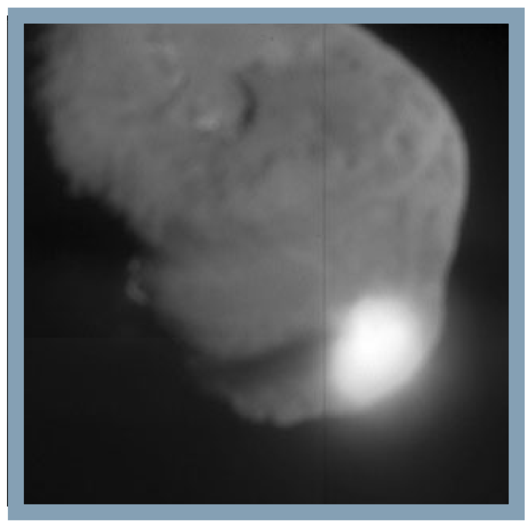
ACTIVITIES

Feel the Impact

Introduction to Comets Teacher Guide



Science Background Information

The background section in this *Feel the Impact* Teacher Guide contains more detailed information on the same topics found in the student texts. We deliberately included only very basic information regarding comets in the accompanying student texts so that they could be useful and effective in different types of classroom settings. Feel free to include any of the background material below in your introduction to these materials, in your questioning, or in feedback sessions, depending upon the background of your students.

The topics in this *Feel the Impact* Introduction to Comets section include:

- Comets—What are they?
- What kind of structure do comets have?
- Why are comets so important to understanding the origin of the Solar System?
- How do comets evolve?
- Why was Comet Tempel 1 chosen for the Deep Impact mission?
- What is scientific modeling?

Comets – What are they?

Comets are remnants from the cold, outer regions of the solar nebula, the gaseous cloud from which our Solar System is believed to have formed. Comets may have within them the last pristine clues to the beginning of the formation of the Solar System.

Comets contain ice and dust; they are believed to be a cold mixture of frozen water, dry ice, and other sandy/rocky materials left over from the early formation of our Solar System 4.5 billion years ago. They contain a large percentage of ice because the regions in which they formed are cold. As gas and dust swirled around the Sun, molecules came together forming compounds. Water and carbon dioxide are two volatile ices. The minerals in the dust and refractory compounds include olivine and molecules that contain carbon, hydrogen, oxygen and nitrogen. So, rather than being a solid ice cube, comets are made of many smaller ice crystals with rocky and organic (carbon-containing) molecules mixed in.

Comets formed in the region of the Solar System beyond the planets, called the Trans-Neptune region. Some of these planetessimals were perturbed by the planets as well as by passing stars. The population of comets that have been flung out beyond the planets to huge distances (100.000 of Astronomical Units) is called the Oort Cloud. Other comets were perturbed into planet-crossing orbits and became Jupiter family comets.

Comets make up a significant portion of the “small bodies” in the Solar System and are found in several regions. Many orbit the sun in a region called the Kuiper belt, a disc shaped region starting beyond the orbit of Neptune and extending out for several hundred earth-orbits. Some comets orbit the sun inside the Kuiper belt much like planets. Whereas the orbits of most planets line up primarily on one plane like rings on a target (ecliptic), Some comets are found in the Oort cloud, far beyond the edge of the Solar System. This spherical shell of comets, located ten thousand times farther from the sun than the earth, may contain a trillion icy comets. Some venture so close to the sun that they fall into it.

Most comets orbit in elliptical paths. These orbits bring them close to the sun and take them far away. With each approach to the sun some of the comet’s dust and **volatile** material leaves the surface and goes off into space; as a result, comets **evolve**. Some comets do not have elliptical orbits, so there is a theoretical possibility that they may pass close to the sun once and never return.

Comets range in size from less than one km in diameter to as large as three hundred km. Tempel 1, the target of the Deep Impact mission, is about five km by seven km. Comets rotate on an axis. Tempel 1 takes almost 41 hours for one rotation.

Comets that orbit the Sun every twenty years or less are called short- period comets. Long-period comets orbit the Sun every two hundred years or longer. Those comets with orbits in between are called Halley-type comets. The Kuiper Belt comets replenish the population of short period comets.

Some comets may have collided with forming planets, thus adding to their water and rock inventory. Other comets escaped to establish their own orbit around the sun. We know a comet could impact Earth and that it is important to understand the nature of comets so we can design better methods to protect ourselves from them should one be on a collision path with Earth. Comets are both a potential threat and a potential resource. Comets have hit Earth in the past.

At some point in the future we will need to know how to draw from their resources and also to protect ourselves against their impact.

