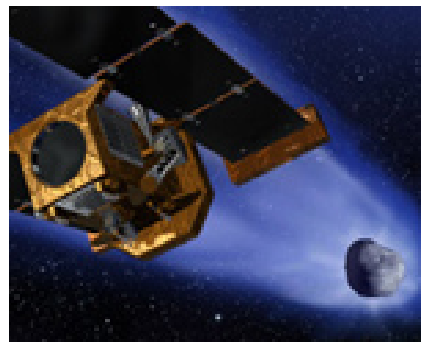
Crater Capture

EDUCATOR GUIDE

Created for the Stardust-NExT Mission
By Dr. Martin Horejsi

Just what does it take to capture clear images of a solar system body like a comet, which orbits the Sun at incredible speeds, with a camera from a spacecraft also orbiting at incredible speed?

In *Crater Capture*, students develop a basic model of comet Tempel 1's nucleus using a basketball. They draw a scale model of a crater on the surface, roll the "comet" along a section of its trajectory around the Sun, and try to image the crater on the moving target using a camera. This simulates mission scientists and engineers' challenge of imaging a particular location on a comet nucleus that is both rotating on its axis as well as cruising in orbit around the Sun.



Mission art: Deep Impact impactor spacecraft approaching comet Tempel 1. Image courtesy NASA

Crater Capture offers a guided inquiry activity to help students comprehend the many complex factors engineers have to keep in mind as they plan a flyby in a real mission context. Extensions offer students ideas for expanding their models through open inquiry exploration.

BACKGROUND

WHY STARDUST-NExT?

"When we see comets up in the sky they're really spectacular.
But unless you get close to a comet, you can't really figure out what's going on."
***Joe Veverka** , principal investigator of the Stardust-NExT mission*

On July 4, 2005, NASA's DEEP IMPACT science team witnessed a spectacular event in planetary science and the exploration of the solar system. The team released a copper impactor spacecraft into the path of a zooming comet, Tempel 1. They hoped to see beneath the surface of the comet and image the crater they would create. Instead, they got a far larger explosion than ever expected. The comet's nucleus appeared to be made of much finer, even fluffy material than had been supposed. What did it mean?

NASA got a chance to get some answers when it became apparent that another spacecraft – Stardust – hanging out in orbit after successfully completing its first mission, had enough fuel to make it back to Tempel 1. NASA's Discovery mission, Stardust-NExT, was born!

Stardust-NExT mission has been exciting for a lot of reasons. It will be the first opportunity NASA had to revisit a comet after a complete orbit around the Sun (called a perihelion passage). Scientists wanted to know: How has the comet changed in the 6 years after Deep Impact visited it? Could we obtain images of the region of the comet that Deep Impact did not see on its flyby? Might they be able to image the crater created by Deep Impact and get a glimpse into the interior of the comet?

WHY CRATER CAPTURE?

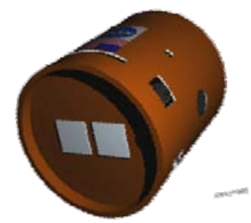
During a mission itself, let alone in planning, science and engineering teams model, model, model. Often those models are computer simulations. But mission teams also develop physical models to help them anticipate situations and plan accordingly.

Models simplify actual events by simulating some of the elements that effect the real object - but not all.

In *Crater Capture*, we will model the comet's rotation as it orbits by rolling a basketball. It is important to note that the distance the ball rolls **is not** comparable to a comet's rotation. A basketball rotates in response to the force of the roll and gravity, as well as friction between it and the ground. A comet nucleus rotates freely in space, in its own orbit around the Sun.

Designing a Spacecraft

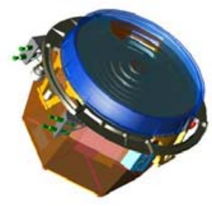
The scientific process is all about flexibility. When the *Deep Impact* mission's two spacecraft were being designed, one early plan for the impactor craft resembled a can of soda pop. But before they built anything, the engineers tested the design using computer models.



The Pop Can Model
Courtesy, NASA

Since we'd never been to Tempel 1, several bits of information had to be assumed, like the exact composition, density, and tensile strength of the comet. Scientists and engineers found that the soda pop can shape made a nice deep crater. Unfortunately, it was also super narrow, too narrow for good viewing.

Back to the drawing board!



The Winner!
The Muffin-Shaped Model
Courtesy, NASA

Ultimately, engineers settled on a design in which the impactor was shaped kind of like a giant muffin. That design created the ideal crater in the computer simulations. Big questions about whether scientists' assumptions were the right ones had to wait until *Deep Impact* reached comet Tempel 1.

