JUST HOW BIG IS BIG?

Activity 9
Teacher section

MATERIALS

Each group will need

- bag of simulated planetary bedrock
- cup of simulated planetary surface
- container
- sieve or large spoon
- simulated bolides (assorted sizes)
- drop cloth or floor cover
- ruler
- chair
- string, weight on the end
- graph paper
- safety goggles for everyone

WHAT IS HAPPENING?

In Activity 8, students experimented with the connection between activity and energy. They learned putting more energy into their sand affected the energy (in the form of heat) of their system. This activity extends that work to a quantitative level. Students learn about kinetic energy and its numerical relation to mass and velocity:

$$\text{kinetic energy} = 1/2\ mv^2$$

Because Part II contains some of the results for Part I, don't hand out the Part II worksheets until Part I has been completed. In Part II, students experiment with the connection between bolide mass and crater size. Qualitatively, heavier masses leave larger craters. Quantitatively, as mass increases, crater volume (measured here as the cube of the crater diameter) increases proportionally. These results occur because as mass is changed in the experiment, so does the bolide's kinetic energy.

Because a numerical relationship exists between kinetic energy and crater volume, quantitative estimates are possible for impact sites. In Part II, students are introduced to the rationale for such estimates and are led to the prediction that:

$$D^3 \text{ will be proportional to } mv^2$$

In exploring this prediction, students gain an appreciation for the numerical relation itself—e.g., that a 1O-fold increase in crater diameter requires a 1 ,OOO-fold increase in mass.

An extension provides the formula for making other quantitative predictions for impacts. Because crater size depends on both mass and velocity, students also might want to explore how changing velocity affects cratering.

The three elements of this activity (Parts I and II, plus the extension below) are designed with increasing levels of abstraction. Such a design allows you to tailor this activity to your students' ability levels and interests. Part I may be presented alone. Likewise, the extension may be passed over without major loss to the learning objectives.

IMPORTANT POINTS FOR STUDENTS TO UNDERSTAND

- Kinetic energy is the energy associated with motion.

- The kinetic energy of a bolide is determined by its mass and velocity, or
$1/2\ mv^2$

- Because a numerical relation exists between a bolide's kinetic energy and crater size, quantitative predictions about impacts are possible.

PREPARATION

Photograph from Apollo 8 of Goclenius Crater (foreground). The three clustered craters (background, left) are Magelhaens, Magelhaens A, and Colombo A. Goclenius Crater is approximately 67 kilometers in diameter. This is image Moon907.tif on Craters!-CD. As an extension to this activity students can be asked to estimate the size of bolides that created particular craters.

Part I

This activity uses a streamlined version of Activity 3. Whereas in Activity 3 the emphasis was on the anatomy of craters, here the point is to connect crater size with the bolide's kinetic energy. Several elements of the experimental design are crucial for good results. First, to keep velocity basically constant, bolides should be dropped from a standard height. Dropping height should exceed 2 meters, and higher drops (closer to 3 meters) are preferable. Students can stand on chairs or ladders if it is safe for them to do so. Create measuring strings of uniform length to standardize dropping height. To keep the string taut, tie a weight onto the bottom end of the string, or tie one end to the container of simulated surface. An alternative is to have students throw bolides to the surface; however, this practice prevents velocity from being controlled during the experiment.

More controlled results are obtained when bolides differ in mass but not in volume Such bolides can be made by hollowing out small balls (table tennis balls, super balls, or reusable ice balls) and refilling them with lead weights or substances of varying densities. When resealed, these simulated bolides should be weighted. Various sizes of BBs can be cast in plaster molds, if enough preparation time is available. Slingshot ammunition also works well for weights.

Number the bolides. Students can measure the mass as part of the activity. Each group should use masses that range at least in one order of magnitude (e.g., 10100 grams). The widest range of bolide masses for this experiment need not extend beyond 5-500 grams. Be sure to test the bolides you create prior to launching this activity in class; optimal weight ranges will vary depending on your choice for simulated planetary materials.

Part II and Extension

The lunar farside as seen by A polio 11 astronauts. The large crater is I.A.U craterno.308(approximately 80 km in diameter). This image is Moon 901.W on Craters!-CD. It also is the same image as Figure 4 in the student section.

No equipment is required for these sections. You may choose to review algebraic manipulation with your students. Also, be sure to work through the answers to student questions prior to beginning these sections. Several steps require knowledge of basic algebraic rules, such as the principle of complementarity (a change on one side of an equation requires a complementary change to the other). Calculations in the extension require the use of power functions: squares, cubes, square roots, and cube roots. For numerical calculations, students are advised to have calculators or spreadsheets available. Remember: finding the cube root of a number, x, is equivalent to raising it to the onethird power, or $X^{1/3}$. Also remind students about the difference between manipulating equalities versus manipulating proportionalities .

SUGGESTIONS FOR FURTHER STUDY

Table 1 in the student section introduces scientific notation. Students can learn how to make computations using this shorthand. Likewise, the standard unit of energy, joule, is introduced in this activity. Students can explore the uses of this unit, its physical meaning (what does 100J feel like?), and its conversion to other energy units, such as calories and ergs.

