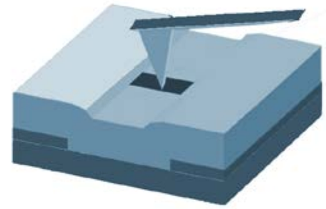
Be a Scanning Probe Microscope



Provided by TryEngineering - www.tryengineering.org

Lesson Focus

Lesson focuses on how engineers have developed and use special tools that can observe the landscape of materials when they are working at the nano scale. Students learn about Scanning Probe Microscopes (SPM) and then work in teams using a pencil to explore and identify the shape of objects they cannot see, just as the SPM does at the nano level. They draw what their mind "sees" on paper, compare their results with other student teams, and share observations with their class.

Lesson Synopsis

The "Be a Scanning Probe Microscope" lesson explores how these microscopes gauge the surface of materials at the nano level. Students work in teams to learn about SPMs, and then use a pencil to visually feel the shape of objects they cannot see. Based on the sense of touch through the pencil, students mimic the function of the SPM. They draw what their mind "saw" and compare their results with other student teams, reflect on the experience, and share observations with the class.

Age Levels

8-14.

Objectives

- Learn about nanotechnology.
- Learn about scanning probe microscopes.
- Learn how engineering can help solve society's challenges.
- Learn about teamwork and problem solving.

Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- nanotechnology
- scanning probe microscopes
- teamwork

Lesson Activities

Students explore how equipment developed by engineers allows us to "see" at the nanoscale. Students mimic the functionality of a scanning probe microscope by exploring the surface of several objects using a pencil as a probe while their eyes are closed. They visualize what is felt through the pencil sensor, draw the object on paper, share their observations with the class, and reflect on the experience.

Resources/Materials

- Teacher Resource Documents (attached)
- Student Resource Sheet (attached)
- Student Worksheet (attached)

Alignment to Curriculum Frameworks

See curriculum alignment sheet at end of lesson.

Internet Connections

- TryEngineering (www.tryengineering.org)
- TryNano (www.trynano.org)
- Scanning Probe Microscopy, University of Illinois at Urbana-Champaign (http://virtual.itg.uiuc.edu/training/AFM_tutorial/)
- The Virtual Microscope (http://virtual.itg.uiuc.edu)
- National Science Education Standards (www.nsta.org/publications/nses.aspx)
- ITEA Standards for Technological Literacy (www.iteaconnect.org/TAA)

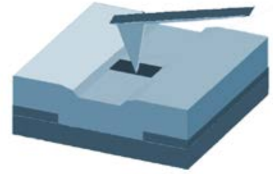
Recommended Reading

- Scanning Probe Microscopy: The Lab on a Tip (Advanced Texts in Physics) (ISBN: 978-3642077371)
- Scanning Probe Microscopy (ISBN: 978-9814324762)

Optional Writing Activity

- Write an essay or a paragraph about how advances through nanotechnology have impacted the field of healthcare and medicine.

Be a Scanning Probe Microscope



For Teachers:
Teacher Resources

◆ **Lesson Goal**

The "Be a Scanning Probe Microscope" lesson explores how these microscopes gauge the surface of materials at the nano level. Students work in teams to learn about SPMs, and then use a pencil to visually feel the shape of objects they cannot see. Based on the sense of touch through the pencil, students mimic the function of the SPM. They draw what their mind "saw" and compare their results with other student teams, reflect on the experience, and share observations with the class.

◆ **Lesson Objectives**

- Learn about nanotechnology.
- Learn about scanning probe microscopes.
- Learn how engineering can help solve society's challenges.
- Learn about teamwork and problem solving.

◆ **Materials**

- Student Resource Sheets
- Student Worksheets
- Class Materials: Box with item affixed to bottom (suggested items: ruler, paper cup, brick, fruit); blindfold.
- Student Team Materials: paper, pen, pencil; access to the internet is optional though helpful.

