



COMET

IMPACT

Learning Resources Guide

SimEx
VIRTUAL VOYAGES™

COMET IMPACT™

Synopsis of the SimEx Virtual Voyages™ Attraction

A newly-discovered giant comet, Kirsch-Kennedy, is heading our way. Its path might be deflected if it is captured by the strong gravitational pull of Jupiter. Or... and this is what scientists fear most... it might continue on a collision course with Earth. If Jupiter's immense gravity captures Kirsch-Kennedy, it will change course to impact there, and Earth will be safe. If not, the comet will hit our planet, possibly destroying all life as we know it. We join in this exciting adventure to the surface of Kirsch-Kennedy, hurtling through space towards an uncertain destiny. Never before has anyone attempted such a dangerous mission. And this one has little room for error...

PRE-SHOW

The year is 2025. We meet Dr. Brian Jamieson and Col. Dana Symes, who are testifying before the United Nations Impact Emergency Council. Dr. Jamieson represents the Shoemaker Impact Center, where scientists study Near Earth Objects (NEOs) and the threat of impacts from space. He is at odds with Colonel Symes of the NEO deterrent Force, entrusted with Earth's safety. Here we learn how the Earth has suffered collisions with spaceborne debris over the ages, the enormous risk Comet Kirsch-Kennedy poses to our planet, and what we might do to avert a global catastrophe.

(Approximate time: 4 minutes 30 seconds)

STORY THEATER

In our pre-mission briefing, the scene shifts to NASA's International Space Station 3 (ISS-3), where Dr. Jamieson prepares for his flight to the comet. We learn that a Comet Lander carrying Dr. Jamieson will fly independently of our ship, the research vessel *Discovery*, to study the comet up close and gather samples of its material. Scientists hope that the comet's collision course with Earth will be altered by Jupiter's gravitational field. Nevertheless, Col. Symes launches an 80-megaton nuclear warhead to intercept the comet along the way... just in case.

(Approximate time: 3 minutes 40 seconds)



ISS-3 orbits high above Earth

ADVENTURE THEATER

We strap ourselves securely into our seats aboard *Discovery* for this dangerous mission. Our task as Science Observers requires us to pay close attention to the nature and behavior of the approaching comet and to report all important discoveries back to the Impact Center.

Our journey begins as our shuttle leaves the docking hatch on ISS-3. We feel Dr. Jamieson's Comet Lander separate from our craft and head out toward Comet Kirsch-Kennedy. Shortly thereafter, we see the failsafe missile launch and head towards its cometary target where it will be detonated, if necessary.

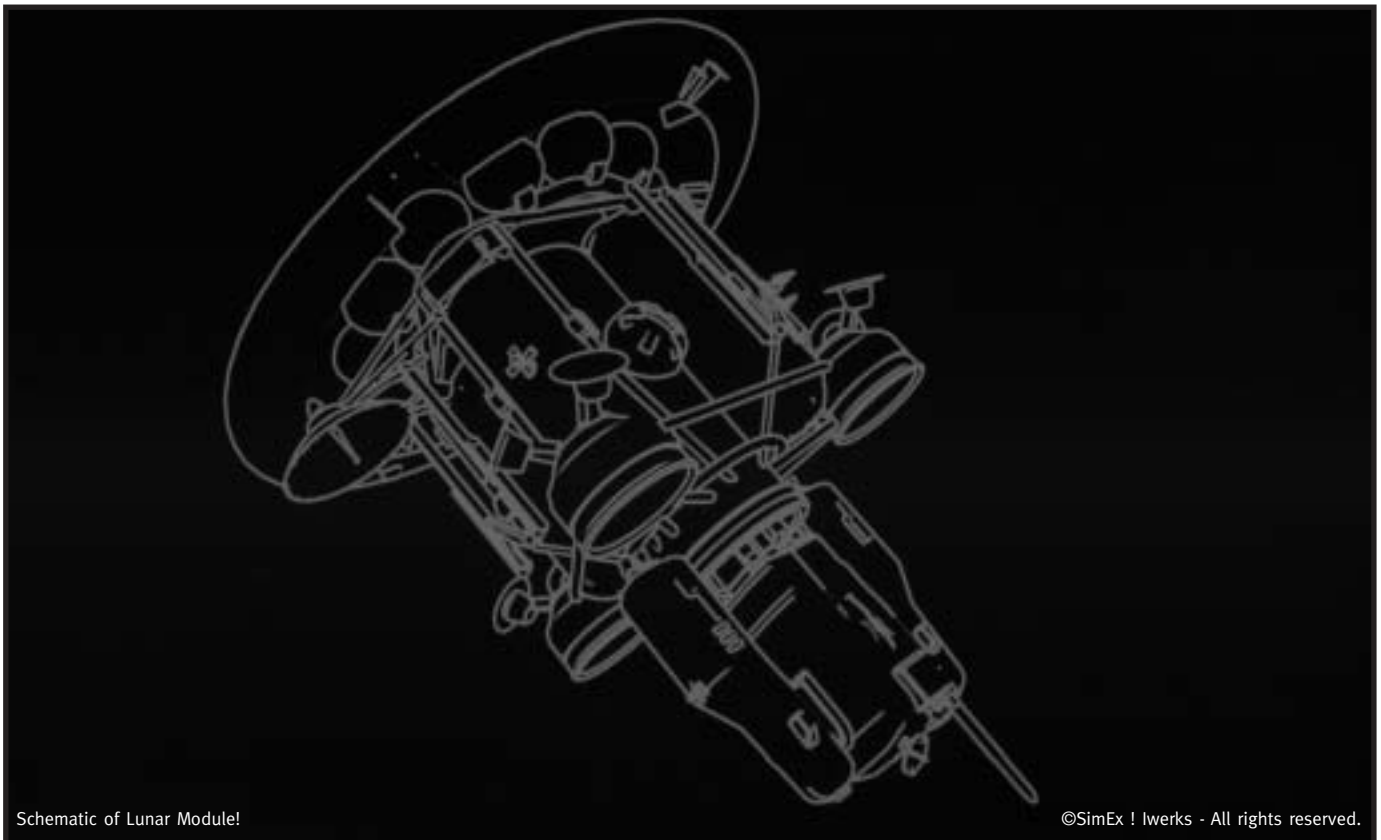
Once at the comet, we follow behind Dr. Jamieson's lander at what should be a safe distance. But, soon thereafter we are pelted by a hail of debris ejected from the cometary nucleus. Only a few meters above the surface, we watch the Comet Lander touch down, but soon discover that the nucleus is beginning to calve. A fissure spreads explosively through the nucleus, knocking Dr. Jamieson aloft! We struggle to rescue Dr. Jamieson, as small fragments of the comet impact on one of Jupiter's moons. The main body of the comet hurtles on towards Earth! Can Kirsch-Kennedy be destroyed before it's too late?