The rolling ball's model **is** somewhat comparable to the multiplying effects of error over time or events. Each comet nucleus rotation may be slightly different in duration from the others, just as each roll of the basketball may cause it to travel slighty more or less than any other. Therefore the more rotations of the nucleus or the basketball, the less precisely we can predict the location of the crater.

Using various measurements, students will define the parameters of their imaging encounter. Then students will simulate the Stardust-NexT mission by predicting the relative locaton of the spacecraft and comet for a successful imaging (photographic) encounter, measured by images caputuring the comet nucleus as it rolls by.

Mission Goals

Stardust-NExT's encounter with Tempel 1 takes place over a short amount of time (70 seconds!) during which many pictures will be taken of the comet's nucleus. Mission scientists have to determine what science data has the highest priority:

- Comparing views from Deep Impact's flyby to see how the surface of the comet has changed since its previous passage close to the Sun
- Getting new brand-new views of Tempel 1
- Imaging the crater created by Deep Impact

The Activity

The value of models is that they can be used to simulate many different situations. In this activity we will explore the challenge of imaging the crater assuming a constant rotation. Each rotation of the basketball as it rolls simulates one rotation of the comet nucleus in space. For other ways to make the rotation more realistic, see the extensions section.

> **Note:**
> For our purposes, we are going to make imaging the crater key to our success. It is important to keep in mind that the science and engineering teams have many goals to balance.

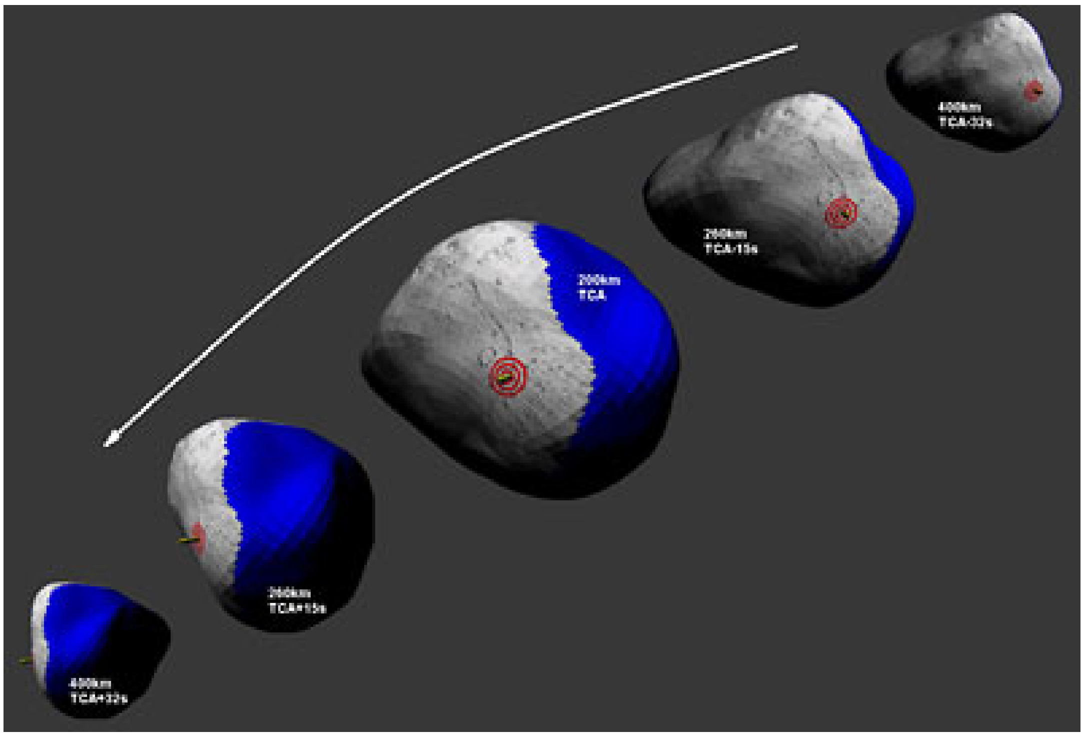
This activity is most easily done in groups of 5-6 students (or the entire class) split into "teams" for various aspects of the mission similar to the teams of the actual mission. Teams can include an orbit team that creates the model of the comet nucleus and rolls the comet, navigation team that models the encounter and positions the camera, an imaging team that phographs the comet as it rolls by, and processing team that presents and discusses the results of the mission. This approach allows each team to concentrate on the specific challenges of that element of the mission as well as practice honing their skills as a team.