Before the Deep Impact mission, scientists expected to see only materials that form under cold temperatures representing the great distance from the hot sun, where the comets formed. They were surprised that dust excavated from beneath Tempel 1's surface contained materials that form at temperatures >1200 K. For more information see Hhttp://deepimpact.umd.edu/mission/update-200608.html
We will explore these findings more fully in Part 4 of these *Feel the Impact* materials.

For more details about comets, see
http://deepimpact.jpl.nasa.gov/educ/ExploringComets04.html
http://deepimpact.jpl.nasa.gov/science/objectives-rbrown.html

What kind of structure do comets have?

A comet that is far away from the sun is a solid body a few kilometers in diameter called the nucleus. Roughly half the mass of this solid center structure is made of ices of volatile components, including water, carbon dioxide and carbon monoxide. The rest is rocky debris a factor in making the surface dark. Some of the surface is blacker than charcoal. Another factor contributing to the dark color is that most of the light is absorbed and scattered just below the surface in its many pore spaces.

As the comet approaches the sun, it becomes a dynamic place. Solar heat warms the surface of the nucleus. The ices sublime; that is, they change from a solid to a gas without going through the liquid phase. As the gas leaves the comet's surface, it carries dust along with it. This "cloud" moves out in all directions, forming a coma, an atmosphere around the nucleus. Because the coma is formed from outgassing from localized regions, its distribution around the nucleus is not uniform. The shape of the coma is also affected by the rotation of the nucleus; this gives it a sort of pinwheel appearance.

Tails become visible when the sunlight causes the ion to fluoresce, giving off light. The ion tail often appears blue in color. The force from the radiating sun, called the solar wind, pushes the ionized gas molecules directly away from the sun. These glowing ions form a straight tail, called an ion tail, emitting blue light as they move away from the nucleus. Dust particles dragged from the nucleus by the subliming gas, enter their own orbit and have a curved trajectory relative to the straight ion tails. A third tail made up of atoms of sodium can also be seen in some comets.

Comets don't have continents or molten rock, but there is evidence of flow of some kind on Tempel 1, as well as multiple layers that may have piled up over time. The coma is the only atmosphere, so there is no water driven weathering as on Earth. But material looks like it has been stripped off the surface. Comets lose material with each passage close to the sun, so they experience erosion in their own sense.

For more details about comets, see
http://deepimpact.umd.edu/mission/update-200602.html p.5
http://reference.allrefer.com/encyclopedia/C/comet-structure-of-comets.html
http://www.weather.gov.hk/gts/event/event-comet_e.htm
http://deepimpact.umd.edu/amateur/beginner/sec1.shtml

Why are comets so important to understanding the origin of the Solar System?

Comets are the primitive, leftover building blocks of the Solar System's formation process. They may contain the last pristine clues to the chemical mixture from which the planets, including Earth, had formed. As gas and dust swirled around the condensed Sun, molecules came together forming compounds. Water and carbon dioxide are two examples of volatiles/ices while olivine (a magnesium iron silicate) and C-H-O-N molecules are dust or refractory compounds. Gravity brings the molecules together in clumps that eventually grow to larger and larger cometesimals

Comets have spent most of their lives frozen in the Oort cloud and/or the Kuiper belt. Astronomers think that the material that formed comets originally lies frozen just below a relatively thin crust.

About forty thousand tons of dust particles from comets and asteroids still fall to Earth every year.

For more details about the importance of comets, see
http://deepimpact.jpl.nasa.gov/science/objectives-rbrown.html
http://deepimpact.jpl.nasa.gov/educ/ExploringComets04.html

How do Comets Evolve?

The ices, dust and rocky debris that originally made up comets have not changed over the billions of years since they were formed. About half the mass of comets is made of ices of volatile components. The other half of a comet's mass is made of rock-like dust bound together by the ices.

Volatiles are substances that change into a vapor at a relatively low temperature. These volatiles are in the form of solid ices when they are at temperatures below 200 K. Examples include solid water, the ice which we are very familiar with, and solid carbon dioxide, also known as "dry" ice. Other ices found in comets include ammonia (NH_3) compounds.

When energy from the Sun warms the region of the comet in which volatiles are found, it "bakes" the ices out of the material near the surface. Sublimation is an active process on comets, leaving the surface with a dry, powdery consistency.

Solids from the comet's interior can be swept out by the sublimating ices. Some of these dust grains have enough energy to move into the coma where they become grains moving in their own orbit, with a velocity smaller than that of the comet. Other grains that are moving more slowly may be swept up by the comet again and some may just not leave the surface.

Impact craters are important from an evolutionary standpoint. Collision with other Solar System bodies may cause craters and debris from these collisions can also "powder the face" of comets. These craters can be modified by later impacts and the evolutionary processes of heating and cooling. Scientists are not sure of the role of impacts in forming the surface of a comet.