(Approximate time: 4 minutes 40 seconds)

A SIMEX VIRTUAL VOYAGES™ ATTRACTION

(TABLE OF CONTENTS)

Introduction	2
Impact Facts	3
Activity 1: Creating a Comet	5
Activity 2: Drawing a Comet's Orbit	6
Activity 3: Collecting Micrometeorites	7
Activity 4: Creating Craters	11
Activity 5: Comet Fears	8
Glossary	12
Resources	13
Acknowledgements	14



Schematic of Lunar Module!

INTRODUCTION

WHAT ARE COMETS?

Comets are large chunks of water and ice left over from the birth of our solar system over 4.6 billion years ago. Most are less than 1.6 km (one mile) across, and orbit the sun billions of miles away - far beyond the orbits of the most distant planets.

Occasionally, the combined gravitational pull of one or more planets, or even that of a passing star, can tug on one of these primordial icebergs and send it careening into our solar system. Some of these comets swing past (or even into!) our Sun, and are never seen again. Others become captured into highly elliptical orbits and return periodically to our solar neighborhood. The most famous example of a periodic comet is Halley's Comet (pronounced HAL-eez), which visits our vicinity every 76 years.

On its way into the inner solar system, a comet often crosses the orbital planes of the planets. Normally, since space is so large, these orbital intersections are uneventful. Sometimes, however, comets can intersect a planet's orbit while the planet is at the same spot, and a collision ensues.

COSMIC COLLISIONS

Earth is not exempt from cosmic collisions. Our world has been hit hard and often in the past. Scientists have identified over 156 impact craters scattered over the surface of Earth. Most have been caused not by impacts with comets, but with rocky or iron asteroids falling from space.

Comets, which sweep close to the Sun as part of their orbit, also pose a potential threat. Although they are thought to account for only about 5-10% of the impacts, they approach Earth with greater speeds and higher energies than Earth-crossing asteroids of the same size. But since they are not solid rock, comets tend to break up into smaller pieces as they smash through Earth's atmosphere, causing locally severe, but not necessarily globally catastrophic damage. In fact, some scientists believe that we owe nearly all the water on our planet and possibly even a supply of organic compounds out of which life has arisen, to cometary impacts in Earth's distant past.

Scientists estimate that one comet passes between the Earth and the Moon each century, and one strikes the Earth about every hundred thousand years. When talking about these cosmic collisions, it is important to put the risk in perspective. During a human lifetime, the chance that the Earth will be hit by something large enough to destroy crops worldwide is about one in 10,000. Those are the same odds of dying from anesthesia during surgery, of dying in a car crash during any six month interval, or of dying of cancer from breathing car exhaust on big city freeways every day. While all of these are possible, most people don't alter their everyday life because of them.

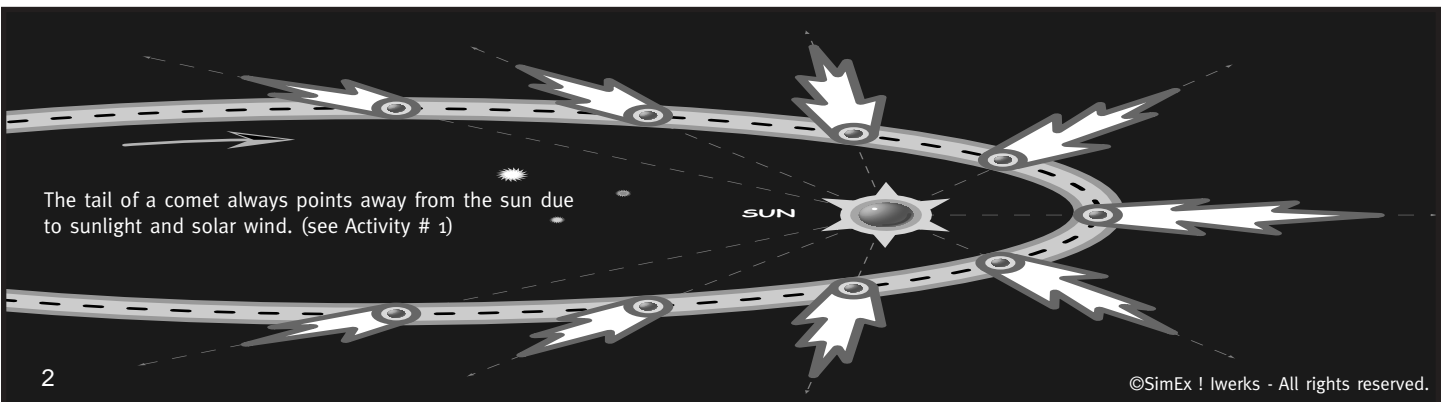
WHO IS WATCHING THE SKIES?