Objectives:

Students will model a real engineering problem with application in current space science by:

- Making a scale model of a cratered comet
- Determining the position of the comet and the location of its crater at a given place in the comet's trajectory
- Testing the model of encounter with the spacecraft camera
- Evaluating their model in terms of accuracy

The image below, developed by Jet Propulsion Laboratory, shows the nucleus of comet Tempel 1 and the Deep Impact Crater as it rotates. The red target is the crater, the gray area shows the sections of Tempel 1 that were imaged by the Deep Impact Mission, and the blue shows areas of the comet nucleus that have never been imaged. To get a good image of the crater, the camera in Stardust-NExT would be operating when the time of closest approach (TCA) is zero (Stardust-NExT is neither approaching nor retreating from the camera). While we are using the scale in the image for our modeling, the image target zone is likely much larger than the actual crater is.



Comet Tempel 1 rotating, courtesy NASA/JPL

MATERIALS (PER STUDENT TEAM OF 5-6):

- A camera (cell phone camera can work)
- Regulation men’s basketball
- US quarter coin
- Scissors
- duct tape (or something similar)
- two meter sticks
- chalk or masking tape
- large flat openspace (gymnasium, hallway, playground)
- measuring wheel, tape measure, or bicycle wheel (to use for measuring) (optional)
- binoculars (optional)

PROCEDURE

1. Students read the first two pages of the Explorer Guide.
   - There are various resources that can support developing student back ground knowledge on the SD-NExT website. For example:
     - a short video with great visuals, *The Comet Interactive*: http://stardustnext.jpl.nasa.gov/multimedia/comet_interactive/index.html
     - An entertaining magazine: *The Comet Chronicle*, http://stardustnext.jpl.nasa.gov/education/pdfs/CometChronicle.pdf

2. Develop a quick KWL chart as a class on the board or chart paper:
   - What do we **know** – about comets in general, about comet Tempel 1 and SD-NExT, about our modeling mission today
   - What do we **want** to know?
   - What have we **learned**?

   Refer back to this chart when appropriate throughout the activity to focus growing knowledge and new questions.

3. Break the students into teams of 5-6. You may require students to work individually on the procedures to integrate the math before they break into teams, or you may have students work in the following subgroups:
   - comet team: creates the model of the comet nucleus (procedure A) and rolls the comet (procedure B)
   - navigation team: models the encounter and positions the camera (procedure C)
   - imaging team: phographs the comet as it rolls by (procedures D and E)
   - analysis team that takes the full team's analysis and presents and discusses the results of the mission (Mission Results and Analysis)

TEACHER NOTES

A. Modeling the comet and crater:

> **Inches or Centimeters?**
> When asked to measure the circumference of the basketball, some students will measure it in inches. This activity is a good place to point out that centimeters multiply and convert into feet much more easily than inches do into feet!

Students confirm that the model of a basketball with a mark the size of a quarter is a reasonable model by comparing the ratio of the diameters of the nucleus and crater – and then the basketball and quarter.

- Given many of the unknowns about the actual crater, our model using a quarter and basketball will work fine to simulate capturing the crater *even if* you round to the nearest whole number.
- However, there is speculation among mission scientists that the diameter of Deep Impact crater on Comet Tempel 1 may be 10 or even 100 times smaller than the target zone we are modeling here. Pointing this out either here or as part of sense-making at the end of the activity can stimulate a discussion about the pros and cons of modeling as part of the inquiry process for scientists and engineers as well as students.

To model the crater on a basketball, place a quarter on duct tape and draw a circle around it with a pen. Then, cut out the circular section of duct tape and place it on the basketball. The "comet" is now ready to roll.

A basketball with the area of the crater modeled with a piece of duct tape.

B. Modeling the comet's motion

In addition to the size of the crater, another great unknown of the Stardust-NExT mission is exactly which side of of the comet nucleus will face the spacecraft during encounter. Not only are Stardust-NExT and the comet moving in their respective trajectories at high velocities, but the comet nucleus is rotating. The rotation of the nucleus is somewhat unpredictable due to jets outgassing on the comet's surface as it approaches the Sun.

- In our model, students will calculate the position of the basketball and crater for image capture after approximately twenty rotations (20 times the basketball circumference).

Telling Shadows?