Although impact craters are still forming, there was an interval in Solar System history between around 4.1 and 3.8 billion years ago, when collisions between interplanetary bodies were relatively frequent. Craters are present on moons, planets and even asteroids. Some of them have been modified by erosion, later impacts, lava flows or tectonic activity for millions of years afterwards.

For more information on comet evolution, see
http://deepimpact.umd.edu/mission/update-200512.html
See also the information on cratering
in Part 2 of these *Feel the Impact* materials

Why was Tempel 1 chosen for the Deep Impact mission?

Ernst Tempel discovered comet Tempel 1 in 1867. The comet has made many passages through the inner Solar System, and it orbits the Sun every 5.5 years at a perihelion distance of approximately 1.5 AUs. Tempel 1's orbit lies between the orbits of Mars and Jupiter. This makes Tempel 1 a good target to study evolutionary change in the mantle, or upper crust.

Determining the size and shape of Tempel 1's nucleus has been difficult because we could not see it. Based on a variety of observations before the Deep Impact mission was undertaken, the nucleus was thought to be about 6 km in diameter and elongated, rather than spherical.

Scientists wanted to know whether comets give up all of their supply of gas and dust to space. Or do they seal the gas and dust inside their crusts?

Scientists wanted to study the structure of a comet's interior. How is it different from its surface? The Deep Impact mission gave us some answers to these questions. We will consider them in Part 4 of these materials.

For more details about Tempel 1, see
http://deepimpact.umd.edu/mission/update-20512.html
http://deepimpact.jpl.nasa.gov/science/tempel1.html

There is composite image of Tempel 1 taken during the Deep Impact mission at:
Hhttp://deepimpact.umd.edu/gallery/T1_Composite_May.html
This image reveals the following surface features of Tempel 1's nucleus:

- two large, smooth regions;
- a 20 m high scarp partly borders them and defines the boundary of one flat area;
- a region of rough terrain marked by contrast variations on a small scale at the bottom of the image;
- some "circular features". Their boundaries are slightly darker than the surrounding material and, since they have a circular ridge, they may be filled in impact craters; and,
- a band of lesser brightness between the two flat areas. It is consists of constituting multiple exposed layers of material rising gradually toward the top of the comet as shown in this image.

In Procedure, Section 9 you will be guiding your students in the exploration of these features, using a tactile graphic based on the image in this URL.

What is scientific modeling?

Scientific modeling is a useful way to understand the world around us. Models are particularly useful in studying events or objects that are difficult to observe. The comet models we are working with are **physical models**. They are smaller than the real Tempel 1, but we can use our physical senses to observe them.

Scientists also work with models that are **graphic descriptions**, like the electron-cloud models of atoms or **mathematical formulas**, like those used to calculate the area of a rectangle or the volume of a cube.

Models always have limitations. They don't always show things correctly because they are not the object or the happening itself. Sometimes we have to design more than one model to show everything we know about the object or happening.

Models allow us to test our theories about an object or a happening. They also allow us to change the model as new observations are made.

The models that your students are using now are based on observations from Tempel 1 made before the comet struck the impactor. You and your students may be altering these models to include the observations of the comet during and after the mission.

For more details about models, see
http://genesismission.jpl.nasa.gov/educate/scimodule/SSWPrOptPDFs/2HowHotIsIt/ModelsInScience-ST-PO.pdf
http://deepimpact.umd.edu/designing_craters/7appendices/appendix_c_crater_research.pdf
http://deepimpact.umd.edu/educ/CometStick02.html

National Science Education Standards Addressed
Grades 5-8

Earth and Space Science
- The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects such as asteroids and comets.
- Most objects in the Solar System are in regular and predictable motion.

History and Nature of Science
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

Grades 9-12

Earth and Space Science
- The sun, the earth, and the rest of the Solar System formed from a nebular cloud of dust and gas 4.6 billion years ago.

View a full text of the National Science Education Standards
Hhttp://newton.nap.edu/html/nses/6a.htmlH

Student Objectives for Introduction to Comets

- Explain the significance of comets in our Solar System.
- Compare and contrast the orbits of comets and planets in the Solar System.
- Describe the general structure of comets.
- Describe the surface features of Comet Tempel 1.

Materials

Student Texts for Introduction to Comets

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

- Introduction to Comets Glossary*
- Comets—What are they?
- What kind of structure do comets have?
- Why are comets so important to understanding the origin of the Solar System?
- How do comets evolve?
- Why was Tempel1 chosen for the Deep Impact mission?