◆ **Procedure**

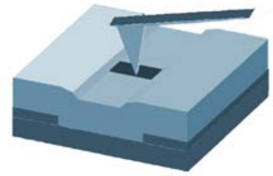
1. Show students the student reference sheets. These may be read in class or provided as reading material for the prior night's homework.
2. To introduce the lesson, consider asking the students how engineers can measure the surface of things that are too small to see.
3. If internet access is available, have students review the virtual tutorial on SPMs at http://virtual.itg.uiuc.edu/training/AFM_tutorial/. The site will illustrate how the scanning probe microscopes work and help students understand how they will perform a similar task through this activity.
4. Teams of 3-4 students will consider their challenge, and use a pencil to "feel" two different objects inside a box (blindfolded). Each individual student will then draw what they "saw" and as a team agree on what the object in the box might be.
5. Teams next develop a detailed drawing showing the object they agreed on.
6. Teams complete a reflection sheet and present their drawings and experiences with the activity to the class.

◆ **Time Needed**

One to two 45 minute sessions.

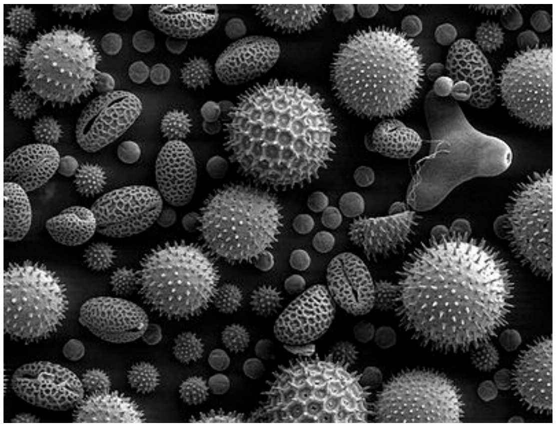
◆ **Options**

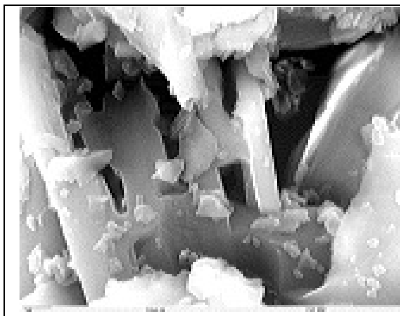
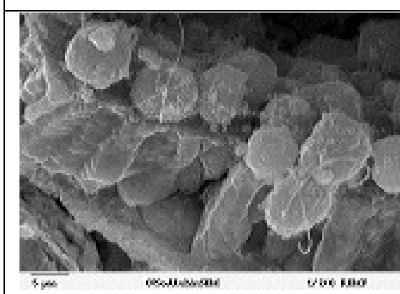
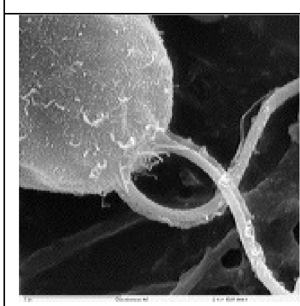
Have students mirror what they "feel" in the box with one hand, by drawing simultaneously on paper with the other hand.



Student Resource:
SPM Imagery (Teacher Solution)

The following photos were taken with Scanning Probe Microscopes. Take a guess at what the image is in full scale! For example, the picture on the left is a SPM image of pollen!

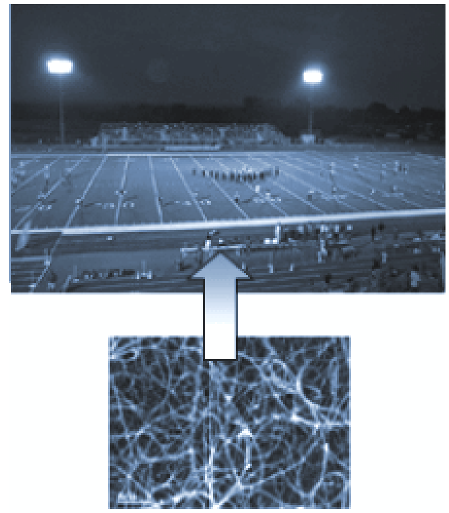
 

	This is volcanic ash.
	This is a sea urchin.
	This is algae (Chlamydomonas).

Source: Dartmouth Electron Microscope Facility at Dartmouth College, New Hampshire, U.S. Other images are at www.dartmouth.edu/~emlab/gallery.)

Student Resource:
What is Nanotechnology?