Some of the largest impacts occur with such force that the raising of the rim actually produces a series of rings encircling the crater. (This is shown in the painting on this book's front cover.) The 150 kilometer, multi-ring Orientale basin on the Moon and crater Lise Meitner on Venus are good examples of such impacts.

CONNECTIONS

Bolides move at considerable velocities. How do they acquire those speeds? Planets' speeds in moving around the Sun typically range in the tens of kilometers per second. So even if two bodies collide at a fraction of that speed, they are likely to crash at kilometers/second. By comparison, a rifle bullet typically moves at a few hundred meters per second.

Students can explore the physics of gravitational attraction and the role gravity plays in altering the directions and velocities of meteorites and comets. Jupiter's massive gravitational field, for example, is responsible for diverting the path of many interplanetary bodies. Planetary scientists use the sling-shot effect of these gravitational fields to steer and accelerate spacecraft.

Although bolides involve complications to the basic approach, this activity provides a launching point into the physics of falling bodies. The modern study of this subject began with Galileo (whose telescope work was discussed in Activity 2), and it forms a basic element in any physics curriculum. Students can explore this topic and the ways bolides offer special cases of free fall.

You might ask students to examine this activity as an application for the principle of conservation of energy. Ask them to trace how the kinetic energy of the bolide is converted to other forms of energy during the impact.

ANSWERS TO QUESTIONS FOR STUDENTS

Part I

1. When students compare crater size to bolide mass directly, they should get a cunve. If they plot bolide mass versus crater diameter cubed, the graph should be closer to a straight line. Such results have allowed scientists to say bolide mass (and energy) are roughly proportional to the cube of the crater diameter.

2. When students graph the cube of crater diameter against mass, their graphs should approximate a straight line. Variations in experimental conditions (e.g., differences in the compactness of the simulated bedrock) will produce noise in the graph. If so, you can discuss "noisy data" and extend the range of masses (and the care taken in the procedure) to clarify the shape of the plotted curve. It's a good chance to talk about how scientists have to work hard to get good data.

3. Students should connect crater size to the kinetic energy of falling bolides.

4. The answers to these questions are explored in Part II.

Part II

1. The mass must be increased 8 times. Why? Follow this chain of reasoning:

   a. For a crater diameter (D_2) twice as large as another (D_1)

   $$D_2 = 2D_1 \qquad \text{and} \qquad m_2 = y\,m_1$$

   b. To predict the mass that made crater D_2, you begin with:

   $$(D_2)^3 \text{ is proportional to } (m_2)v^2\text{, or,}$$
   $$(D_2)^3 \text{ is proportional to } (y\,m_1)v^2\text{, or,}$$
   $$(2\,D_1)^3 \text{ is proportional to } (y\,m_1)v^2$$

   and solve for y, the proportional change in mass to compensate for the 2-fold increase in crater diameter. Remember: to maintain the principle of complementarity, equal changes must be made to both sides of the equation. Solving for y gives the value to add as a complement.

c. Assume the two bodies move at the same velocity, so velocity becomes irrelevant:

$$(2\,D_1)^3 \text{ is proportional to } (y\,m_1)$$

d. Expand the equation. This is the key step! Watch what happens to the left side of the proportion.

$$(2^3)\,(D_1)^3 \text{ is proportional to } (y\,m_1)\text{, or,}$$
$$8\,(D_1)^3 \text{ is proportional to } (y\,m_1)$$

e. To keep the proportional ity constant, both sides of the equation must be changed equally, so solve for y:

$$8 = y$$

Thus, to increase crater diameter 2X, mass must increase 8X. Substituting a variable, x, for 2 in this equation produces the generalization that change in mass will be equal to the cube of the change of the diameter, or $y=x^3$

2. Once students are comfortable with the explanation for Question 1, they can use the cube relation for Table 1.

y	requires	x^3
2X	requires	8X
5X	require	125X
10X	requires	1,000X
20X	requires	8,000X
50X	requires	125,000X
100X	requires	1,000,000X
200X	requires	8,000,000X
500X	requires	125,000,000X

3. Velocity is assumed to be constant in Question 1, as shown in step (c).

4. Beyond the equation, other elements of the impact are assumed to be constant. For examples it is assumed that both impacts occur on surfaces of the same density. If students are interested, they can identify numerous assumptions. Knowing what is assumed is an important skill for understanding models in science.

5. Answers will vary.

EXTENSION

If students are comfortable with the algebra involved, you can ask them to make additional predictions. This requires manipulating steps (a-e) in Question 1 as follows:

• If crater diameter increases by x, what will be the increase in velocity?
Answer: for step (b), begin with the equation; $(xD)^3$ is proportional to m $(yv)^2$ 1)
[Velocity will increase as the square root of x cubed, or $(x^3)^{1/2}$]

• If mass increases by x, what will be the increase in crater diameter?
Answer: for step (b), begin with the equation: $(yD)^3$ is proportional to (xm), v^2
[Crater diameter will increase by the cube root of x, or $x^{1/3}$]

• If velocity increases by x, what will be the increase in crater diameter?
Answer: for step (b), begin with the equation: $(yD)^3$, is proportional to m $(xv)^2$,
[Crater diameter will increase by the cube root of x squared, or $(x^2)^{1/3}$]