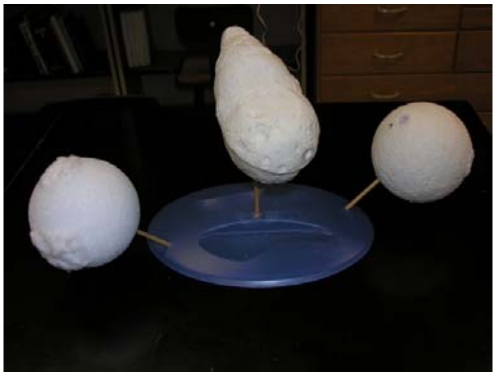
* The Introduction to Comets Glossary is a separate file so that students can read the definitions of terms that are probably new to them before reading the other student texts and refer to it while reading the texts.

Modeling materials list for Introduction to Comets

Make copies of Tactile Cards 1-4 templates in either low vision or Braille version for each of your students. Click here to access templates.

Optional modeling materials

- Three or more objects of different shapes and textures for students to evaluate as models for a comet nucleus
- Dry ice and shallow container
- Recipe for making "Oobleck"
  Measure 1 1/2 cups of cornstarch and put in a pie pan or container; then gradually add approximately 1/2 cup of water to the cornstarch. Stir well (this will take some time). Add small amounts of more water or cornstarch until you get a mixture that "tears" when you quickly scrape your finger through it and then "flows" back together again.
- Modeling clay —shape one piece as a flat, smooth surface a depression and another as a smooth plateau with an escarpment; see Procedure, Section 9 for illustrations.
- Can of baby powder or sample of flour



To access the instructions for making a Styrofoam and Plaster of Paris model of Comet Tempel 1, click model.

Materials needed for optional activities, Ice Cream Comets and Comet on a Stick, are found in the files describing these activities. Click on the titles to access the complete activities.

Procedure for Implementing Introduction to Comets Materials

Introduction

1. Introduce the Deep Impact Mission using some of the following information
Deep Impact, a NASA Discovery Mission, is the first space mission to probe beneath the surface of a comet and reveal the secrets of its interior. On July 4, 2005, the Deep Impact spacecraft arrived at Comet Tempel 1 to impact it with a 370-kg (~820-lbs) mass. The flyby spacecraft was nearly as large as a Volkswagen Beetle automobile and the impactor spacecraft had about the same dimensions as a typical living room coffee table.

   Comet Tempel 1 approached the impactor spacecraft at a *relative* velocity of 23,000 mph. On impact, the crater produced was expected to range in size from that of a house to that of a football stadium, and two to fourteen stories deep. The effects of the collision with the comet were observed from both large and small telescopes in certain locations on Earth and in some cases with smaller telescopes. We do not know the actual size of the crater that was formed since the ice and dust debris ejected from the crater obscured it from the cameras. The dust never cleared during the flyby time, as had been expected based on laboratory experiments. The data, both from images and spectroscopy, is being analyzed and combined with that of other NASA and international comet missions. It is hoped that the results from these missions will lead to a better understanding of both the Solar System's formation and implications of comets colliding with Earth.

2. Start the inquiry with questions similar to the following. Accept student answers. You may wish to keep a written record of student responses so that as you introduce information that is important to correcting any of their misconceptions, you can refer to their ideas.

   What do you know about comets?

   What do comets have in common with the solar planets in the Solar System?

   What are some of the major differences between comets and the planets in the Solar System?

3. When students have exhausted their responses, distribute copies of the "Introduction to Comets Glossary" *and the* Student Text, "Comets—What are they?" in the format appropriate for each student, use the audio tape of the student text, or give them some information about comets from the background information on the topic above.

   Distribute Tactile Cards 1 and 2 so that however students receive the background, they can observe the
   a) location of the Kuiper belt in the Solar System (50 AUs from Earth); and,
   b) difference in the shape of comet and planetary orbits.

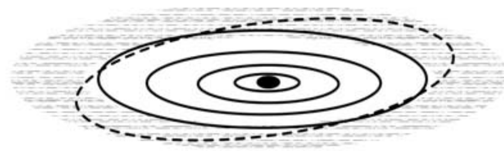
> An optional approach would be to have students "observe by touch" three or more objects of different shapes and textures. Ask them which of the objects might be the best model of a comet and give reasons for their choice.

> During pilot testing students needed some clarification of the term "nebula". The analogy of being able to detect the odor of a spray deodorant or perfume when walking into a room where it had been sprayed helped clarify the concept of a nebula. The particles are so small that you might not be able to feel them but their presence cam be detectable using other senses.

> How large is an Astronomical Unit? One AU is equal to 30,000 trips across the United States.

Give students time to read through the glossary and the first part of Student Text, “Comets—What are they?”. If you wish to read the observation instructions for your students, use the following text as students observe the Tactile Card 1 graphic. Remember that this is only part of the information found in the student text.

Tactile Card 1. The location of the Kuiper Belt in the Solar System



Use Tactile Card 1 to observe the location of the Kuiper belt in the outer Solar System.