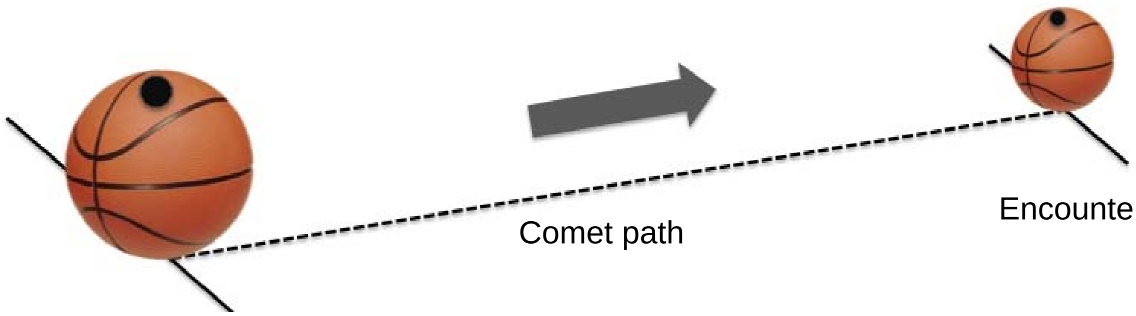
Stardust-NExT spacecraft will attempt to image the crater at an angle of 20 degrees off-center. This is because the position of the Sun and the depth of the crater are also factored into the position of the camera to enhance the information gathered from the imaging.

C. Modeling Comet, Crater and Spacecraft Positions:

Students should be able to determine the distance between the initial position of the basketball (Launch Line) and its predicted position after the number of rotations you decide.

- 20 is the suggested number because it adds to the multiplying effects, helping students understand how factors can build on one another.
- However, 20 rotations is a big distance, requiring a gym or outside space. Adjust as your space requires.
- You may want to create, or invite students to create, a measuring device that more easily measures long distances using a bicycle wheel. Directions are included in the Explorer Guide.

The diagram on the next page shows the Launch Line, Encounter Line, and comet path. The basketball is placed crater face-up on the Launch line, and the imaging will take place directly over the Encounter Line. If video is used, then you can follow the ball as it rolls over the Enounter line.



D. Modeling the Encounter

The Stardust-NExT encounter is of extremely short duration as flybys often are - the comet is imaged during an encounter that will last about 70 seconds. In *Crater Capture*, the encounter will last from less than a second to a couple seconds depending on the speed of the ball and if video is used.

Teams need to prepare for the mission overall, each team member rehearsing his/her individual duties. They need to practice:

- Putting the comet (basketball) into orbit (rolling it on its trajectory) to meet up with the spacecraft
  - so the ball rolls straight, (this is harder than you would expect)
  - at an appropriate speed, and
  - from the correct starting position (crater up).
- Taking a picture of the basketball-comet rolling over the Encounter Line
  - Watch for an electronic delay between when the camera's button is depressed and when the camera actually takes the picture.
  - If video is used, then the video can record the entire motion of the comet from start to finish with the target zone line being used to measure success.

In all, about 70 images will be taken by the real Stardust-NExT spacecraft to improve the odds of a usable image. That's about one second per picture – not bad for a spacecraft that was launched from Earth in 1999.

E. Launch!

Have the students do a final launch – this is the one where the image of the crater "counts."

MISSION RESULTS AND ANALYSIS

WRAP UP

- ✓ Allow students time to evaluate their model as a team.
  - what aspects of the model are accurate (and worked well)
    - e.g., model travels along a path as the comet moves in its trajectory path
  - what aspects of the model are inaccurate (or needed improvement)
    - e.g., model traveled because of the navigation team's throwing arm's force as well as it's friction with surface of floor, etc., while real comet nucleus rotates in orbit as the Earth does – due to inertia
    - e.g. model does not take into account the nucleus' jets and irregular shape
  - how might they revise their model to broaden their learning next time?

- ✓ The <u>analysis team</u> takes the full team's analysis and presents the results of the mission for the entire class to discuss.
  - Leading a class return to the KWL chart, reviewing where the class was and gathering feedback on what has been learned, can structure this nicely.
  - Be sure to ask what new questions have arisen – every NASA mission leads to as many new questions as answers!

Stardust-NExT, a spacecraft re-commissioned for new work exploring comet Tempel 1 – is bonus science. <u>Any</u> images we receive will give us fresh information. Images of the same regions of the nucleus that Deep Impact imaged enable scientists to look at the comet's nucleus "before" a trip around the Sun and "after" a trip around the Sun. Any images of regions of the nucleus that Deep Impact did not see will give us even more information about Tempel 1. Images of the crater – even if not in the most desirable position we aimed for -- should still give information about its depth.