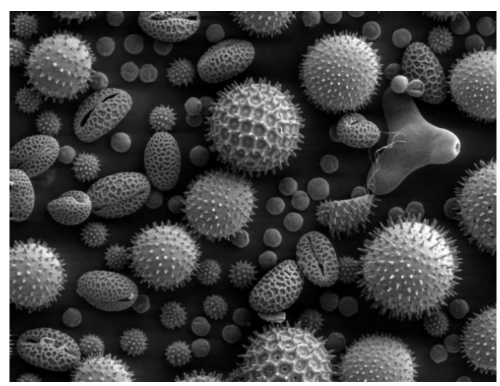
Imagine being able to observe the motion of a red blood cell as it moves through your vein. What would it be like to observe the sodium and chlorine atoms as they get close enough to actually transfer electrons and form a salt crystal or observe the vibration of molecules as the temperature rises in a pan of water? Because of tools or 'scopes' that have been developed and improved over the last few decades we can observe situations like many of the examples at the start of this paragraph. This ability to observe, measure and even manipulate materials at the molecular or atomic scale is called nanotechnology or nanoscience. If we have a nano "something" we have one billionth of that something. Scientists and engineers apply the nano prefix to many "somethings" including meters (length), seconds (time), liters (volume) and grams (mass) to represent what is understandably a very small quantity. Most often nano is applied to the length scale and we measure and talk about nanometers (nm). Individual atoms are smaller than 1 nm in diameter, with it taking about 10 hydrogen atoms in a row to create a line 1 nm in length. Other atoms are larger than hydrogen but still have diameters less than a nanometer. A typical virus is about 100 nm in diameter and a bacterium is about 1000 nm head to tail. The tools or new "scopes" that have allowed us to observe the previously invisible world of the nanoscale are the Atomic Force Microscope and the Scanning Electron Microscope.

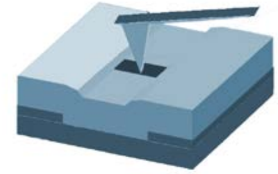


Four grams of carbon nanotubes has the same surface area of a football field.

◆ Scanning Electron Microscope

The scanning electron microscope is a special type of electron microscope that creates images of a sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. In a raster scan, an image is cut up into a sequence of (usually horizontal) strips known as "scan lines." The electrons interact with the atoms that make up the sample and produce signals that provide data about the surface's shape, composition, and even whether it can conduct electricity. The image to the right is Pollen from a variety of common plants, magnified about 500 times. It was taken with a scanning electron microscope at the Dartmouth Electron Microscope Facility at Dartmouth College in New Hampshire, US. Other images are at www.dartmouth.edu/~emlab/gallery.



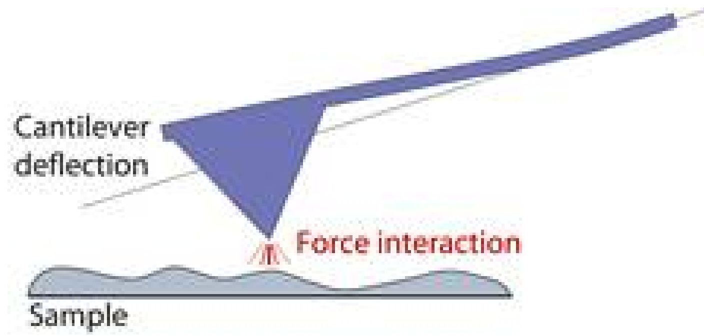


Student Resource:
Atomic Force Microscopes

◆ Imaging at the Nano Scale

In order to "see" what the surface of materials looks like at the nano scale, engineers have developed a range of devices and systems to explore how the surface of an object behaves.

◆ Atomic Force Microscopes

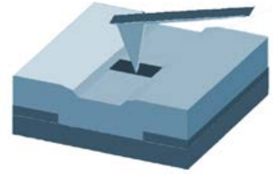


The atomic force microscope (AFM) is one of the families of scanning probe microscopes, and is widely used in biological applications. The AFM uses a flexible cantilever as a type of spring to measure the force between the tip and the sample. The basic idea of an AFM is that the local attractive or repulsive force between the tip and the sample is converted into a bending, or deflection, of the cantilever. The cantilever is attached to some form of rigid substrate that can be held fixed, and depending whether the interaction at the tip is attractive or repulsive, the cantilever will deflect towards or away from the surface.