Find the card number, either in print or in Braille, in the upper left corner. From the card number move your left pointer finger to the right. Find the open circle starting point in the middle of the top of the card.

Place another finger of your left hand on the edge of card to help your pointer finger travel straight down from the starting dot.

Move your fingers down until your pointer finger finds the solid oval in the middle of the image.

This oval represents not only the sun but also the inner Solar System including the planets Mercury, Venus, Earth, and Mars.

Moving out in any direction from this solid oval you will find some concentric solid lines.

The first of these lines represents the oval orbit of Solar System’s largest planet, Jupiter. Move your finger around the orbit of Jupiter.

Now move your finger outward to the next solid oval line. It represents the orbit of the ringed planet Saturn.

Continue moving outward to the orbit of Uranus, the next planet.

Move your finger around Uranus’ complete orbit. Uranus was discovered in seventeen hundred eighty one.

It’s orbit is so large that it takes Uranus eighty-four Earth years to orbit the sun.

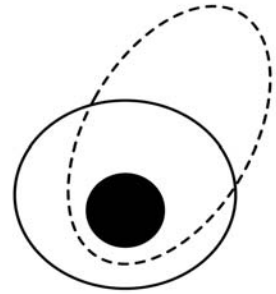
The outermost solid line in our Solar System is the orbit of Neptune. The Voyager Two flew by Neptune in August of nineteen eighty-nine.

As you move your finger around Neptune’s orbit, try to locate a dashed line. Follow this new orbit. This dashed line represents the orbit of the dwarf planet Pluto.

Observe the textured area that surrounds the orbit of Pluto. It represents the Kuiper belt.

Give students time to read through the second part of Student Text, “Comets—What are they?”
If you wish to read the observation instructions for your students, use the following text as students observe the Tactile Card 2 graphic. Remember that this is only part of the information found in the student text.

Tactile Card 2. Orbits of planets and comets.



> Circles and Ellipses
> To help students understand the difference in orbit shapes, have them feel the shape of a circular rubber band, which can then be stretched to form an ellipse.

> Comets orbit around the Sun as do the planets. Use tactile card 2 to follow this description of comet orbits.
>
> Find the card number, either in print or in Braille, in the upper left corner. From the card number move your left pointer finger to the right. Find the open circle starting point in the middle of the top of the card.
>
> Place another finger of your left hand on the edge of the card to help your pointer finger travel straight down from the starting dot.
>
> Move your fingers down until your pointer finger finds the large filled circle in the middle of the graphic. This represents the Sun.
>
> Comet orbits are elliptical. Move your finger to the dashed line to right of the Sun. Track that dashed line back to and around the Sun to feel the elliptical shape of the comet’s orbit.
>
> Now move your finger past the dashed line to the solid line. Track that line to feel the shape of Earth’s orbit. Earth is one of the solar planets.
>
> How is the shape of Earth’s orbit different from the shape of a comet’s orbit?
>
> If you did not feel the difference, try again.

4. Continue the discussion of planet and comic orbits by asking,
   “*How is the shape of Earth’s orbit different from the shape of a comet’s orbit?* “

   [Accept student answers. Make sure they include: the Earth stays about the same distance away from the Sun as it moves around the Sun; whereas a comet’s orbit brings it close to the sun and takes it far away.]

> To illustrate the difference between rate of rotation and period of orbit, turn a student 360º in place saying that Comet Temple 1 rotates completely around every 40 hours. Now have the student walk around a desk or some other object that represents the Sun. Comet Tempel 1 goes around the Sun once every 5 1/2 years. Help the student turn as he/she moves around the Sun.

Ask: "*How is the shape of Earth's orbit similar to that of a comet?"*

[Accept student answers that may include that they both:
orbit the sun;
are elliptical orbits;
may on a similar plane (ecliptic); and,
are influenced by the sun's gravity.]

Ask: *If Tempel 1's period is five and a half years, would it be a short- or long- period comet?*

[Based on definitions in student text, Tempel 1 is a short-termed comet.]

Continue discussion of comets by asking:

"In our first student text, we read that comets are made of ices, dust and rocky debris. What does the term ices mean?"

[Wait for student answers. Since students have the most experience with water ice, you will probably need to spend a little time explaining the plural term, ices, can apply to other solid compounds such as solid carbon dioxide and solid ammonia.]

Explain that, here on Earth, ice melts when it is heated, but when a comet's nucleus is heated by the sun in space, water, carbon dioxide and ammonia ices do not melt. They sublime, that is, they change immediately into gases.

Ask: "What shape do you think comets have?

