" and "Variables involved in Cratering" Student Texts from the Cratering in the Solar System section.
 3. Have students brainstorm the factors that they think would be relevant in examining how craters are formed, both for the low velocity classroom model and high velocity space impacts. Factors that should be considered are: object used—size, shape, mass, density; height from which it was dropped; impact velocities; angle of impact; acceleration; qualities of the surface material (fluffy or packed, dry or moist, smoothness); crater—size, shape, depth; size of ejecta pattern; general length and number of rays. If you have congenitally blind students in your class you need to check with them and see if they have ever thrown an object into mud and felt it to find out if what you are asking makes sense to them. If they have not done this it would be best to take a moment here and show them a tactile model of a crater so they have this in their minds eye as the discussion continues about factors.
 4. Following the brainstorming session, distribute the "Student Data Sheet A for Exploring Cratering" in the form most appropriate for your students. Explain to your students that for this activity that they are going to be using systematic experimentation (varying just one thing at a time, and taking measurements as well as qualitative notes) to discern how a sample crater was produced.

Feel the Impact Student Data Sheet A: Exploring Cratering Activity
 (The actual student handout has multiple 'Impactor Used:' sections.)

Impactor Used:	
Procedure:	Observations:
	Object Mass
	Object Shape
	Drop Height
	Crate Depth
	Crater Diameter
	Crater Shape

5. Arrange students in teams that incorporate all levels of visual impairment. Allow students to explore some of their ideas about the effects that different variables have on the characteristics of craters. Have them select a couple of objects from a variety of objects you have provided. Do not let the teams select objects from the sets to be used for the systematic experimentation. **Emphasize that there are to be no unsafe actions such as throwing an object as hard as they can into the surface medium.** Have them keep informal records of their observations to be compared with the systematic experimentation aspect of the activity. Allow approximately ten minutes for this activity or less if student engagement declines.

Section 2. Time Trials

Materials Needed:

- Impact container with dampened sand
- Stop watch
- Meter stick
- One set of pre-selected steel impactors
- C-Clamp
- Either a fixed vertical angle PVC guide support or a variable angle PVC guide support
- One set of three impactor guides one meter long or one set of three guides two meters long
- Safety glasses
- Small scale (pan scale with weights or electric scale)
- Drop cloth
- A Student Time Trial Data Sheet handout

6. For this section of the activity you should have a minimum of two teams. After students have compiled their informal observations, have one team obtain a vertical drop PVC guide, the 1-meter ½ and 1 inch PVC guides, a set of small and large metal impactors, different surface mediums to impact, a stop watch, a small scale, measuring devices, and their data observation sheets. Have the second team pick up the variable angle PVC guide, the 2-meter ½ and 1 inch PVC guides and duplicate the rest of the items obtained by the first team.

7. Have each team designate a Dropper, Timer, Recorder, and a person to help hold and steady the PVC tube. The holder for the variable PVC stand needs to ensure that the tube is at 45 degrees before each release of the impactor. More consistent and valid results will be obtained if the Dropper and Timer individuals remain the same for all of the time trial runs.
8. Have the students use a dampened sand surface as this is less messy and can be easily smoothed back over. Ask the students to create a table to record and calculate the times for each impactor or hand out the prepared chart below. Each team should do at least six time-trials dropping all of the objects through the 1-meter and 2-meter PVC guides and then have them average the time for each object.. Have the students designate a data observation sheet for each impactor, recording the mass, shape, size, and average time for each impactor. The team with the variable PVC holder should perform these same operations with the impactor guide set at a 45 degree angle of impact. A C-Clamp placed at the 45 degree point on the protractor will ensure a consistent angle for positioning the PVC tube. Instruct both teams to insure that the opening end of the impactor tube is two centimeters above the surface material. This is to maintain a constant distance from the influence of the guide to impact and minimize projectile free-fall arc and tumbling after leaving the angled guide. If you have the luxury of enough time, have the teams trade the vertical and angled PVC guides and redo each other's time trials. This will decrease the percent of error and provide a great teaching moment for discussing the variation or closeness of each team findings. Doing such will emphasize the importance of not accepting as absolute the first set of any measured values. Be ready to assist any of the blind students on proper techniques with the PVC guides, if needed, but once you have done this stand back and let them be responsible for their own experimentation. Only step back into the picture if it becomes apparent that problems with the equipment have created a frustration level where no further productive learning is taking place. When all teams have completed their computations, have everyone share their findings.

