Lesson 1
Engage
Explore
Explain

What Is Technology?

Overview
This lesson consists of two activities linked by classroom discussion. Its purpose is to engage students in the general topic of technology. The first activity involves classroom discussion and a short scenario to allow students to develop a sense of what technology is and to dispel the notion that technology relates mostly to computers. The second activity introduces students to the concept of scale by using the classroom to represent a cell and other smaller objects to represent subcellular components.

At a Glance

Major Concepts
Technology is a body of knowledge used to create tools, develop skills, and extract or collect materials. It is also the application of science (the combination of the scientific method and material) to meet an objective or solve a problem. Scale is a way to represent the relationship between the actual size of an object and how that size is characterized, either numerically or visually.

Objectives
After completing this lesson, students will

- be able to explain what technology is,
- recognize that human intervention is the common bond among technologies, and
- describe the use of **scale** to distinguish between objects of different size.

Teacher Background
See the following sections in Information about Using Technology to Study Cellular and Molecular Biology:

1 Introduction *(page 23)*

2 Major Preconceptions *(pages 23–24)*

3.1 Scale *(pages 24–25)*

In Advance

Web-Based Activities

Activity	Web Version
1	No
2	No

Photocopies

Activity 1	none
Activity 2	Master 1.1, *Searching for Scale*, 1 copy per student

Materials

Activity 1	none needed
Activity 2	• meter stick • rulers • objects of various sizes (see Teacher note on page 49)

Preparation

Activity 1
No preparations needed.

Activity 2
No preparations needed.

Procedure

Activity 1: *Technology—What's It All About?*

Assessment:
This activity is designed to engage students in learning about technology and to help the teacher assess the students' prior knowledge of the subject.

Tip from the field test: Activities 1 and 2 can be conducted in several ways. You can engage the class as a whole in discussion as directed. Alternatively, you can divide the class into groups of three to five students each, ask each group to consider the questions you ask, and then have each group provide its responses. It is also possible to have student groups consider only a limited number of the questions and then handle the remainder with the whole class. If you choose either of the last two approaches, you should limit the time allotted for groups to consider each question to several minutes. Field-testing indicated that no approach was superior to another.

1. **Begin by asking the class, "How do you define *technology*?"**

   Accept all answers and write student responses on the board. Do not attempt to have students refine their definitions of technology at this point. They will revisit their definitions and refine them in

Step 5. Students, like older individuals, may harbor the preconception that technology relates mostly to computers. Through advertisements and media articles, they are familiar with the terms *information technology* and *computer technology*.

Teacher note: Asking this question requires students to call on their prior knowledge, and it engages their thinking. At this point, do not critique student responses. Appropriate teacher comments are short and positive, such as “good” and “what else?” Other appropriate teacher responses include, “Why do you believe that?” or “How do you know that?” Questions such as these allow the teacher to assess students’ current knowledge about the subject and to adjust lessons accordingly. They also provide a springboard to “Let’s find out” or “Let’s investigate.” In general, it is time to move forward when the teacher sees that thinking has been engaged.

2. **Ask students, “In general, what does technology do for us?”**

   This question may help students understand that technology helps us solve problems, makes our lives easier, and extends our abilities to do things. Technology is used to develop skills or tools, both in our daily lives and in our occupations.

3. **Focus discussion on technologies that are relevant to each student’s life. Ask students to look around the room. What technologies do they see? How do these technologies solve problems and make their lives easier?**

   Accept all responses and write them on the board. Students may mention any number of items. Some may be school-related, such as binders, backpacks, pens, pencils, paper, and paper clips. Other items may be more personal, such as water bottles, personal stereos, and hair clips. Students may neglect items such as shoelaces, zippers, buttons, fabric, eyeglasses or contact lenses, makeup, and bandages. Discussion should reinforce the notion that humans develop technology with a specific objective in mind. A related concept is that a given task requires the right tool or tools.

4. **Pick a technology that students have mentioned. Ask them what types of knowledge were required to develop that technology.**

   Students may not realize that technologies are generally developed by applying knowledge from multiple disciplines. For example, producing today’s audio devices, such as a portable CD player, requires knowledge obtained from engineering, physics, mathematics, chemistry, and computer science.

5. **On the basis of previous discussions, ask students to rethink and refine their definition of technology (from Step 1).**

Students should mention that technology is a way of solving problems through the application of knowledge from multiple disciplines.

6. **Tell students to imagine that they live in the Stone Age. Their only garment has been ripped and requires mending. How would they do it?**

   Students first should recognize that the ripped garment is a problem requiring a solution. They should consider what technologies they have available. The Stone Age was a period early in the development of human cultures when tools were made of stone and bone. Clothing consisted of animal skins or fabrics woven from threads derived from plant fibers. Bones and sharp reeds were used to make needles.