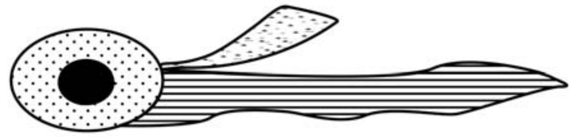
[If they have heard someone describe comets as dirty snowballs, they may think that comets have spherical nuclei. Although there may be some spherical comets, most of them have irregularly shaped nuclei. They may also think that comets are spherical because planets tend to be spherical.]

5. When students have exhausted their responses, distribute copies of the Student Text, "What kind of structure do comets have?", in the format most suitable to your students' visual capabilities. Have them read the in the appropriate format, use the audiotape of the student text, or give them some information about comets from the background information on the topic above.

Comparing a 3-D model and a tactile graphic of Comet Tempel 1

Give students time to read the Student Text, “What kind of structure do comets have?”
If you wish to read the observation instructions for your students, use the following text as students observe the Tactile Card 3 graphic. Remember that this is only part of the information found in the student text. Text between { } is not found in student text.

Tactile Card 3.
Cross section of a comet



Use tactile card 3 to follow the description of these comet parts.

This graphic represents a slice through the comet, like a slice of an apple cut through its equator. Just like the whole apple extends in all directions, every part of the comet that you feel is also coming out at you and going back into the paper,

Find the card number, either in print or in Braille, in the upper left corner. From the card number move your left pointer finger to the right until you find the open circle starting point

Place another finger of your left hand on the edge of the card to help your pointer finger travel straight down from the starting dot.

Move your fingers down until your pointer finger moves through a textured area and finds the large filled oval. This oval represents the nucleus of the comet.

The nucleus is the solid center structure made of ice, gas, and rocky debris. It has a dark, surface. {The nucleus is blacker than charcoal. We think that the reason for the dark color is that most of the light is absorbed and scattered just below the surface in its many porous spaces.}

{The nuclei of comets range in size from less than one kilometer in diameter to as large as three hundred kilometers.} Comet Tempel 1 is almost seven kilometers on it longest axis.

As a comet approaches the sun, solar heat warms the surface of the nucleus. The ices sublime; that is, they change from a solid to a gas without going through the liquid phase.

As the gas leave the comet’s surface, it carries dust along with it. This “cloud” moves out in all directions, forming a coma, an atmosphere around the nucleus.

Move your finger out in any direction from the solid oval to feel the textured region inside the boundary line that represents the coma.

Can you feel that the nucleus is embedded in the coma? Together the nucleus and the coma form the head of a comet.

The solid dust particles and the gases from the nucleus and coma fan out to form a curved dust tail and a straight ion gas tail.

Move your finger to the right of the coma to feel two regions filled with different textures.

The top curved region represents the dust tail. This tail always points away from the sun. So sometimes this tail can be in front of the comet as the comet heads away from the sun along its orbit.

(Continued on next page)

The bottom region represents the straight ion tail. The ion tail becomes visible when the sunlight causes the ions to fluoresce, giving off light. The ion tail often appears blue in color.

Energy from the sun ionizes some of the particles in the straight gas tail. These glowing ions emit a blue light as they move away from the energy source.

A third tail made up of atoms of sodium can also be seen in some comets.

Comet tails can vary in length from very short ones to those that extend millions of miles through space.

Comets don't have continents or molten rock. But there is evidence of flow of some kind on Tempel One as well as multiple layers that may have piled up over time.

The coma is the only atmosphere, so there is no water driven weathering as on Earth.

After students have completed their observation of the comet structure, ask:
"*Why do you think that we were not sure what Tempel 1 looks like before the Deep Impact Mission?"*

[The coma hid the shape of the nucleus of Tempel 1.]

6. Distribute copies of these student texts in the format most suitable to your students' visual capabilities and give them time to read:
"Why are comets so important to understanding the origin of the Solar System?"

"How do comets evolve?"

During the feedback sessions, revisit the questions that you asked earlier, looking for more clarity and accuracy of student answers, indicating more understanding of comets, their origins, structure, and properties.

To model the way in which the solar wind causes the comet tail to form and trail behind the comet, use a sheet of paper or a hairdryer to blow one student's hair so that another may feel it streaming out behind. Have students note that the hair always blows away from the paper or dryer, just the way the comet tail is always away from the Sun.

You can also use a hair dryer to blow mylar strips attached to a paper or Styrofoam model of a comet as described in Comet on a Stick. See **Materials** section above.

Continue by saying: "*When we defined comets earlier, we said that they are 'remnants from the cold, outer regions of the solar nebula.'"*
Ask: "*What was the solar nebula?"*

[A rotating cloud of gas and dust that began to collapse about 5 billion years ago to form the solar system.]

Ask: "*How do you think comets could tell us what kinds of material were in the solar nebula"?*

[They were formed from the solar nebula.]