ASSESSMENT OPPORTUNITIES

- ✓ The Jet Propulsion Laboratory has been producing computer simulations of the encounter – other models of the same event! It can be used after students have evaluated their models to see a how their representation of the event was similar to the mission scientist's model and how it was different. Investigate on the SD-NExT website for the latest images: http://stardustnext.jpl.nasa.gov/index.html
- ✓ Students design a new model that characterizes different elements of the actual encounter. For more ideas, see the **Extensions and Further Challenges** listed below.

EXTENSIONS: OPEN INQUIRY OPPORTUNITIES

Having had this experience, what elements of the Stardust-NExT's mission to Tempel 1 would you like to model next? Student answers may address any of the following. Encourage them to develop a new model that helps expand understanding of one new element of the encounter. The following are listed in order of complexity.

- The crater may be smaller than predicted – use a smaller diameter crater (try a nickel and/or dime to see how these ratios compare) to observe how this affects the model and images.
- The comet nucleus is not a sphere – use a football or other non-spherical object to see how observations might change.
- The comet is in an arcing trajectory - use a surface that is not perfectly flat to simulate this. For example, streets are highest at their center line, lowest at the gutters for drainage.
- The spacecraft is moving about half the speed of the comet nucleus - add spacecraft movement and see how this affects the model.
    - For example, the imaging team could walk on a trajectory that flies by the comet as it rolls by.
- Design a mission to image the region unexplored by Deep Impact.
- Other!? Students are sure to come up with intriguing ideas.

After the actual Stardust-NExT images arrive on Earth in 2011, you can compare your results.

Further Challenges:
With the Model

Bumps in the road: adding predictable variablility

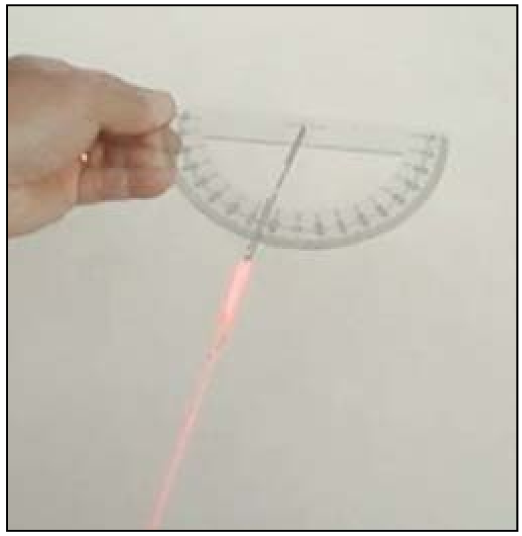
There are always unknowns in any space mission, and one of those unknowns specific to the Stardust-NExT mission is that the rotation of the comet nucleus has changed slightly during several measurements. Imagine that in the *Crater Capture* exercise, there were some uniform bumps in the road. For instance, what if the basketball rolled over an electrical line, garden hose, or thin textbook? The change in rotation would need to be factored into the final measurement for encounter. How could you measure the variations, and how might you take the changes into consideration when positioning the imaging spacecraft?

Degrees of Success

Even if the crater is not in the most desirable position we aimed for during encounter, there will still be valuable information gained as long as the crater is near where we had hoped. Since the comet nucleus has a curved surface, it is possible to estimate how many degrees off a bulls eye we can be and still have a usable image. To model this aspect of the mission, we will first need to simulate the distance between the Stardust-NExT spacecraft and Comet Tempel 1.

- This is done by assuming the basketball is 6km in diameter and the spacecraft is 200km away. This comparision is calculated by dividing the distance between the two objects by a the size of the comet (since we already have a model of the comet). Then multiple the result times the model's diameter (basketball). You will then have the distance between the comet and spacecraft measured in basketball diameters. Now multiply the number of basketball diameters by the actual diameter of a basketball and the product will be a scaled distance between the comet nucleus and the spacecraft.

- The second part of this exercise is to look at the comet from the distance calculated above and decide how far off of bullseye you can be and still discover answers to the questions the mission was designed to answer. Using binoculars can help here since you might be surprised how small the crater target area is at the scaled distance. Set up the the dynamic protractor by attaching one end of the 20m of string to the dynamic protractor, and the other by the chin of the observer at the scaled comet-spacecraft distance. With the base of the dynamic protractor flush with the crater, and the crater facing the observer (the paperclip on on 90 degree mark) slowly turn the basketball while keeping the protractor's position fixed on the ball. Note the degree indicated by the paperclip when the observer considers the size of the visible crater to be too small to yield much information. This position marks the degree to which the encounter imagery can be off center, yet still be somewhat a success.