Content Standard E: Technological design is driven by the need to meet human needs and solve human problems.

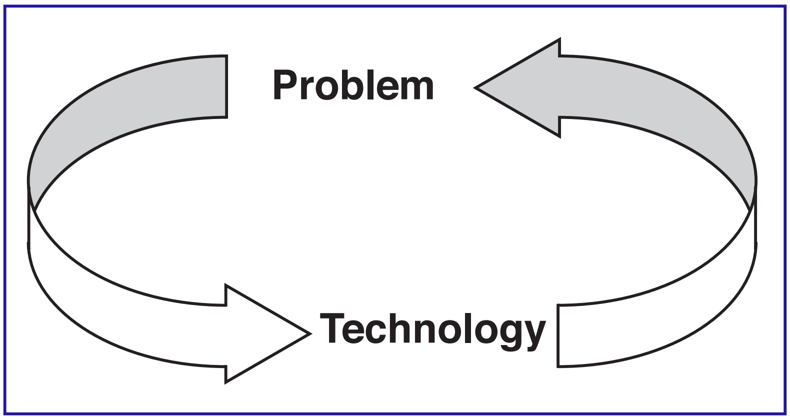
7. **Ask students how their approach to mending the garment would change as time advanced from the Stone Age to the present. What new knowledge would allow the development of new technology?**

   Student responses will vary, and some students may want to jump directly from the Stone Age to the modern sewing machine. Slow them down and have them consider incremental changes in knowledge and technologies. They may cite the use of metals to fashion repair tools, like knives and finer needles. New knowledge of metals and chemistry would help here. Later advances in engineering and mechanics would lead to the development of human-run machines for assisting with repairs. Eventually, advances in physics (electricity) and engineering led to the invention of modern sewing machines. Similarly, advances in agriculture, chemistry, and engineering produced better fabrics and threads. Students should derive an understanding that technology advances through interactions among multiple disciplines. While a problem may remain basically the same over time (for instance, the need to make or repair clothing), advances in technology change how the problem is solved.

Assessment: Listening to students' responses will help you assess their understanding of the relationship between problems and technology.

8. **Write the words *problem* and *technology* on the board. Ask students to use arrows to draw a graphic that represents the relationship they believe exists between a problem and the technology to solve it.**

   They can use arrows of any kind, and they should be prepared to defend their suggestions. The graphic should illustrate that a problem does not drive technology unidirectionally, nor does technology exist solely in search of a problem to solve. Rather, these two areas exist to support and drive one another. Solving problems does require the development of new technologies, which can then be applied to other problems. A graphic to depict this indicates the cyclic relationship between the two:



Activity 2: *Searching for Scale*

1. **Biological molecules are small, but how small *is* "small"? Ask students these two questions:**

    a. **How do biological structures, such as cells, organelles, bacteria, and viruses, compare in size with one another?**

    b. **How do molecules compare in size with biological structures such as cells, organelles, bacteria, and viruses?**

    Accept all responses and write them on the board. Students will explore these size relationships in the next steps.

2. **Tell students that they will now investigate the relative sizes of different biological structures and see how close their estimates of relative size were.**

3. **Give each student a copy of Master 1.1, *Searching for Scale*. Work with the class to complete column 3, Size relative to cell.**

    The table with column 3 completed is as follows:

Biological Structure	Actual Diameter (in Meters)	Size Relative to Cell	Object Used to Model Biological Structure	Measured Size of Model Object	Size Relative to Model Cell (the Room)
Cell	1×10^{-5}	$\frac{1 \times 10^{-5}}{1 \times 10^{-5}} = 1$	Room	10 m	$\frac{10}{10} = 1$
Bacterium	1×10^{-6}	$\frac{1 \times 10^{-6}}{1 \times 10^{-5}} = \frac{1}{10}$	Desk	1 m	$\frac{1}{10} = \frac{1}{10}$
Mitochondrion	5×10^{-7}	$\frac{5 \times 10^{-7}}{1 \times 10^{-5}} = \frac{1}{20}$		0.5 m	
Virus	1×10^{-7}	$\frac{1 \times 10^{-7}}{1 \times 10^{-5}} = \frac{1}{100}$		0.1 m (10 cm)	
Ribosome	1×10^{-8}	$\frac{1 \times 10^{-8}}{1 \times 10^{-5}} = \frac{1}{1,000}$		0.01 m (1 cm)	
Protein	5×10^{-9}	$\frac{5 \times 10^{-9}}{1 \times 10^{-5}} = \frac{1}{2,000}$		0.5 cm	
Glucose molecule	1×10^{-9}	$\frac{1 \times 10^{-9}}{1 \times 10^{-5}} = \frac{1}{10,000}$		0.1 cm (1 mm)	
H_2O molecule	1×10^{-10}	$\frac{1 \times 10^{-10}}{1 \times 10^{-5}} = \frac{1}{100,000}$		0.1 mm	

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Content Standard A: Mathematics is essential in all aspects of scientific inquiry.