Making an Ice Cream Comet is a multi-sensory way for students to learn that: comets are cold; that they have debris from the early Solar System; and we still aren't exactly sure what is in them or how they behave. Click on Ice Cream Comets in **Materials** section above.

Ask: “*Has the Earth changed since it was formed billions of years ago? Why do you think so?”*

[Yes, it has changed and it is still changing. Answers could include: volcanoes erupt, lithospheric plates move and cause earthquakes, mountains erode, etc.]

Ask: “*Do you think comets have changed since they were formed? If so, in what ways have they changed?”*

[Yes, volatiles sublime, evidence of craters.]

> If you want your students to experience sublimation as you describe what happens on the surface of a comet nucleus as it comes close to the Sun, try of the following:
> 1. Place a piece of dry ice in a shallow container. Have students hold up the palm of one hand on one side of the container as you blow on the CO_2 vapors toward their hands from the other. They can experience the change in temperature without risk.
> 2. Place the dry ice in water and let students hear the bubbling vapor and experience the cool CO_2 vapors by placing their hands at least six inches above the water.
> **Caution:** Do not blow the CO_2 vapors toward their faces and do not do this in a small, enclosed space.

7. Continue by saying: “*You have just read (or we have just talked) about impact craters being an important part of the evolution of planets. The Deep Impact mission was designed to create an impact crater that would bring the inside of comet Tempel 1 out in order to study what is in the interior of the comet.”*

   Ask: “*Why do you think Tempel 1 was selected as the target comet”?*

   [Accept student answers.]

   Distribute copies of the “Why was Tempel 1 chosen for the Deep Impact mission?” student text in the format most suitable to your students’ visual capabilities. Either read it together or give them time to read. Ask for answers to the question during feedback session.

   Ask: “*What new ideas do you have about the origin, composition, or physical parts of comets?”*

   [Accept student answers]

   Ask: “*How might we make a model of the comet nucleus?’*

   [Accept student ideas and, if possible, furnish the materials for construction of their models. If the materials are not available, ask students to explain what specific materials in their model ideas represent. Otherwise, consider making an Ice Cream Comet or a Comet on a Stick if you haven’t already done this. See links in the **Materials** section above.]

8. Continue by saying: *“We have thought about how the surface of a comet may change over time. We found that ices can vaporize leaving a powdery surface. We also know that ices and solids can be carried away in the coma and tails of comets and that other objects may form impact craters on a comet’s surface.*

   Let’s take a closer look at the surface of Tempel 1. ***Remember that the surface features that we are observing were not known until 2005, when the Deep Impact spacecraft took images of the comet.”***

9. Introduce a physical 3-D model of the comet and/or distribute copies of Tactile Card 4 in the appropriate format for each student. Use the procedure below to help students observe the surface features of Comet Tempel 1. There is no student text that describes Tactile Card 4. If you are using another model, adapt these instructions for use with that model.

Procedure for observing Tactile Card 4
Have students follow these instructions:

1) Find the card number, either in print or in Braille, in the upper left corner.
2) Move your right hand index finger just to the right of the number to find the open circle starting point.
3) Follow the line to the right of the starting point, as it goes down and around and back to the starting point. What you just followed is the outline of the shape of the nucleus of Tempel 1, the comet that was the target of Deep Impact. Try it again.

Tactile Card 4.
Surface features of Comet Tempel 1

Ask: *"Is the outline of Tempel 1 a circle?"*
[No, so Tempel 1 isn't spherical]

Ask: "*Does Tempel 1 have a shape that you are familiar with?"*
[Maybe, if the students have observed potatoes or other vegetables.]

Ask*: "How would YOU describe Tempel 1's shape?"*
[Accept student answers if they are plausible. During pilot testing students suggested the shape of a human heart or a potato.]

During pilot testing answers included:
- something hit it there
- it melted and then froze
- solar wind swept it smooth

4) Now let's examine the surface of the comet's nucleus. Find the starting point dot again. Move your finger to the right and down just inside the outline. Can you find a large smooth untextured region?

Continue by saying: "*When you feel something smooth, like a tabletop or a smooth rock, it usually means that it has been polished to make it smooth. What do you think might have made these smooth surfaces on Tempel 1?"*
[Accept reasonable student answers, such as sandblasting from dust grains or weathering from flowing water.]

Continue: "*But remember that Tempel 1 does not have water-driven weathering and that there is only a powder, no loose sand on the surface. So we need to look for another cause for these smooth surfaces."*

Have samples of "Oobleck" available for students to observe:
1) a smooth surface;
2) that this substance acts like a solid when you put pressure on the surface;
3) how a solid can flow by adding only body heat; pick up a handful and feel it "flowing" through your fingers; and
4) it forms a solid with a smooth surface again.