This cantilever deflection must be detected in some way and converted into an electrical signal to produce the images. The detection system that has become the standard method for AFM uses a laser beam that is reflected from the back of the cantilever onto a detector. The optical lever principle is used, which means that a small change in the bending angle of the cantilever is converted to a measurably large deflection in the position of the reflected spot.

The position of the laser spot is measured by comparing the signals from different sections of the detector. Most AFMs use a photodiode that is made of four quadrants, so that the laser spot position can be calculated in two directions, by comparing the signals. The vertical deflection (measuring the interaction force) can be calculated by comparing the amount of signal from the "top" and "bottom" halves of the detector. The lateral twisting of the cantilever can also be calculated by comparing the "left" and "right" halves of the detector.

Some content provided by the U.S. Department of Energy.



Student Resource:
SPM Imagery

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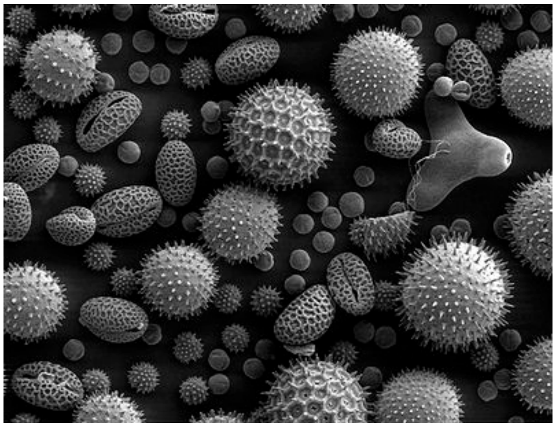
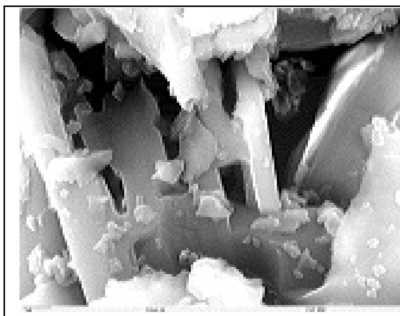
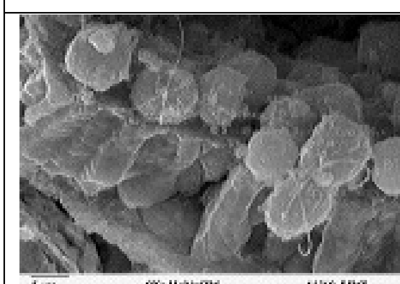
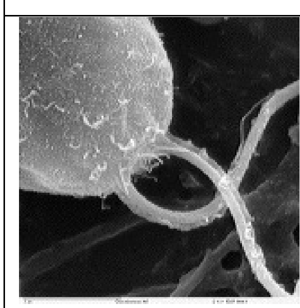


	Your guess?
	Your guess?
	Your guess?

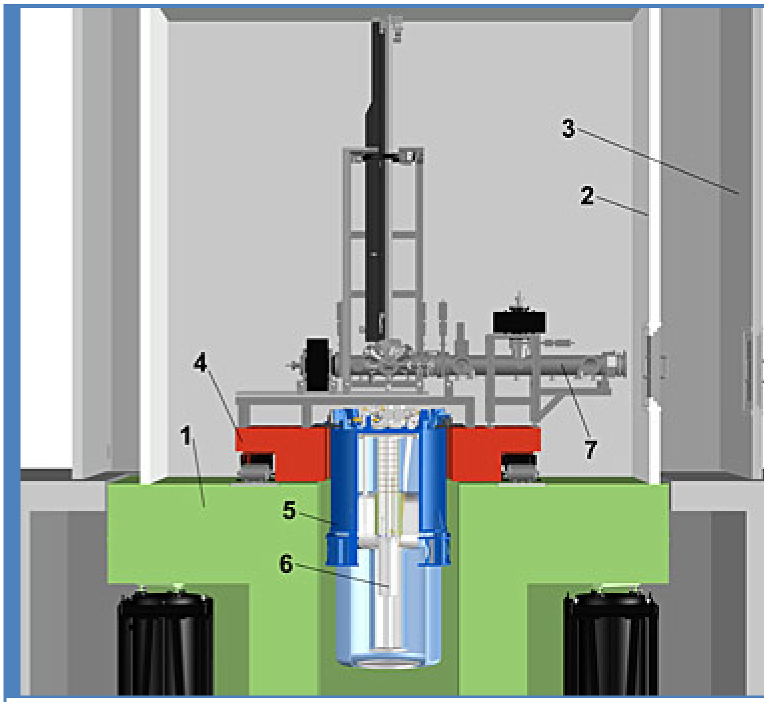
Source: Dartmouth Electron Microscope Facility at Dartmouth College, New Hampshire, U.S. Other images are at www.dartmouth.edu/~emlab/gallery.)