Is there anything we can do to prevent another major collision? Perhaps. In 1997, NASA hosted a conference to address the question of detecting objects that approach the Earth. They concluded that a network of six telescopes of 2-3 m (2-3 yards) diameter, located worldwide, would detect 90% of the asteroids that pose the threat of global catastrophe (those 0.8 km, or 1/2 mile across and larger) and 35% of the comets (discovered at least three months before a potential impact) which would do the same, over the course of a 25-year search.

What if we do detect an object headed straight for Earth?

The farther away an object is intercepted, the easier it is to deflect or destroy (a closer NEO (near earth object) has to be given a bigger push to get it to miss the Earth, due to gravity). So far, only nuclear energy is powerful enough to deflect an asteroid like the one that struck the Earth 65 million years ago. A nuclear blast on an asteroid's surface would blow off some of its material. The movement of that material away from the surface would act like a kick, pushing the asteroid in the direction opposite to the moving material.

On the other hand, comets could fragment into many dangerous pieces if a bomb exploded on their surfaces. But, a nuclear-warhead detonated nearby could melt some of the comet's frozen gases, turning them into jets that act like rocket exhaust, nudging the comet away from its original path. There's no doubt that entirely new technologies will exist in the future when we might need to deflect an incoming cosmic cannonball.



IMPACT FACTS

METEORS, COMETS & ASTEROIDS

Space is not empty. It contains left over matter from the formation of our solar system 4.6 billion years ago, as well as deadly radiation from the sun, and debris from several comets.

1. Almost 500,000 kg (1,102,300 lbs) of meteoric material has been found on Earth. Some of it has come from our moon or Mars as debris from collision explosions there. However, most has come from the asteroid belt: a collection of rocky material orbiting the Sun between Mars and Jupiter.
2. The largest meteorite, 60 tons, was found in Namibia, Africa.
3. When a meteorite hits the surface of the Earth, it is usually travelling at 36,000 to 252,000 km/second (22,000-157,000 miles/second.)
4. A meteor is a rocky fragment, often no bigger than a grain of sand. It is a tiny bit of a comet that was left behind in a debris trail as it melted on its way through the solar system. When Earth passes through that debris trail, meteors are caught by gravity and pulled into our atmosphere. These bits of comet sand vaporize in a flash of light. That's what we see as a "shooting star". The few meteors that do reach the ground are called "meteorites".

A comet is often described as a dirty iceberg. At the edge of our solar system are billions of comets, left over from the formation of our solar system. Occasionally, one is pulled into an orbit around the Sun by the gas giant planets or a passing star. Once a comet makes one elliptical orbit around the Sun, its return visits become regular and can often be predicted. But, until a new comet makes its first trip around the Sun, its path is difficult to predict.

Asteroids are chunks of rock left over from the formation of planets more than 4 billion years ago. Between Mars and Jupiter, in an orbit around the Sun, is a large collection of these mini-planets. Occasionally, they collide with each other and send fragments out into space. These chunks can travel great distances as they move around the Sun in their own orbit. Occasionally, they impact another planet.

A 10 km (0.2 mile) wide asteroid impacted Earth 65 million years ago and may have sent 80% of all life to extinction including, quite possibly, the dinosaurs.

5. Meteors up to 50 meters (53 yards) in diameter usually burn up after they enter Earth's atmosphere.
6. Impactors with a diameter of 75 meters (82 yards) can cause a crater the size of the Barringer Meteor Crater in Arizona, with a force of a 10 to 100 megaton atomic bomb.
7. The Barringer Meteor Crater was created 50,000 years ago. The result is a crater more than 1200 meters (1312 yards) in diameter and 200 meters (656 feet) deep.
8. An impactor with a diameter of 160 meters (175 yards) would release energy the equivalent of 100 to 1000 megatons and could destroy a city the size of Tokyo or New York.
9. An impactor with a diameter of 1.7 km (1.05 miles) would release the energy of a 100,000 to 1,000,000 megaton atomic bomb and would create a hole 21 km (13.05 miles) wide. It would cause massive extinction of life on Earth.
10. There are about 1000 asteroids with diameters larger than 1 km (0.6 miles) that cross the orbital path of Earth in its annual trip around the Sun.
11. An object 1 km (0.6 miles) or more in diameter hits Earth once every 300,000 years, on average.
12. In 1908, an object of about 100 meters (106 yards) in diameter exploded over Tunguska, Siberia. The 100 megaton explosion was heard as far away as London, England.
13. The impact craters on our moon are several hundreds of millions of years old. On Earth, we have few examples of impacts, as weather erosion and geological activity have obliterated all but the most recent and the largest. As 75% of our planet is covered in water, most impacts have occurred in the ocean.
14. The largest impact crater on Earth is 1.85 billion years old and is located at Sudbury, Canada.
15. There have been 156 confirmed impact sites found to date. Twenty-Six are in Canada; Twenty-Four in the United States.



IMPACT FACTS

17. EARTH'S GREATEST HITS:

The ten largest impact craters on Earth.

	LOCATION	DIAMETER
1.	Sudbury, Ontario, Canada	240 km / 180 miles
2.	Yucatan, Mexico	170 km / 105 miles
3.	Acraman, Australia	160 km / 99 miles
4.	Vredefort, South Africa	140 km / 87 miles
5.	Manicouagan, Quebec, Canada	100 km / 62 miles
5.	Popigai, Russia	100 km / 62 miles
6.	Puchez-Katunki, Russia	80 km / 50 miles
7.	Kara, Russia	65 km / 40 miles
8.	Beaverhead, Montana, USA	60 km / 37 miles
9.	Siljan, Sweden	55 km / 34 miles
9.	Tukunuka, Australia	55 km / 34 miles
10.	Charlevoix, Quebec, Canada	54 km / 33.5 miles

18. NEAR MISSES!!

There has been no major catastrophe due to a cosmic collision in our lifetime. However, in geological time, we are overdue for one. Every 300,000 years, on average, there is an impact that causes massive loss of life, and even extinctions.