4. **Tell students that the information in columns 2 and 3 each can be used to construct *scales* to describe the sizes of the different biological structures in the table. Ask students to define *scale*.**

   Accept all answers and write them on the board. Guide discussion so that students realize that scale is a way to represent the relationship between the actual size of an object (for example, its length or mass) and how that size is characterized either numerically or visually. A scale is a series of ascending and descending steps to assess either some relative (column 3) or absolute (column 2) property of an object. In this case, the property being investigated is size.

5. **Ask students to try to visualize the 100,000-fold difference in size between a cell and a water molecule. Can they do it? How could they demonstrate this large size difference more easily?**

   Master 1.1, *Searching for Scale* provides the necessary clues for students, since the heading of column 4 is *Object used to model biological structure*. Students can use larger structures, such as a room, to model smaller ones, such as a cell, to make size differences more apparent and bring them into the realm of common experience.

6. **Ask two students to use a meter stick to mark approximately 10 m along both the length and width of the classroom.**

It is okay if the classroom does not allow 10 m to be measured in either or both directions. A distance of 7 to 9 m will still make the point visually. However, for ease of calculations to follow, use room dimensions of 10 m even if the actual dimensions are smaller than that.

7. **Tell students that the space defined by 10 m wide, 10 m in length, and the height of the room now represents a cell. In other words, this space is now a *model* for a typical cell.**

8. **Organize students into pairs and give each pair a ruler.**

9. **Tell students that they will be searching the classroom for objects that model the biological structures on Master 1.1, *Searching for Scale*.**

   Explain that they will be looking for objects that have the same size relative to the model cell (the room) that the actual biological structure has to a real cell.

10. **Ask students to look at the last three columns on Master 1.1, *Searching for Scale*. As an example, a desk measuring 1 meter high is provided as a model for a bacterium. Important points are as follows:**

    a. **A bacterium is $\frac{1}{10}$ the size of an actual cell (column 3).**

    b. **Similarly, the desk is $\frac{1}{10}$ the size of the model cell, the room (1 m compared with 10 m; columns 4 and 5).**

    c. **Because it is of the correct scale, the desk can be used to model a bacterium if a cell is modeled by a room 10 m across.**

11. **Instruct student pairs to locate items in the classroom that can be used to model the biological structures listed on Master 1.1, *Searching for Scale*. They should enter their results in columns 4, 5, and 6 of the master. Allow 15 minutes for this activity.**

    Students may approach this activity in different ways. Some may find it useful to determine the size of the object they are looking for first by multiplying the ratio in column 3 by 10 m. Some students may begin by locating objects, measuring them, and then determining whether they meet the size requirements.

    Teacher note: It is helpful to have objects available in the classroom that will meet the size requirements for modeling the biological structures in Master 1.1. Objects, such as erasers, marbles,

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Content Standard A:
Recognize and analyze alternative explanations and models.

Assessment:
Circulate around the room, noting whether students understand the mathematics involved in scaling objects for this activity.

Assessment:
Listening to student responses will help you assess their understanding of scale and modeling. Collecting their completed tables (Master 1.1, *Searching for Scale*) allows a more formal opportunity to evaluate students' understanding.

fine- and ultrafine-tip pencils or pens, pieces of candy, an inflated balloon, balls of different sizes, and other easily obtained materials, ensure that students will be able to find something to serve as a model for each structure.

12. **Ask student pairs to share some of their results with the class.**

    Students should realize that the size ratios in columns 3 and 6 are the same. In other words, modeling allows *relative* sizes to be studied, although the *actual* sizes of the real biological structure and its model differ quite a bit.

Discussion Questions

1. **If a cell of 1×10^{-5} m (10×10^{-6} m, or 10 µm) diameter is represented by a room 10 m across, what distance would represent a human 2 m tall?**

   First, as in column 3 of Master 1.1, *Searching for Scale*, derive the relationship between the size of the human and the size of the cell:
   $$2 \text{ meters} \div (1 \times 10^{-5} \text{ meter}) = 2 \times 10^{5}.$$
   Thus, a 2-m-tall individual is 2×10^{5} times larger than a cell 1×10^{-5} m in diameter.

   If the cell is represented by a distance of 10 m, the 2-m-tall individual would be represented by a distance of
   $$10 \text{ m} \times (2 \times 10^{5}) = 2 \times 10^{6} \text{ m (2,000 km, or 1,250 miles)}$$

   As a reference, this distance is the same as that from Boston to Miami, Kansas City to Boston, or Los Angeles to Dallas. This calculation is intended to provide a "wow" for the students, and they derive an understanding of the difference in size between a human and a molecule (in this example, the difference between 2,000,000 m for the human and 2 to 5 mm for a protein). This should help students understand the need for specialized technologies for studying living systems at the cellular and molecular levels.