Feel the Impact Student Time Trial Data Sheet

Type of Impactor:		Height dropped:				
Mass of Impactor:		Angle of Impact:				
Time of Trial in Seconds	T-1	T-2	T-3	T-4	T-5	T-6
Total Time =			Average Time =			

9. After the time trials have been recorded, each team needs to make observations for all of the designated impactor objects and record the perceived facts into the appropriate data table. Run at least three trials for each variable being examined. Remind the teams that it is critical to maintain the same 2 cm elevation of the PVC tubing above the surface to be impacted as they did for the time trials. By this point, all of the teams should be comfortable using the PVC guides regardless of their visual impairment.

Section 3. Structured Testing of Impact Factors

Possible variables to be tested:

- Impactor mass
- Impactor size
- Impactor Shape
- Height traveled
- Type of material impacted
- Firmness of material impacted
- Angle of impact

Things to measure and notice:

- Crater depth
- Crater diameter
- Crater shape
- Angle of impact
- Ejecta pattern
- Number & length of rays
- Distance traveled
- Time traveled
- Drop height
- Object mass
- Object shape

Materials Needed:

- Different impact materials in containers that have surface indicator lines attached
- One set of pre-selected steel impactors
- One set of three impactor guides one meter long or one set of three guides two meters long
- C-Clamp
- Either a fixed vertical angle PVC guide support or a variable angle PVC guide support
- Ruler, string, thin piece of wire or piece of uncooked spaghetti pasta to make measurements
- Felt tip Sharpie marker
- Small scale (pan scale with weights or electric scale)
- Safety glasses
- Impactor extractors
- Vernier type calipers or other size-measuring apparatus
- Drop cloth
- Student Data Sheet B

Feel the Impact Student Data Sheet B: Exploring Cratering Activity

Impactor Used:			
Procedure:	Variable Tested:		
	Trial 1	Trial 2	Trial 3
Type of Material Impacted:	Object Mass		
	Object Shape		
	Object Dia/length		
Observations:	Drop Height		
	Distance Traveled		
	Time Traveled		
	Angle of Impact		
	Crater Depth		
	Crater Shape Draw or describe		
	Crater Diameter		
	Ejecta Pattern		
	# of Rays & length		

10. Again have each team designate a Dropper, Timer, Recorder, and a person to help hold and steady the PVC tube. The holder for the variable PVC stand needs to ensure that the tube is at 45 degrees before each release of the impactor. More consistent and valid results will be obtained if the Dropper and Timer individuals remain the same for all of the time trial runs.

11. Have teams decide what variable they will test, find and record the mass, diameter or length of the impactor, along with the drop height and angle of impact. A C-Clamp placed at the 45 degree point on the protractor will assist the holder in maintaining the correct angle. Remind them that only one variable at a time is to be tested.

12. Make sure that teams are using impact containers with surface indicator lines and that these lines are not covering the impact site prior to the impactor being released. After impactor strikes the surface, have student pull the surface indicator line tight over the impact site and make their measurements. If the surface material is loosely compacted and will fall into the crater as the impactor is removed, leave the impactor in place to find the depth of the crater. Have students measure from the surface indicator line to the top of the impactor with either the wire or uncooked pasta and add this measurement to the diameter or length of the impactor to determine crater depth. When all of the observations have been made and

recorded, have students remove the impactor and remind students that they need to smooth the surface material before they do the next two runs to test the current impactor.