1. In 1994, a large asteroid 5 to 12 km (3-7.5 miles) in diameter crossed Earth's orbit just 5 minutes before our planet, travelling 792,000km/h (492,000 mph), reached the same position. The object was seen only after it passed by. It was just 104,000 km (64,625 miles) away. This is a Near Earth Object (NEO), and there are many of them that are potentially deadly. Since then, there has been feverish interest in locating such NEOs and planning how we might destroy them before they become a deadly danger to life on Earth.
2. Each year, military satellites detect dozens of asteroids approximately one meter (3.28 feet) in size as they explode in Earth's upper atmosphere.
3. In 1998, 54 Near Earth Objects were discovered.

4. Each year, Earth crosses the path of several comet orbits. Eleven comets have left a debris path of tiny rocky bits. As they enter our atmosphere and burn up, we see them in the night sky as meteors or "shooting stars". These "showers" are most common in August and November, with up to 90 per hour. November 1999 marks Earth's latest pass through dense debris left from Comet Swift-Tuttle's last visit. This comet has returned every 33 years since it was first discovered in 1866.

5. Several near misses during our lifetime have alerted us to the danger of NEOs. In April 1974, a 1000 ton asteroid skipped through our atmosphere like a rock over the surface of a pond. It entered Earth's thin atmosphere near Montana, flaming through the sky from south to north and returned to space when it reached Edmonton, Canada. Depending on mass, a 1000 ton asteroid would be from 3 to 14 meters (10-46 feet) in diameter.

In January 1994, a similar asteroid streaked through the sky and exploded over the Pacific Ocean somewhere near Fiji.

6. NEO Watch. Since scientists have been actively-looking for NEOs, they have found several that are of concern:
 - In 1991, an asteroid 1 km in size, named 1991-OA, passed by Earth only 4.5 million km (2.8 million miles) away. That is considered very close. 1991-OA will return in 2070.
 - The asteroid 1994-XMI, 5 to 12 km (3-7.5 miles) in size, came within 5 minutes of Earth as it crossed our planet's orbit. It will return early in the next century.
 - Asteroid 1997-XF is 2 km (1.25 miles) in size, and will return for a closer approach to Earth in 2028.



Activity #1 (CREATING A COMET)

OBJECTIVE:

To learn the chemical composition of comets, and how they sublimate and calve over time, by constructing a scale model in the classroom. A dramatic and memorable exercise for all.

IN THE COMET IMPACT STORY:

A large, fictional comet is heading towards Earth. As Science Observers on a mission to intercept Comet Kirsch-Kennedy, our task is to observe the comet, take measurements, and record its behavior over time.

BACKGROUND:

Comets are huge chunks of ice, sprinkled with dust and rocks, that orbit in the outer regions of our solar system. When one is tugged inward by gravitational forces, it warms until its ices sublimate and its dust breaks loose, until they are both blown outward into tails by sunlight and solar wind. Comets are made mostly of water ice and organic molecules. Some scientists believe impacts with these cosmic nomads are responsible for much of the water on our planet, and possibly life itself. In a sense, comets are frozen pieces of time that tell us much about our origins.

TEACHER PREP NOTES:

This activity is designed for use by students in grades 5-8, though it can be a useful demonstration for students of all ages. Always practice this activity before doing it with students, since it can take some practice to get it right. Dry ice is available from ice companies in most cities; look under “ice” in the Yellow Pages for a local source. Day-old dry ice works best, so you might want to buy it the afternoon before doing the activity. Most ice companies have a minimum on the amount of ice they will sell—usually 5 pounds (2.25 kg). Having extra dry ice on hand will be useful because some will evaporate, and also to enable you to practice. Also, be aware that dry ice is extremely cold, with a temperature of $78^{\circ}\text{C}/109^{\circ}\text{ Fahrenheit}$. Store it in a styrofoam container where it can maintain its own temperature. A typical freezer is much too warm for dry ice to last long. To avoid frost burn on your skin, always wear thick work gloves when handling dry ice.

MATERIALS NEEDED:

- 2 cups (500 mL) of water (hydrogen and oxygen)
- A dash of ammonia
- 2-3 ounces (60-80 g) of sand or dirt
- A dash of organic material (corn syrup works well)
- 5-10 (2-4 kg) pounds dry ice (frozen carbon dioxide)
- Work gloves
- Safety goggles
- Ice chest
- Large mixing bowl (plastic, if possible)
- 4 medium-sized plastic garbage bags

- A hammer, meat pounder or rubber mallet
- Large wooden or plastic mixing spoon
- Plenty of paper towels

TO DO AND NOTICE:

Building the comet

- Place dry ice in three garbage bags that have been placed inside each other. Crush dry ice as fine as possible by pounding it with a hammer. Caution: Always wear gloves while handling dry ice. Safety goggles are also an extremely good idea.
- Arrange all ingredients and tools in front of you.
- Cut open a garbage bag and use it to line your mixing bowl.
- Pour water in lined mixing bowl.
- Add sand or dirt, stirring well.
- Add dash of ammonia.
- Add dash of corn syrup, stirring until well mixed.
- Add 1/2 to 1 kg (a pound or two) of dry ice to the mixing bowl while stirring vigorously. Continue stirring until mixture is almost frozen. Lift the comet out of the bowl using the plastic liner and shape it as you would a snowball. As soon as it is frozen sufficiently to hold its shape, unwrap the comet.

Observe the comet up close while it is still fresh. As the ices begin to melt and sublimate, a number of interesting phenomena become visible. It's reasonably safe to touch without getting burned by the dry ice, but it's still best to have a spoon or a stick for the students to use while examining it.

Notice the gas escaping from the comet. It's this gas that, in space, forms the comet's coma and is blown outward by pressure from sunlight into a long and beautiful tail. These always point away from the sun, regardless of which direction the comet is moving. Blow gently on the comet as you move it, and watch as the gases flow in the direction you are blowing.