2. **As a lead-in to Lesson 2, write the following terms on the board in random order: Eye; Light Microscopy; Electron Microscopy; X-ray Techniques. Ask students to speculate on which technology (or technologies) could provide useful information about the objects on Master 1.1, *Searching for Scale*. What would make one technology more useful than another in any given situation?**

   Students should realize that naked-eye observation is useful only for relatively large objects and is not useful at all for discerning cellular and subcellular objects. They also will realize that light microscopy is useful for looking at cells and resolving some organelles, like the nucleus and vacuoles. Students should know from material in their texts that electron microscopy is used to provide details about cells and subcellular structures. Some may have seen electron micrographs of DNA. Most students know little about X-ray technologies, although they may have heard of X-ray crystallography as a technique that was used to help resolve the structure of DNA. If students have ideas about why certain technologies are better for some tasks than others, write those responses on the board. Indicate that the reason for having the right tool for the right task is addressed in Lesson 2.

Lesson 1 Organizer

Activity 1: *Technology—What's It All About?*

What the Teacher Does	Procedure Reference
Ask students, • "What is technology?" • "In general, what does technology do for us?"	Pages 44–45 Steps 1–2
Focus discussion of technologies relevant to each student's life. • Ask students to look around the room; what technologies do they see? • How do these technologies solve problems and make their lives easier? • Pick a technology mentioned. Ask students what types of knowledge were required to develop that technology. • After discussion, ask students to rethink and refine their definition of technology.	Pages 45–46 Steps 3–5
Tell students to imagine that they live in the Stone Age. Their only garment is ripped and requires mending. Ask, • "How would you mend the garment?" • "How would your approach to mending the garment change as time advanced from the Stone Age to the present?" • "What new knowledge would allow the development of new technology?"	Page 46 Steps 6–7
Write the words *problem* and *technology* on the board. Ask students to use arrows to draw a graphic that represents the relationship they believe exists between a problem and the technology needed to solve it.	Page 46 Step 8

Activity 2: *Searching for Scale*

What the Teacher Does	Procedure Reference
Ask students, • "How do biological structures, such as cells, organelles, bacteria, and viruses, compare in size with one another?" • "How do molecules compare in size with biological structures such as cells, organelles, bacteria, and viruses?"	Page 47 Step 1

Tell students that they will investigate the relative sizes of different biological structures. • Give each student a copy of Master 1.1, *Searching for Scale.* • Work with the class to complete column 3, Size relative to cell. • Ask students to define *scale* based on the information in columns 2 and 3. • Ask students if they can visualize the 100,000-fold difference in size between a cell and a water molecule. How could they demonstrate this large size difference?	Pages 47–48 Steps 2–5 M
• Ask two students to measure and mark approximately 10 m along both the length and width of the classroom. • Tell students that the space defined by 10 m wide, 10 m in length, and the height of the room is a model for a typical cell.	Pages 48–49 Steps 6–7
Organize students into pairs. • Give each pair a ruler. • Tell students that they will be searching the classroom for objects that model the biological structures on Master 1.1, *Searching for Scale.* • Tell students to use the information provided in the last three columns of Master 1.1 to help in their search. • Instruct students to complete the last three columns of Master 1.1 as they locate appropriate objects.	Pages 49–50 Steps 8–11
Ask students to share some of their results with the class.	Page 50 Step 12

M = Involves copying a master.

Lesson 2
Explore
Explain

Resolving Issues

At a Glance

Overview

This lesson consists of two activities linked by classroom discussion. In the first activity, which is similar to the game Battleship, students investigate the concept of resolution and the relationship between probe size and resolution. The second activity incorporates results from the first activity and classroom observation and discussion. Students discover that in order to understand the complete structure of an object, it is necessary to have information in three dimensions rather than just two.

Major Concepts

Doing research in cellular and molecular biology requires scientists to identify the right technology (tool) for the job. An important consideration is the technology's ability to resolve structural details of biological objects. Two objects can be resolved by using a probe (radiation) of a size (wavelength) that is not larger than the distance separating the objects. Generally, the smaller the probe, the greater the structural detail, or resolution, that results. Detailed structural knowledge about biological objects requires information obtained in three dimensions.

Objectives

After completing this lesson, students will

- be able to define resolution,
- be able to explain the relationship between probe size and resolution, and
- be able to explain why information in three dimensions is necessary to describe the structure of an object.