With Mathematics

<u>A Chance Encounter?</u>

One of the questions students might have wondered about is what is the chance of capturing a picture of the crater at random. In other words – is this math really necessary – or what is the chance that the crater would be in a picture of the comet if the picture were taking without trying to match up the crater's position with the spacecraft's location? To answer this question, one must calculate the proporton between the area on the comet nucleus that contains the crater, the surface are of the comet nucleus, and the size of the region the crater could be in that when captured in a photograph would be considered a success. First, make a guess. Could it be 1/10? Or 1/100? Or 1/1000?

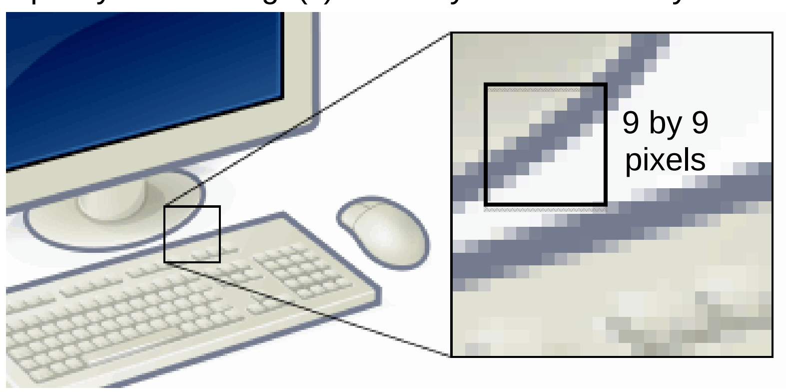
The Comet Tempel 1 nucleus is aproximately 7.1km by 4.9km with an average diameter of about 6km. You may use the ratio of nucleus diameter to crater diameter generated earlier. However, you may draw a larger ring around the crater that you would consider an acceptible or successful crater image and use that area as well.

The probability of success for a random imaging = $\frac{1}{\frac{surface\ area\ of\ nucleus}{surface\ area\ of\ crater\ region}}$

Surface area of a sphere = πd^2
Area of a circle: πr^2

For example, if the surface area of the comet was 100km and the acceptible target region was 1km, the probability of success equals $\frac{1}{100}$ or 0.01 or one chance of success in one hundred trys. However, if the crater area was only 0.1km or 100 meters in diameter, then the random chance of a successful image would be around one in one thousand trys!

Camera Resolution and the Crater:
Since the size and depth of the impact crater on the nucleus of Comet Tempel 1 is unknown, it is hard to predict the quality of the image(s) that may be collected by Stardust-NExT. The best resolution the Stardust-NExT camera is capable of at the closest approach is about 12 meters per pixel.
This means that one pixel would represent a region 12 meters by 12 meters. For each crater depth of 12 meters, the image will show one pixel so if the crater is 100 meters deep, there will be nine pixels of depth data.



If each pixel contains some data about the crater, how many pieces of information will be collected if the crater has a diameter of 10m, 50m, or 100m and a depth of 10m, 50m or 100m?

"We thought Comet Wild 2 would be like a dirty, black, fluffy snowball," said Dr. Donald Brownlee, Stardust's principal investigator. "Instead, it was mind-boggling to see the diverse landscape in the first pictures from Stardust, including spires, pits and craters, which must be supported by a cohesive surface."

Crater Capture

National Science Education Standards

Grades K-12

Unifying Concepts and Processes

All students should develop understanding and abilities aligned with the following concepts and processes:

- Evidence, models, and explanation
- Change, constancy, and measurement.

Grades 9-12

Science as Inquiry

Abilities necessary to do scientific inquiry

- Design and conduct scientific investigations
- Use technology and mathematics to improve investigations and communications
- Formulate and revise scientific explanations and models using logic and evidence

Understandings about Scientific Inquiry

Earth and Space Science

The origin and evolution of the Earth System

- 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. The early earth was very different from the planet we live on today.

Science and Technology

Abilities of technological design

- Propose designs and choose between alternative solutions
- Evaluate the solution and its consequences

Understandings about science and technology

Science as Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

The ISTE National Educational Technology Standards (NETS•S)

- Communication and Collaboration
- Critical Thinking, Problem Solving, and Decision Making