As the comet begins to melt, the students may see and hear small jets of gas shooting from it. These are places where the gaseous carbon dioxide is escaping through small holes in the still-frozen water. This type of activity is also detected on real comets. In fact, such eruptive jets can sometimes expel sufficient quantities of gas to make small changes in a comet's orbit, making its path and behavior somewhat unpredictable.

Place the comet on display for the students to watch during the day. After several hours, the comet will become a crater-filled ice ball as the more volatile carbon dioxide sublimates before the water ice melts. You may even see the comet calve as pieces break off and fall away. Real comets also change in these ways each time they near the sun. Old comets may break into several pieces or even completely disintegrate. In some cases, the comet may have a solid, rocky core that is then left to travel around the comet's orbit as a dark barren asteroid.

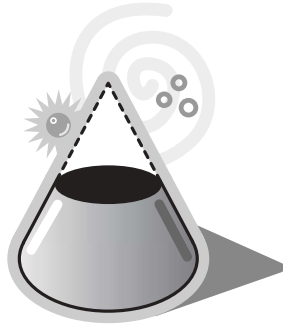
DRAWING A COMET'S ORBIT

OBJECTIVE:

To learn how comets (and other celestial bodies) orbit the sun by making drawings of ellipses.

IN THE COMET IMPACT STORY:

A large, fictional comet is on a path around our Sun, and its orbit might intersect that of Earth. Scientists need to learn about its orbit before they can determine if it will strike our planet.



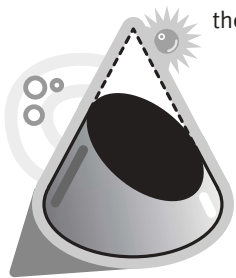
1. Circle- section cut parallel to base of cone.

BACKGROUND:

All orbits are ellipses. Even the Earth's orbit around the sun, which is almost a circle, is actually an ellipse. While ellipses look like ovals, they are very specifically defined mathematically. Technically speaking, ellipses are members of a special class of geometrical shapes known as conic sections. They are so named because all of these shapes (circles, ellipses, parabolas, and hyperbolas) can be made by slicing a cone in different directions with a plane. You may demonstrate this to the class by cutting solid cones (like miniature styrofoam tree forms) at different angles and examining the resulting cross sections.

TEACHER PREP NOTES:

A circle is defined as a figure where every point is the same distance from its center. One can easily construct a circle by tying a pencil to a string, securing the string to the paper with thumbtack, and keeping the string taut while moving around the thumbtack. The string forms the circle's radius and the thumbtack marks its center. An ellipse is somewhat more complicated to define and construct. Instead of one point of interest, the center, there are two points, the foci (singular: focus). The sum of the distances from each point on an ellipse to the two foci is a constant.

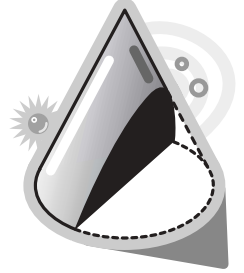


2. Ellipse- section cut at an angle to the base of the cone.

The farther apart an ellipse's foci are, the more eccentric it is said to be. A circle is just a special case of an ellipse; if the two foci are at exactly the same place, the ellipse is a circle. Despite the rather unusual and precisely mathematical way we have defined the ellipse, it's really very easy to construct. Terms like "eccentricity" will gain more meaning as the students experiment with different distances between the foci.

MATERIALS NEEDED:

- Thick cardboard or plywood, about 30cm x 30cm (1 foot by 1 foot)
- Standard 8 1/2" x 11" sheet of white paper
- About 1m (3 feet) of string
- Sharp pencil
- Two thumbtacks



3. Parabola- section cut parallel to the side of the cone.

TO DO AND NOTICE:

Making the Ellipses

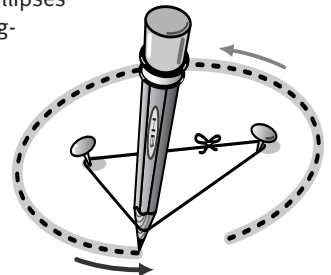
Place the sheet of paper on the cardboard backing and secure with the two thumbtacks. Do not push the thumbtacks all the way in! You must be able to loop the string around them. Tie the string into a loop and hook it around the thumbtacks. The loop should be large enough to fit around the thumbtacks, but not so large that, when taut, it won't fit on the paper. Pull the loop taut with the point of a sharp pencil. Keeping the loop taut, move the pencil (which is tied to the string) around the tack to draw the ellipse. Try experimenting with different distances between the foci. What happens when they are farther apart? Closer together? How can we make the ellipse rounder (less eccentric)? Flatter (more eccentric)? What if the two thumbtacks are right next to one another? What if there's only one thumbtack?



4. Hyperbola- section cut at an angle greater than the angle of the slope of the cone.

DISCUSSION:

With only one thumbtack, the figure is a circle. A circle, then, can be said to be a special case of an ellipse; i.e., a circle is an ellipse with zero ellipticity! This is a common way of grouping shapes; a square, for instance, is just a special case of the rectangle, in which two adjacent sides are of equal length. [Extension for older students: If basic logic such as group theory exists in your curriculum (e.g., "If all circles are ellipses and all ellipses are smooth figures, does that imply that all smooth figures are circles?"), this might be a good place to discuss it.]



(COLLECTIVE MICROMETEORITES)

OBJECTIVE:

To gather and study the leftover dust of meteors that has drifted to Earth after the meteors have burned up in the atmosphere.

IN THE COMET IMPACT STORY:

A large, fictional comet is heading towards Earth, and is destroyed by a warhead. Some of the remaining fragments of this planetary interloper may fall harmlessly into the Earth's atmosphere where they will burn up. In such a case, sky watchers on the ground would see a meteor shower or meteor storm. Eventually, the remaining ash would fall to Earth's surface as micrometeorites.