Teacher Background

See the following sections in Information about Using Technology to Study Cellular and Molecular Biology:

3.1 Scale *(pages 24–25)*
3.2 Resolution *(pages 25–26)*

In Advance

Web-Based Activities

Activity	Web Version
1	No
2	Yes

Photocopies

Activity 1	• Master 2.1, *Probing for Answers Score Sheet*, 1 copy per 2 students; 1 transparency for classroom demonstration • Master 2.2, *Probes*, 1 copy per 12 students (see Preparation) • Masters 2.3 to 2.8, *Probing for Answers—Levels 1–6*, 1 copy of each per 12 or fewer students; 2 copies of each for 13–24 students; 3 copies of each for 25–36 students
Activity 2	• Master 2.9, *Solution to Probing for Answers*, 1 transparency (*print version* only)

Materials

Activity 1	manila folders (1 per group, optional)
Activity 2	• 2 hard-crusted bread rolls, unsliced • knife to slice bread • food coloring • syringe with needle, or 1-mL pipette

Preparation

Activity 1

From Master 2.2, *Probes*, cut out each 3 × 3, 2 × 2, and 1 × 1 square (1 copy produces 6 of each size of probe).

Activity 2

Just before the class period in which students will do this activity, inject a small amount of colored food dye into two locations in each of two unsliced, hard-crusted bread rolls. One location should be to the right of center and the other, to the left of center. The same or different dye colors can by used. Injecting the dye can be accomplished several ways to meet the primary objective, which is to color the inside and not the outside of each roll. Use either a syringe with a needle long enough to reach well into the roll or a carefully inserted 1-mL pipette. Wipe the outside surface of the needle or pipette to remove any dye solution before inserting it into the roll. It may help to use a sharp object, such as the sharp, pointed portion of a compass, to make a small hole before inserting a pipette containing dye. Try not to leave traces of the dye on the outside of the rolls.

If you have Internet access, have at least one computer at the URL *http://science.education.nih.gov/supplements/technology/student.* This is a main menu page from which you can access this activity.

Activity 1: *Probing for Answers*

Procedure

1. **Begin by stating or writing on the board, "Technology is a means of extending human potential or of extending human senses." Ask students to raise their hands if they agree with this statement.**

2. **Ask students to provide justification for their responses. Can students relate specific technologies to the extension of specific human attributes or senses?**

   Students will generally agree that technology extends human potential. Obvious examples include the wheel and other transportation innovations that extend our potential for movement, and electronic devices, such as TV, radio, and telephones, that extend our ability to communicate. Microscopes, telescopes, eyeglasses, and contact lenses extend and enhance our sense of vision. Computers and written materials can be seen as ways to extend memory. There are many other examples.

   Tip from the field test: Some students correctly pointed out that technology is also used to extend animal potential.

Assessment:
Steps 1 to 5 are intended to be a quick method to assess students' prior conceptions about the use of technology in biological science.

3. **Ask students to consider only technologies that have increased our understanding of living systems. Do they extend any human attributes? If they do, which attributes are extended?**

   Students will probably focus on those that extend vision, since they are the easiest to recognize. Examples could include radar, eyeglasses, contact lenses, and telescopes. Students also know that microscopes allow us to see objects that we cannot see with the naked eye. Students should be familiar with the light microscope, and many may have heard of electron microscopes. Through figures in textbooks, they may know X-ray crystallography as a technology that helped us "see" the structure of DNA. Other technologies might be mentioned. Accept all responses and write them on the board. This is an opportunity to identify students' current understanding of these technologies.

   A Gary Larson Far Side cartoon, "Early Microbiologists," can be used to engage students. Pictured is a caveman "laboratory," in which several cavemen peer intently into Petri dishes filled with agar. Since they do not have microscopes, they hold the dishes in various ways, such as very close to the face. One of the cavemen imitates binoculars by holding his hands to his eyes. (The cartoon can be found in several published works, including *The Prehistory of the Far Side*, by Gary Larson, copyright 1989 by FarWorks, Inc., distributed by Universal Press Syndicate, published by Andrews McMeel, Kansas City, Kansas.)

4. **Ask students to focus on technologies as tools that allow us to "see" biological objects (the eye, microscopes of all kinds, and X-ray techniques).** ***One at a time*****, ask the following questions:**

   a. **What technologies would you use to study a whole (intact) organism and why?**

   b. **What technologies would you use to study cells and why?**

   c. **What technologies would you use to study molecules and why?**

   Accept all reasonable responses, but challenge those that are incorrect. Students should understand that no single technology is useful at all levels of organization of biological organisms. In other words, no single technology is able to resolve structural details from the intact organism to the molecules that make up that organism. This discussion introduces students to the idea that there is a right tool for the job.

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Content Standard A: Identify questions and concepts that guide scientific investigations.

5. **Ask students why a single technology cannot provide information at all levels of organization of biological organisms.**

   You might remind students that at the conclusion of Lesson 1, they were asked to speculate on what would make one technology more useful than another in a given situation. If students need prodding, you can ask whether they would use a microscope to study a whole organism, or whether they would use their eyes alone to study molecules. While a microscope is required to study single-celled organisms, such as bacteria and protists, most multicellular organisms can be observed with the unaided eye. High-resolution technologies, such as X-ray crystallography, are required for investigations of molecular structure.