Student Resource:
Press Release:
NIST's New Scanning Probe Microscope is Supercool

The discoveries of superconductivity, the quantum Hall effect and the fractional quantum Hall effect were all the result of measurements made at increasingly lower temperatures. Now, pushing the regime of the very cold into the very small, a research team from the National Institute of Standards and Technology (NIST), the University of Maryland, Janis Research Company, Inc., and Seoul National University, has designed and built an advanced ultra-low temperature scanning probe microscope (ULTSPM).

The ULTSPM operates at lower temperatures and higher magnetic fields than any other similar microscope, capabilities that enable the device to resolve energy levels separated by as small as 1 millionth of an electron volt.

"To get these kinds of measurements, you need to combine coarse and extremely fine movement (the mechanical positioning of a probe tip about two atoms' distance from the sample surface), ultra-high vacuum, cryogenics and vibration isolation," says NIST Fellow Joseph Stroscio, one of the device's co-creators. "We designed this instrument to achieve superlative levels of performance, which, in turn, requires achieving nearly the ultimate in environmental control."

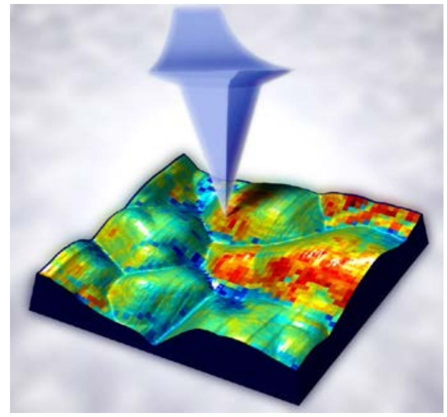


The ULTSPM lab rests on a separate 110-ton concrete slab (1), supported by pneumatic isolators. Inner (2) and an outer (3) enclosures shield from acoustic noise, with the inner enclosure also acting as a radio-frequency shield. The microscope is mounted on a 6-ton granite table (4), also supported by pneumatic isolators. The cryostat (5) is mounted in a hole in the granite table and in the concrete slab on a third set of pneumatic isolators. Inside the cryostat, the dilution refrigerator insert (6) hangs immersed in the liquid helium bath. Samples from the processing lab enter the enclosed room through two hatches on the right via a central vacuum line (7). Credit: NIST

Past designs used mechanical systems to move the probe tip that did not work over a wide range of temperatures. Researchers overcame this by creating piezoelectric actuators that expand with atomic scale precision when voltage is applied. For vibration control, the group built the ULTSPM facility on top of a separate 110-ton concrete block buffered by six computer-controlled air springs. The ULTSPM, itself, sits on a 6-ton granite table, isolated from the concrete block by another set of computer-controlled air springs. To achieve the ULTSPM's ultra low operating temperature of 10 millikelvins, the team designed a low noise dilution refrigerator to supplement the device's chilly 3-meter deep, 250-liter liquid helium bath. Because electromagnetic radiation entering through wires and cables can heat up the microscope, the ULTSPM lab is nested inside a separate, electromagnetically shielded room.

In order to ready new samples and probes without disturbing ongoing measurements, experimenters built a vacuum-sealed "railroad" system that they can disconnect from the chamber.