BACKGROUND:

When pieces of space dust or rocks hit the atmosphere, the interaction with our atmosphere causes them to burn dramatically. We see them as meteors flashing across the sky. At certain times of the year, we experience more meteors than normal. During these meteor showers, we might see as many as 100 meteors per hour falling from a clear, dark sky far from city lights. As these specks of dust disintegrate in our atmosphere, their ash drifts about until it falls to the ground as a micrometeorite.

TEACHER PREP NOTES:

Micrometeorites are iron flecks that can be collected by simply using a magnet. The exercise allows students to collect their own ancient fragments of the Solar System. This activity can be performed on school grounds where rain gutters are present, or at home. To raise the odds of a significant find, plan this activity at a time of year when there are strong meteor showers occurring. Arrange with other schools locally or on the internet to do similar experiments and compare results.

The Most Intense Meteor Showers of the Year

Meteor Shower	Peak Date
Quadrantids	January 3
Perseids	August 12
Leonids	November 17
Geminids	December 14

MATERIALS NEEDED:

- Strong magnets (enough for all students or groups)
- Plastic bags large enough to wrap around magnets (enough for all magnets)
- Petri dishes or clear glass dish small enough to fit under microscope (enough for all students or groups)
- Index cards (enough for all dishes)

- Crayons or colored pencils (enough for all students or groups)
- Microscope
- Distilled water (about one litre/gallon) is optional. Tap water also works.

TO DO AND NOTICE:

After a rainstorm, students should go outside and locate the rain gutter spouts. On the ground directly under the spout, drag the magnet (enclosed in a plastic bag) carefully in a straight line along the ground, without tearing the plastic. Keep passing the magnet across the ground in one direction, i.e., from left to right only, or top to bottom only. Fill Petri dishes with distilled or tap water. Dip the plastic bag and magnet into the dish and gently remove the plastic into the dish. Slosh the plastic around until you feel anything that was on it has been rinsed into the Petri dish. Set aside.

Repeat step one, but move the magnet in the other direction, and collect the particles as in step 2.

With a crayon or pencil (it will not smudge or run with your wet hands), write on an index card the date and time when you were collecting. You might want to write your address as well to compare later with students across the school or world. Keep the index cards with the Petri dishes.

Leave the Petri dishes out on a windowsill until the water evaporates.

When the water is gone, put the Petri dish under a microscope. You should hopefully be seeing very tiny particles of meteoritic material. Observe these, count them, draw them, and record the information on the index cards. Repeat for each Petri dish. If samples were taken from several different locations, can anyone find any major differences in the sizes or number of micrometeorites found at these different locations?

Compare results with those of other local schools or those on the internet.

DISCUSSION:

How do the students feel about their ability to do research experiments with the success / failure of this one? How could they use this type of activity in a Science Fair project? Could students be able to make their own determination of when meteor showers were occurring by repeating this experiment throughout the year and recording the findings in a table? Why are you able to obtain these micrometeorite particles? Are any students feeling uneasy about the amount of material which is falling on top of their homes or school?

Adapted from **Eyes on the Sky, Feet on the Ground: Hands-on Astronomy Activities for Kids** by Smithsonian Institution

Activity #4 (CREATING CRATERS)

OBJECTIVE:

To learn how craters are formed with many different shapes, sizes and physical characteristics, and what factors control these visible features.

IN THE COMET IMPACT STORY:

A large, fictional comet is headed towards Earth. If not diverted or stopped, it may collide with our planet, creating a global catastrophe. At the point of impact, the collision would create an immense crater. Not only those people living in the strike zone would be threatened but, since material would be blasted out from the crater in all directions, people in the general vicinity and around the world could be injured or killed.

BACKGROUND:

Impact craters exist around our world. Over 156 dozen have been identified, with 51 of these found in North America. They also exist on other worlds as well. A glance at the moon through a small telescope or binoculars will show that its surface is peppered with craters. Most were created billions of years ago when our solar system was populated with many large pieces of debris left over from its birth. Earth seems not to have as many craters as the moon because wind, rain, volcanism, plate tectonics, and other atmospheric and geological processes have worn the oldest craters away over time.



TEACHER PREP NOTES:

This activity is aimed primarily at junior high or high school science students. Impact craters can be demonstrated with younger or less advanced students using mud instead of sand and ball bearings. Add water to dirt until the mud has the consistency of thick cake batter, or until it slowly drips off a spoon. Then, drop spoonfuls of mud onto a pie pan full of the thick mud to create craters. For more details on this variation, see **Ranger Rick's Naturescope: Astronomy Adventures**, by the National Wildlife Federation (1989), or **Astronomy for Every Kid**, by Janice Van Cleave (John Wiley and Sons Publishers, 1991).

MATERIALS NEEDED:

- A tray or strong box at least 61 cm (two feet) on a side and about 10 cm (four inches) deep
- A large supply of extremely fine sand, flour or corn starch, enough to fill tray or box above
- Four identical marbles or small ball bearings 6-8 mm (1/4 inch) across
- Three solid spheres about 2.5 cm (one inch) across and made of different materials; e.g., glass, plastic, steel
- Meter/yard stick and 30 cm (12 inch) ruler
- Toy slingshot (optional)
- Kitchen tea strainer
- Dark color of dry tempera paint (powder)
- Safety glasses or goggles
- Large pack of marbles of assorted sizes
- One steel ball bearing about 2cm (1/2 inch) in diameter
- Safety goggles (if using slingshot)

TO DO AND NOTICE:

Pour the sand into the tray to a depth of at least 8cm (3 inches), smooth it with the edge of the yardstick, and divide the surface into two equal areas.

IMPORTANCE OF IMPACTORS' MASS ON CRATERS:

1. From a height of about 2 meters (6 feet), drop each of the three different large spheres into one area of the sand. Each represents a meteorite of different mass. Carefully measure the diameter of the craters formed by each impact without disturbing the sand. Students should then be asked to answer the following questions [answers in brackets]:
 - Which sphere created the largest crater? [The most massive.]
 - What is the only difference in the way each crater was made? [The mass was varied.]
 - What can you say about the importance of the mass of a meteorite in making a crater? [Crater diameter increases with increasing mass.]