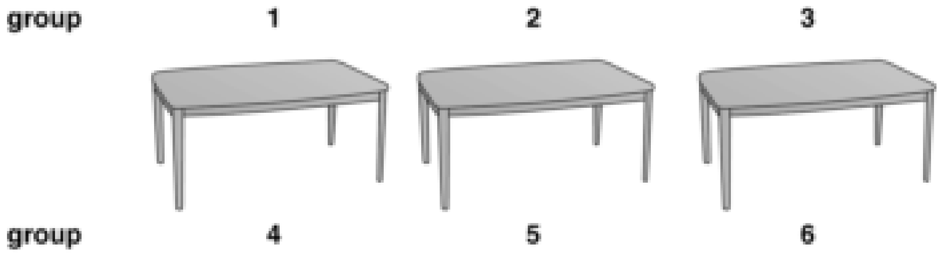
6. **Tell students that what makes some technologies better than others for a given job relates to the concept of "resolution." Ask them what** ***resolution*** **means.**

   Tip from the field test: Students generally had no concept of resolution as it relates to technologies used in biological science. Responses often related to resolution of computer monitors, personal resolve, or New Year's resolutions.

7. **Tell students that they will investigate resolution. Organize the class into groups of two and then pair two groups.**

   This activity works best if you have a minimum of six groups so that each can receive one of the six Masters 2.3 through 2.8.

8. **Ask groups to arrange their seating so that one is directly opposite another:**



   Allow sufficient room between tables so that groups do not interfere with one another.

9. **Explain to the class that this activity resembles the game Battleship, with which some of them might be familiar. Each group's task is to locate and define the shape of an object or objects on the master held by the opposing group.**

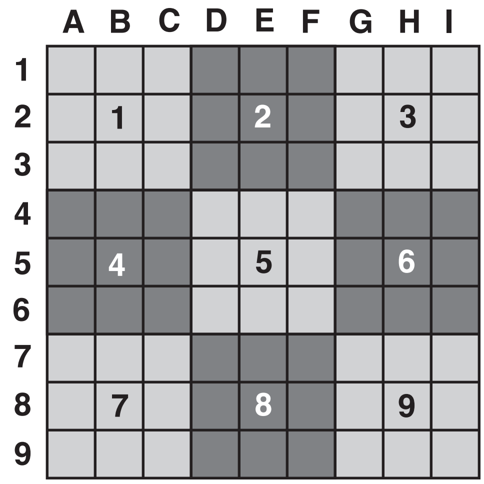
   Tip from the field test: Field-testing indicated the need to point out that this activity is not exactly like Battleship. Students do not "sink" or "destroy" an opposition's force. Rather, they use the Battleship strategy to locate and define the shape of a shaded region or regions on the master held by an opposing group.

10. **Give each group a copy of Master 2.1, *Probing for Answers Score Sheet.***

    Students use this sheet to record hits and misses as they probe for the location of the opposing group's shaded region(s).

11. **Randomly color several regions on a transparency of Master 2.1, *Probing for Answers Score Sheet*. Use this transparency and a 3 × 3 probe from Master 2.2, *Probes*, to demonstrate how this activity is done.**

    a. **Use this probe to locate areas 3 squares by 3 squares on the transparency. To save time, you may instruct students to probe only the nine nonoverlapping 3 × 3 regions, as shown on the following diagram:**



b. One group begins by calling out the location of the 3 × 3 area they wish to probe, such as A-C, 1-3.

c. If the opposing group's Master (2.3, 2.4, 2.5, 2.6, 2.7, or 2.8) has a shaded square within the area called, they indicate this as a hit; if not, a miss.

d. The first group records the result on their score sheet. Draw an X in 3 × 3 squares that are misses, and put an O in the 3 × 3 squares that are hits.

e. It is then the opposing group's turn to select an area to probe, which is then recorded as a hit or a miss.

f. Groups take turns trying to locate the opposing group's shaded squares.

12. **Give each group a copy of *one* master selected from Masters 2.3 to 2.8. Instruct groups to hide this master from their opposing group.**

Make sure that each of these six masters is used by at least one group. In larger classes, the same master may be used by more than one group. You may choose to place each master in a manila folder. Students can use the folder in various ways (for instance, opened and stood on its edge) to keep their master from being seen by the opposing group.

13. **Give each group a 3 × 3 probe from Master 2.2, *Probes*. Instruct students to use this probe to locate areas 3 squares by 3 squares that contain the opposing group's shaded area(s).**

Limit the time allowed for this portion of the activity to no more than five minutes.