◆ Types of SPMs

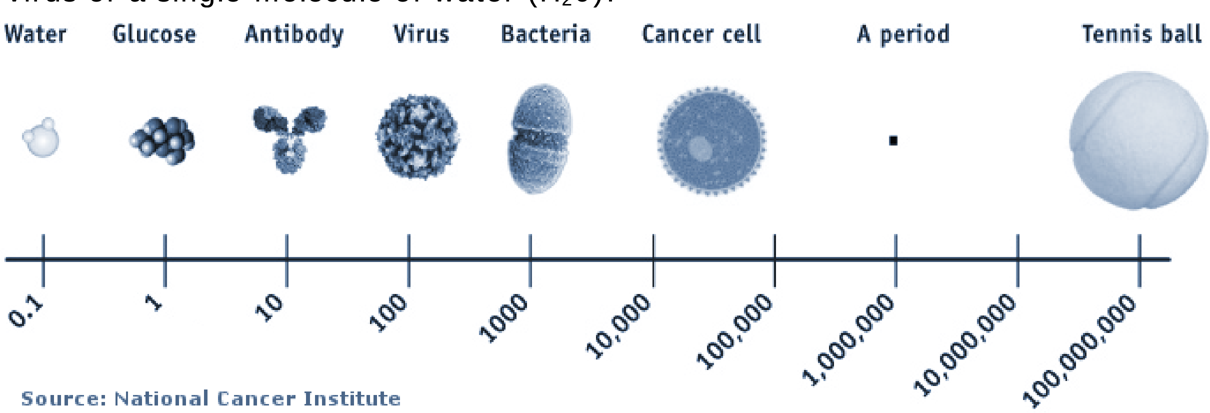


There are many different types of Scanning Probe Microscopes that have been developed by engineers. And, new ones or adaptations are developed all the time. For example, the picture to the right shows an electrochemical strain microscopy (ESM) technique developed at Oak Ridge National Laboratory of the US Department of Energy that can map lithium ion flow through a battery's cathode material. In this example, it is used to examine the movement of lithium ions through a battery's cathode material. Lithium-ion batteries are used in many products because of their low weight and ability to recharge. This new type of SPM will help researchers learn more to help extend battery performance as they understand more about how the materials function.

◆ How Big is Small?

It can be hard to visualize how small things are at the nanoscale. The following are drawings of items you may recognize…. a bowling ball, a billiard ball, a tennis ball, a golf ball, a marble, and a pea. Think about the relative size of these items.

Now take a look at the chart below that was developed by the National Cancer Institute (U.S.) and think about how much smaller the various items are…moving down from the familiar tennis ball. The "." on this page is 1,000,000 microns -- quite gigantic compared to a virus or a single molecule of water (H_20).

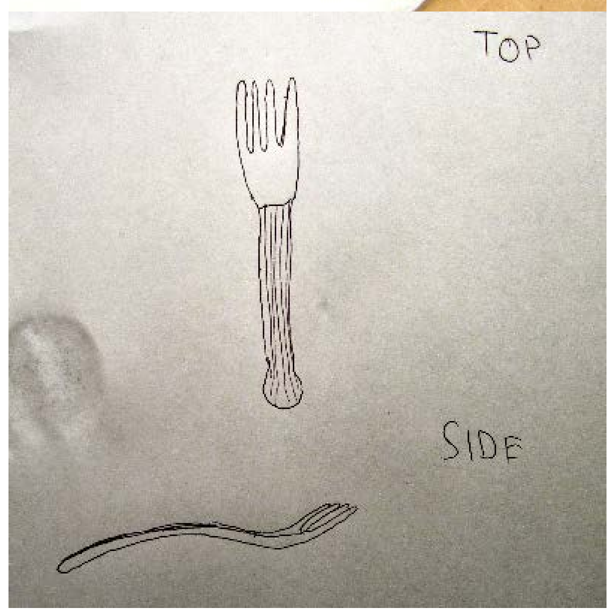


Student Worksheet:

Try your hand at being a Scanning Probe Microscope!

◆ Research Phase

Read the materials provided to you by your teacher. If you have access to the internet, also view the tutorial on this website: http://virtual.itg.uiuc.edu/training/AFM_tutorial/. It will illustrate how the scanning probe microscopes work and help you understand how you will perform a similar task through this activity.



◆ Try It Out!

Each student on your team will take turns using a pencil probe to determine the shape or identify of an object in a box. You may either be blindfolded, or have a hole cut into a box so that your hand and the pencil can be inside without you seeing what is in the box.