IMPORTANCE OF IMPACTORS' VELOCITY ON CRATERS

- From different heights, 0.3 to 2 meters (one to six feet), drop the four identical marbles into the second area of sand. Each marble represents a meteorite of the same mass. If you wish, launch the third and fourth marbles from an extended slingshot, .2 and .4 meters (one to two feet) above the sand, aimed directly down into the sand.

Caution: The slingshot is a potentially hazardous device. Use extreme caution when using it for this activity. At no time should it be aimed horizontally. Safety goggles should be worn. Without disturbing the sand, carefully measure the crater diameters. Students should then be asked the following questions [answers in brackets]:

- What did dropping marbles from different heights (and propelling two marbles, if the slingshot was used) accomplish? [This varies the velocity at impact.]
- Did you measure any difference in the diameters of the craters? [Yes, as velocity increases, so does crater diameter.]
- Besides diameter, do you notice any other difference in appearance among the craters? [No, all look qualitatively similar.]
- Which do you think is more important in creating larger craters, more mass or more velocity? [Velocity increases have more effect on crater diameter than mass increases. Velocity has a greater contribution to the energy of impact.]



THE STRUCTURE OF A CRATER

- Remove all marbles and spheres from the sand and smooth the surface well. Again, divide the tray into two areas. This time, sprinkle a fine layer of dry tempera color over the sand using the tea strainer. The layer of colored powder should cover the surface just enough to conceal the sand. **Caution:** Wear safety goggles and be sure that no glass or breakable materials are nearby. Use the slingshot to shoot the 12mm ball bearing vertically into the sand. Do not disturb the resulting crater in the following steps. Draw two pictures of the crater, one looking down from above (map view), and one as seen from ground level (side view). Label the drawings with the words **rim**, **ejecta** and **impact crater**. Notice the sharp details of the crater. Students should then be asked the following questions [answers in brackets]:

- Where do you find the thickest ejecta? [On the crater's rim.]
- What do you think caused the crater rim to form? [Sand blown out by the impact was deposited on the rim. The colored powder represents the most recent sediment deposited on a planet's surface. Any material beneath the top layer must have been deposited at an earlier time, making it older.] If you were examining a crater on the Moon, where would you probably find the oldest material? [Near the rim.]
- Why do you think so? [Because the deepest material ejected lands closest to the crater, i.e., on the rim.]

CRATERING ON THE MOON

- In the second area, create another crater using the half-inch ball bearing. Drop each marble from an arbitrary height into the sand. Be careful to drop the marbles near, but not directly on top of, the crater formed by the slingshot method. Watch the process very carefully as you do it. Students should then be asked the following questions [answers in brackets]:
 - How does the appearance of the original crater change as you continue to bombard the area? [It loses its crispness.] Look at a photograph of craters on the Moon. Do all the craters have the same fresh, sharp, new appearance? Describe the various appearances. [No. Smooth rims to sharp rims, bowl-shaped to elliptical, etc.]
 - What do you think has happened in this area? [Long-term bombardment.]
 - What do you think is an important source of erosion on the Moon? [Impact cratering.]
 - What does the appearance of a crater tell you about its age? [The younger the crater, the crisper the features; the older, the more subdued.]

Adapted from NASA workbook **Activities in Planetary Geology**, and from Ronald Greeley of Arizona State University

Activity #5 COMET FEARS

OBJECTIVE:

To discuss how comets affect the mindset of people, and how history has portrayed them as evil stars that cause disastrous events on Earth.

IN THE COMET IMPACT STORY:

A large, fictional comet is on a path around our Sun, and its orbit might intersect that of Earth. Fictional scientists and leaders work to destroy it before it strikes the Earth, attempting to save the population of our planet. If such a body were really threatening to hit Earth, public reaction and debate on what to do would be quite strong.

BACKGROUND:

In ages past, and sometimes even today, those not familiar with comets became quite frightened at the appearance of one. If you've ever seen a comet, you might wonder why people would be afraid of such a tiny white smudge in the night sky. However, ancients knew these were out of the ordinary and did not belong in the normal sky.

Some word origin experts have tracked the root of the word disaster to the words **bad** (dis) and **star** (aster), and some think this may have originated with ancient comets. Throughout history, many disastrous events seem to have occurred around the time of bright comets. For example:

- A comet in 44 BC followed the assassination of Julius Caesar.
- In 837, King Louis I died of fear resulting from the appearance of a comet.
- In 1493, a month of rain, thunder, lightning, and withering crops was blamed on a comet.
- The plague of 1665 struck after a comet appeared in 1664.
- The 1665 appearance of a comet preceded the great fire of London in 1666.
- Good wine in 1811 was credited to the appearance of a great comet of that year.
- The 1910 appearance of Halley's Comet caused some individuals to commit suicide.

TEACHER PREP NOTES:



Encounter Between the Earth and a Comet of 13 June 1857, from "Actualite's Astrologiques."

You can read the background section aloud in class, or print it out for students to read on their own. Small student teams could each take a different aspect of researching Halley's 1910 encounter and then present their findings to the

class. Student teams can be evaluated on their written and oral presentations. If your local newspaper was publishing in 1910, research issues during the month of May for articles on Comet Halley. Check your local library or contact the person responsible for the newspaper's archives. A nearby city's paper, a large city paper like the Globe and Mail, or New York Times, could be used if your town didn't have a local paper at that time. This activity can be used with students from grades 5-8.

DISCUSSION:

Questions to Ask Yourself

Have students visit a library or historical museum and read newspaper or book accounts of the 1910 visit of Halley's Comet.