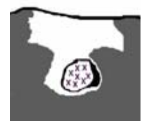
"We have evidence of flow of some kind. Let's observe a substance that might model what has happened on Tempel 1's surface." Let students observe the properties of Oobleck described in the box.

Ask: *"Do you think the surface of Tempel 1 could have been something like Oobleck at one time?"*

[Accept student answers and probe for understanding. During pilot testing, one student suggested that at one time there might have been internal pressure that caused heating and surface melting.]

5) Move your finger to the lower right of this smooth area. You should feel a larger irregular textured circular feature with a heavy line on the right side of it. The textured area indicates a large depression in the surface of Tempel 1. The heavy line indicates a change in elevation. In this case, we are moving from a lower elevation to a higher one.

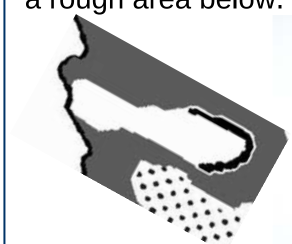
Shape a piece of modeling clay with a thumbprint in it so that students can experience the shape of the large depression shown in this section of Tactile Card 4.



6) There is another large smooth untextured region farther down on the comet's surface. It is shaped a little like the sole of a shoe. Can you feel it? This smooth untextured region is at a higher elevation than the textured surface adjacent to it. This means that it is raised above the textured parts of the surface of Tempel 1. You might think of it as being like a lump of clay with a smooth top surface sitting on your desktop.

7) To the right of and up from the smooth region, you will feel a curved heavy line and then a rough area. The heavy line again indicates a change in elevation. In this case, it an escarpment, a steep slope that is about 20 meters high that stretches from that smooth region to a rough area.

Shape some clay so students can observe the shoe-shaped plateau shown in Tactile Card 4 with an escarpment that descends to a rough area below.



8) Now move your finger up and to the right. Do you feel two circular areas?

Continue by saying: *"These **may** be the remains of two craters, made by objects that crashed into Tempel 1 many years ago."*

Summarize their observations by saying: *"The rugged surface of Tempel 1 reveals that it is an aging comet. You have observed elevated smooth areas and the lower rough areas—the traces of impact craters and a large depression. We can assume that these features were not present when the comet was formed."*

"Tempel 1 heats up and cools down rapidly as it rotates on its axis and as it moves closer to and away from the sun. This thermal cycling contributes to what we earlier called baking the ices out of the surface material leaving it with a powdery consistency."

Have a can of powder or some flour ready to sprinkle on their cards.

"If I put a little baby powder (or flour) on your tactile cards, you can feel that the model has a powdery surface."

"So we have seen some evidence of Tempel 1's evolution–the powdery surface due to the lack of volatiles near the surface, the different levels of terrain and the presence of impact craters."

At this time, it would be very appropriate to lead a discussion relating to limitations of the specific model(s) used with the students. Emphasize the following concepts in your discussion.

Scientific modeling is a useful way to understand the world around us. Models are particularly useful in studying events or objects that are difficult to observe. The comet models we are working with are physical models. They are smaller than the real Tempel One, but we can use our physical senses to observe them.

Models always have limitations. They are not the object or the happening itself so they don't always show things correctly. Sometimes we have to design more than one model to show everything we know about the object or happening.

Models allow us to test our theories about an object or a happening. They also allow us to change the model as new observations are made.

The models that you are using now are based on observations of Tempel One made before the Deep Impact mission.

1. What features of Tempel 1 could we observe in our model?
2. What features were difficult to show in our model?
3. What could we have done to the model to make it a more accurate representation of Tempel 1?
4. Can you think of a way to make a better model of Tempel 1 than what we have used?

Lead into ACE *Feel the Impact* Introduction to Cratering materials by saying:

"The model(s) of surface features that we have been studying were based on optical images taken by instruments on the Deep Impact "flyby" spacecraft. But just seeing the surface of an object does not tell us much about the interior of that object."

"If all you knew about an orange were how its surface feels and how it smells, we wouldn't know very much about the tasty fruit segments inside it, would we? Of course, all we have to do is remove the orange peel and those tasty segments are revealed."

"Deep Impact scientists wanted to know what is under the surface of Comet Tempel 1, but they could not just peel off the surface to observe the interior. Just sending a scientist up to the comet with a shovel to dig into the surface wasn't possible, either. So, how did they plan to observe the interior of the comet? They decided to form a crater in the comet's surface by inserting a moving "impactor" spacecraft <u>*into the comet's path for a planned collision*</u> *and sending another spacecraft with cameras and other instrumentation to observe the impact and send data back to them on Earth."*

"Why did they decide on this approach? Because we do know something about the results of impact craters on other solar bodies. In the next section of these materials we will investigate how craters are formed and what we can learn from them."