14. **Ask students whether they believe they have gathered enough information to specify the *exact* shape(s) and location(s) of the opposing group's shaded object(s).**

    Make sure students in opposing groups do not share information about their shaded patterns. Students should realize from looking at their own shaded pattern that the 3 × 3 probe is too large to identify the shape and location of smaller objects; that is, the large probe cannot resolve the size and shape of the smaller objects.

15. **Ask students what would help them define the shape and location of the opposing group's shaded object(s).**

    A smaller probe is required.

    Tip from the field test: Field-testing indicated the importance of having students come to this conclusion on their own.

16. **Next, give each group a 2 × 2 probe. Groups are to focus on those areas that were determined to be hits with the larger probe.**

    Students are to repeat with this probe what they did earlier (see Step 13 above) and try to determine the structure and location of the opposing group's shaded pattern. Limit the time allowed for this portion of the activity to no more than several minutes.

17. **Ask students whether they believe they now have enough information to specify the exact shape(s) and location(s) of the opposing group's shaded object(s).**

    Make sure students in opposing groups do not share information about their shaded patterns. At this point, some students may believe they have sufficient information to predict the pattern held by the opposing group. Ask those willing to speculate on the opposing group's pattern to provide their justification, especially how they know that all four squares in a 2 × 2 "hit" region are shaded.

18. **Next give each group a 1 × 1 probe.**

    Students should focus only on those areas determined to be hits with the 2 × 2 probe. They should continue to define the structure and location of the opposing group's shaded pattern. Limit the time allowed for this portion of the activity to no more than several minutes.

19. **Ask students if they believe they now have gathered enough information to specify the exact shape(s) and location(s) of the opposing group's shaded objects. Do they need another probe to complete the task?**

Students should justify their responses. Students cannot know for sure what the opposing group's pattern looks like, even though they see that their own pattern is composed of 1 × 1 squares. If they speculate that the opposing group's pattern is constructed similarly, then no additional probes are required, since the objects being resolved (the 1 × 1 squares, both shaded and unshaded) are the same size as the final probe. Importantly, the final probe is not larger than the objects being resolved. If students believe that additional probes are required, they should justify this based on what they believe to be the size of the objects being resolved (shaded and unshaded). Their suggestion for an additional probe should indicate a probe size no larger than that of the objects being resolved. No matter what the response, ensure that students derive a general relationship between probe size and the size of the objects being resolved before proceeding. They should be able to explain that the size of the probe should be no larger than the objects being resolved.

Assessment: Listening to students explain their answers, defend their reasoning, and modify their responses after listening to other students explain their logic will help you assess students' understanding of resolution.

20. **Have opposing groups confirm that after using the series of three probes, they were able to determine the correct pattern on one another's master.**

Discussion Questions

1. **Why not use the smallest probe first?**

   A similar question is, Is there an advantage to using larger probes first and then using smaller probes? The larger probes allowed the students to quickly identify the general location of the object(s) being investigated. In some cases, even information about structure, albeit crude, can be obtained. Remind students of the procedure they follow when using a light microscope. They first use the lowest magnification to locate the object of interest and then switch to a higher magnification to gain more information. Using the smallest possible probe first can be time consuming and expensive. In some cases, using the smallest available probe also can be inappropriate; for example, when the probe is very much smaller than the objects being resolved. As an example, consider the time and expense involved in using an electron microscope rather than a light microscope to count yeast cells or to assess fruit fly traits in a genetics experiment.

2. **On the board, write these wavelengths:**
   - **visible light, 4 to 7 × 10^{-7} m;**
   - **electrons, 2.7 to 0.9 × 10^{-10} m; and**
   - **X-rays, 1 × 10^{-8} to 1 × 10^{-11} m.**

   Refer to Master 1.1, *Searching for Scale,* and ask students which

of these they think would be appropriate probes (that is, provide the appropriate level of resolution) for the objects listed.

Visible light could be used to resolve cells, bacteria, and mitochondria. Longer-wavelength electrons are potential probes for viruses, small cell organelles such as ribosomes, and large molecules such as proteins. Shorter-wavelength electrons and short-wavelength X-rays are potential probes for molecules, even small ones like glucose. They also may be used to resolve adjacent atoms in molecules (which requires probes smaller than 2×10^{-10} m).

Teacher note: Whether or not a probe is useful in a given situation also depends on whether the technology actually exists to make use of the probe. For instance, are appropriate sample-preparation techniques available? Are appropriate sample handling technologies available (for example, can the sample be rotated if necessary, and in a way that does not interfere with the rest of the procedure)? Can the probe be focused sufficiently? Is there technology to view and evaluate the results of such analyses?

Activity 2: *More Than Meets the Eye*

1. **Begin by holding one of the bread rolls up to the class. Make sure that no dye is showing. Ask students to describe what they see.**

   Students will recognize the object, and they may describe it by noting its color, shape, and apparent external texture. They should indicate that the roll is a three-dimensional object.