1. What were the reactions of people around the world when they heard that Earth would pass through Comet Halley's tail of deadly cyanogen gas on the night of May 18? What precautions did people take? Were comet pills effective? How did cartoonists, advertisers and artists portray the comet? Where did many people around the world go on the night of May 18? Do you think people's fears were justified?
2. Are the disastrous events that occurred around the time of comets really brought on by comets, or were they just coincidence?
3. How would people react today if they knew a comet was to impact on Earth? Would it be similar or different? What kinds of stories, cartoons and predictions might come about today?

Adapted from **Outer Orbit**, Army Times Publishing Co, By Barbara Sprungman

GLOSSARY

Asteroid:

A small, rocky object revolving around the sun, sometimes called a minor planet or planetoid.

Asteroid Belt:

The region of space between Mars and Jupiter where the great majority of asteroids are found.

Bolide:

A very bright meteor that fragments or explodes. Sounds of the explosion can be heard if the observer is close enough.

Coma (Head) of a comet:

The diffuse, luminous cloud of dust and gas that develops around a comet's nucleus as it nears the sun.

Crater:

A bowl-shaped depression on the surface of a planet or moon, often caused by a meteorite impact.

Ejecta:

Material ejected by an impact which produces a crater.

Fireball:

A meteor which is brighter than any planet or star.

Megaton:

The force of an explosion equal to a million tons of TNT.

Meteor:

Popularly called a "shooting star" or a "falling star", a meteor is actually an object usually ranging from the size of a dust particle to a rock, that enters Earth's atmosphere and is heated by the friction of air resistance. Most meteors originate from comets.

Meteorite:

A meteor that is large enough to survive its fall through the atmosphere and hit the ground.

Meteoroid:

A meter-sized boulder that has probably escaped from the asteroid belt and thus roams the solar system.

Meteor Shower:

A shower of meteors occurs when Earth's orbit intersects the orbit of a meteor stream.

Meteor Storm:

This is a rare event that occurs when Earth encounters closely grouped meteors within a meteor stream. Such events can see meteor rates exceeding 1000 per minute.

Near-Earth Object (NEO):

An object whose orbit brings it relatively close to Earth. Also known as Near-Earth Asteroids (NEA).

Nucleus:

The actual solid body of a comet: the dirty snowball within the coma. The glowing, star-like nucleus always includes a cloud of dust and gas around the true nucleus. Most comets have a nucleus that measures only a few miles across.

Period:

The amount of time, usually given in years, that a body takes to orbit the sun.

Radiant:

The point from which a meteor or shower appears to originate in the sky.

Sublimate:

Changing directly from solid ice to a gas. This is what carbon dioxide (dry ice) does at room temperature, and what the water and ice in comets does when heated by the sun under the conditions of interplanetary space.

Tail:

When a comet comes close to the Sun, the dust and gas surrounding it is pushed away from the comet's head. This extension from the coma is called the tail. Tails typically point away from the Sun, and can be straight, curved, or fan-shaped. A comet can have more than one tail.



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Dr. Jamieson steps onto the surface of Kirsch-Kennedy

RESOURCES

PRINTED MEDIA

Related Books:

Chapman, Robert D., and Brandt, John C., **The Comet Book**, Jones and Bartlett Publishers, Inc., Boston, 1984, ISBN: 0-86720-029-4

Flaste, Richard; Noble, Holcomb; Sullivan, Walter; Wilford, John Noble; **The New York Times Guide to the Return of Halley's Comet**, Times Books, New York, 1985, ISBN: 0-8129-1148-2

Levy, David H., **The Quest for Comets**, Avon Books, New York, 1994, ISBN: 0-380-72526-6

Yeomans, Donald K., **Comets: A Chronological History of Observation, Science, Myth, and Folklore**, John Wiley & Sons, Inc., New York, 1991, ISBN: 0-471-61011-9

Related Magazine Articles:

Bortle, John E., "Great Comets in History," *Sky & Telescope*, January 1997, pp 44-50

Gould, S., "An Asteroid to Die For" *Discover*, Oct. 1989, p. 60
Mercury (Journal of the Astronomical Society of the Pacific), Special Comet Issue, Nov/Dec., 1996

Morrison, D. and Chapman, C., "Target Earth: It Will Happen" *Sky and Telescope*, Mar. 1990, p. 261

Sinnott, R., "An Asteroid Whizzes Past the Earth", *Sky and Telescope*, July 1989, p. 30.

Weissman, P., "Are Periodic Bombardments Real?", *Sky and Telescope*, Mar. 1990, p. 266

ELECTRONIC MEDIA:

Websites

Impacts

Asteroid / Comet Impact Hazards:
<http://impact.arc.nasa.gov/index.html>

Solar System Collisions Calculator:
<http://janus.astro.umd.edu/astro/impact.html>

Comet Shoemaker-Levy 9 impact with Jupiter:
<http://www.jpl.nasa.gov/sl9/>

Spacewatch Project:
<http://xlr8.lpl.arizona.edu/spacewatch/>

Comets & Meteors

Meteor Showers:
<http://medicine.wustl.edu/~kronkg/index.html>

Related Space Missions

Stardust Sample Return Mission:
<http://stardust.jpl.nasa.gov/>

Near-Earth Asteroid Rendezvous:
<http://hurlbut.jhuapl.edu/NEAR/>

Astronomy Education

Astronomy Course:
<http://www.cnde.iastate.edu/staff/jtroeger/astromy.html>

Education Projects:
<http://www.aspsky.org/html/naep/naep.html>

Astronomy Activities:
http://hea-www.harvard.edu/ECT/the_book/index.html

General Space Info

NASA Spacelink:
<http://spacelink.nasa.gov>

The Nine Planets:
<http://seds.lpl.arizona.edu/billa/tnp/>

Views of the Solar System:
<http://www.hawastsoc.org/solar/eng/homepage.htm>

Related Motion Pictures

Deep Impact motion picture:
<http://www.deepimpactmovie.com/>



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This educator's guide is appropriate for grades 2 and above. It is a valuable resource on its own for classroom study of comets.

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