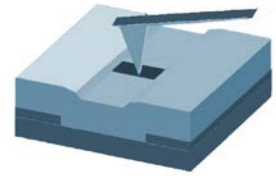
Use just the tip of the pencil to examine the content or surface area of the bottom of the box. In your mind, keep track of the height of the objects you sense, their shape, and overall size.

Next, draw what you "saw" on a piece of paper -- you might want to consider a top and side view to help determine what is in the box.

When each student on the team has done the investigation, work together and share your drawings and opinions of what is in the box. Come up with a consensus as a team and develop a final drawing that includes estimated measurements of the object

◆ Presentation and Reflection Phase

Present your ideas, drawings, and measurements to the class, and listen to the presentations of the other teams. See how close your team, or the other teams were, in determining the actual size and shape. Then complete the reflection sheet.



Student Worksheet:

◆ **Reflection**

Complete the reflection questions below:

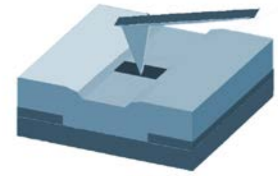
1. How accurate in terms of the shape was your team in identifying the object? What did you find in the box?

2. How accurate was your team in determining the actual size of the object in the box?

3. By what percentage was your size estimate off from the actual size of the object in the box?

4. Do you think that the amount of time you took to "see" inside the box with the probe impacted how accurate your findings were?

5. Did you think that working as a team made this project easier or harder? Why?



For Teachers:
Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (http://www.nextgenscience.org/)
- International Technology Education Association's Standards for Technological Literacy (http://www.iteea.org/TAA/PDFs/xstnd.pdf)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (http://www.nctm.org/standards/content.aspx?id=16909)
- U.S. Common Core State Standards for Mathematics (http://www.corestandards.org/Math)
- Computer Science Teachers Association K-12 Computer Science Standards (http://csta.acm.org/Curriculum/sub/K12Standards.html)

◆National Science Education Standards Grades K-4 (ages 4-9)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understanding about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of the activities, all students should develop an understanding of

- ✦ Properties of objects and materials
- ✦ Position and motion of objects

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ✦ Abilities of technological design

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Science and technology in local challenges

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ✦ Science as a human endeavor

◆National Science Education Standards Grades 5-8 (ages 10-14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ✦ Properties and changes of properties in matter

CONTENT STANDARD E: Science and Technology

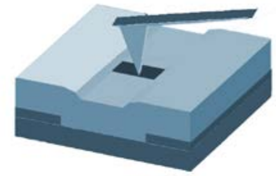
As a result of activities in grades 5-8, all students should develop

- ✦ Abilities of technological design
- ✦ Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Science and technology in society



For Teachers:
Alignment to Curriculum Frameworks (cont.)

◆**National Science Education Standards Grades 5-8 (ages 10-14)**

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ✦ Science as a human endeavor
- ✦ Nature of science

◆**National Science Education Standards Grades 9-12 (ages 14-18)**

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop understanding of

- ✦ Structure and properties of matter

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ✦ Abilities of technological design
- ✦ Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Science and technology in local, national, and global challenges

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ✦ Science as a human endeavor
- ✦ Nature of scientific knowledge
- ✦ Historical perspectives

◆**Next Generation Science Standards Grades 2-5 (Ages 7-11)**

Students who demonstrate understanding can:

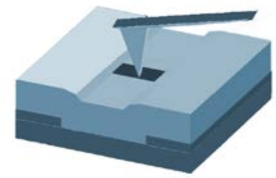
Matter and its Interactions

- ✦ 5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.
- ✦ 5-PS1-3. Make observations and measurements to identify materials based on their properties.

◆**Standards for Technological Literacy - All Ages**

The Nature of Technology

- ✦ Standard 1: Students will develop an understanding of the characteristics and scope of technology.
- ✦ Standard 2: Students will develop an understanding of the core concepts of technology.
- ✦ Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.



For Teachers:
Alignment to Curriculum Frameworks (cont.)

◆**Standards for Technological Literacy - All Ages**

Technology and Society

- Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.
- Standard 6: Students will develop an understanding of the role of society in the development and use of technology.
- Standard 7: Students will develop an understanding of the influence of technology on history.

Abilities for a Technological World

- Standard 13: Students will develop abilities to assess the impact of products and systems.