2. **Do students have maximum information about the roll? Is there anything they do not know about the bread roll from just looking at it?**

   Student responses will vary from, "Is it tasty?" and "Where does it come from?" to "What is inside?" Some students may realize that although they might have made an assumption about the roll's interior (for example, it is just plain bread), they actually know nothing about what is under the crust.

3. **Focus discussion on what is inside the bread roll. Ask students how they would get that information.**

   Students will suggest cutting or tearing the roll.

4. **Slice the roll to reveal the presence of dye in one of the two dye locations. Hold the roll so the class can see**

the two cut edges. Do the students now feel they have complete information about this object? If not, what questions do they have?

Even though they know there is a dyed region inside the roll, students should realize that they do not know what this region looks like. What is the shape of the dyed region and how far does it extend in any given direction? Is there only a single dyed region, or are there multiple regions? If there is more than one dyed region, is it the same color as the region they can see?

Tip from the field test: Some students suggested cutting the roll as one would if making a sandwich. The second bread roll is helpful if this possibility is raised.

5. **Ask students how they could obtain information to answer these questions.**

   A simple approach would be to make additional slices in the roll. Students may suggest more exotic means (for example, use a fiber optic light source connected to a minivideo device to view the roll's interior on a remote screen). If suggestions fall in the latter category, congratulate students for their ingenuity. Ask them to think about how to gain the information required quickly and using simple, available technology. In the end, focus student attention on increasing the number of slices. This requires only a knife and can be done quickly.

6. **Ask the students how many slices would be required to define the dyed region(s) in the roll's interior. What are their considerations in providing an answer to this question?**

   The actual number of slices that the students believe is correct is not the important issue. If students do provide a specific answer, ask them to justify it. It is important for them to understand the following. First, multiple slices *are* required to define the object's properties. The *size* of the slices will determine the resolution used to define the object's properties. Thicker slices will provide less resolution, just as the 3 × 3 probes provided low resolution in Activity 1. Thinner slices will provide greater resolution, just as the 1 × 1 probes did in Activity 1.

7. **Ask students to have their group's Master 2.3 to 2.8 available. Explain that the "level" designation below the grid (Level 1, 2, 3, 4, 5, or 6) on the master indicates the location of a slice through an object.**

   Level 1 is the top slice, followed by 2, 3, 4, 5, and 6 (at the bottom).

8. **Ask students to visualize their pattern in three dimensions by imagining that their shaded pattern represents the top of a stack of gray blocks. Their level is a slice two blocks thick.**

9. **Ask the groups to share their data (that is, the location of the shaded regions) and try to reconstruct the three-dimensional object that has been cut into six slices.**

   Do not provide additional guidance. Give students about five minutes to do this. Students may or may not be able to reconstruct the object in this time.

For those using the Web version *of this activity, proceed as follows:*

10. **Were students able to arrive at a solution? What might have made the task of reconstructing the object in three dimensions easier?**

    Students might suggest that a computer could provide the technology to make reconstruction easier.

11. **Have students proceed to the URL *http://science.education.nih.gov/supplements/technology/student*. Students should then click on the link to "Lesson 2—Solution to Probing for Answers." This brings up the unit's desktop, from which students can access this activity.**

12. **Students can enter their data by first selecting a level (1 to 6) and then clicking on the squares they determined to be shaded. The reconstructed object will appear as data are entered.**

    It may be easier and less time consuming for the teacher to enter the data provided by the students.

NSES

Content Standard E: Identify a problem or design an opportunity.

Content Standard E: Implement a proposed solution.

Content Standard A: Scientists rely on technology to enhance gathering and manipulating data.

For those using the print version *of this activity, proceed as follows:*

10. **Show students a transparency of Master 2.9, *Solution to Probing for Answers*. Were they able to arrive at this solution? What might have made their task easier?**

    Some students do well thinking in three dimensions, and others do not. Many may recognize the need for additional technology, such as a computer and appropriate software, to make the job of reconstruction easier. Even a simple technology, such as wooden blocks or Legos, could have been used to construct a three-dimensional model of the intact object.

NSES

Content Standard E: Identify a problem or design an opportunity.

Assessment:
This question allows students to integrate the information they have learned in the first two lessons and refine their understanding of what technology is.

Discussion Question

1. **As a follow-up, ask students, "Have these activities expanded your understanding of technology? If they have, how?"**

   Activity 1 demonstrates the use of multiple probes to achieve different levels of resolution. It also demonstrates that the right tool, in this case a probe of appropriate size, must be selected to solve a problem (resolving the structure of an unknown object). Therefore, students should realize that there is an appropriate technology for a given problem (that is, the right tool for the job). Activity 2 demonstrates that solutions to a problem may involve more than one technology (the use of slices to determine the structure of a three-dimensional object and technologies to collect and analyze the data).