13. Monitor the teams to keep them on task to test all of the impactors in a timely manner.
14. When the experimenting has been completed and cleaning up has been accomplished, hand out the Student Data Sheet: Factors that Influenced Cratering to have the teams summarize their findings.

Student Data Sheet: Factors that Influenced Cratering

<p>Factor investigated:</p> <p>Did factor affect crater shape, depth, or diameter?</p> <p>If yes what effect did it have?</p>	<p>Factor investigated:</p> <p>Did factor affect crater shape, depth, or diameter?</p> <p>If yes what effect did it have?</p>
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15. When the students have finished summarizing their findings, hand out the questions to begin the computation and interpretation of the obtained data.

Section 4: Making Sense of the Data Gathered

Questions: You may want to add questions that would pertain to a “teachable moment” event that occurred with the activity your students actually carried out along with those listed below. Utilizing the observations and data gathered and recorded in their data sheets, have students answer the following questions.

1. Using the formula [$V_i = V_o + at$] where V_i = velocity at impact; V_o = initial velocity; a = acceleration due to gravity (9.8 m/s^2); t = time traveled, calculate the velocity of the impactor at the moment it struck the surface material. Calculate the velocity for each impactor used, applying the variables of height and angle of decent. Do you find any patterns? Explain any patterns or variations you may find.
2. Using the formula [$KE = \frac{1}{2} mv^2$] where KE = kinetic energy; m = mass of object; v = the velocity of the object, calculate the kinetic energy of each impactor using the same parameters given in question #1. Look for patterns and variations and explain why you think they occurred.
3. Using the formula [$PE = mgh$] where PE = potential energy; m = the mass of the object; g = acceleration due to gravity; h = the height above the surface in meters, calculate each impactors potential energy. Seek out patterns and variations and explain why you think they occurred.

4. Noting the time it took each object to drop the released distance, how do you explain the identical time of each object for the vertical or 90 degree drop and the variations of times for the 45 degree angle drop?
5. Reviewing your data, compare the size of all the craters and the resulting ejecta patterns. Describe what factors you think appear to have the greatest affect on producing craters and ejecta patterns that might provide scientists an opportunity to gather information about sub-surface materials?
6. Pick one of the surfaces you made craters in to answer the next question. As you changed variables, what affect did they have on shape of the crater and the resulting ejecta patterns? For example, what happened when the distance traveled was doubled or the mass of the impact was increased? Of all the variables you changed, which variable had the greatest effect?
7. What information or techniques from this experiment could be applied to the challenge the Deep Impact scientists had in determining what characteristics their impactor should have to create a crate on Tempel 1?
8. What are some disadvantages in using a low energy impact experiment to try and obtain insights on how to construct a high-energy impact event?
9. After answering all of the above questions and feel like trying a challenging math problem related to the activity you just completed, ask you teacher for the Extension Problem.

Extension:

For those students with advanced math skills try this challenge to explore the relationships between mass, density, and velocity with respect to the impact energy of a sphere. The impact energy of a sphere can be expressed by the following equation: $KE = \frac{2}{3} \pi(\rho r^3 v^2)$ where KE = kinetic energy at impact in Joules (unit J), the $\frac{2}{3}$ and π (3.1415) are constant numbers, ρ = density (unit kg/m³), and r = the radius of the sphere (unit m). By using this formula, one can mathematically demonstrate that the energy of an impact will be proportional to:

- The density (twice the density, twice the energy)
- The cube of the radius (twice the radius, eight times the energy)
- The square of the velocity (twice the velocity, four times the energy)

Using the two steel ball impactors from the cratering experiment, apply the parameters of these two spheres to prove the three proportional statements above. Other helpful formulas are:

$\rho = m/V$ where ρ = density, m = mass in kg, V = volume;

Volume of a sphere is $V = \frac{4}{3} r^3$ where V = volume, $\frac{4}{3}$ is a constant number, r = radius.

What problem do you see in using two spheres of the same material to prove all three proportional statements?