

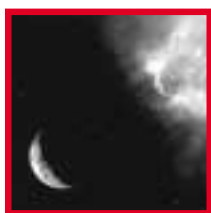
The background of the cover is a deep space scene with a dense field of stars and numerous bright, colorful streaks of light in shades of blue, purple, and teal, suggesting high-speed travel or cosmic phenomena. A white crosshair is centered on the page, with the title text overlaid on it.

COSMIC VOYAGE

A TRAVEL GUIDE FOR EDUCATORS

C O S M I C

V O Y A G E



A TRAVEL GUIDE FOR EDUCATORS

Educational Services Department
National Air and Space Museum
Smithsonian Institution

Presented By
The Smithsonian Institution's National Air and Space Museum and the Motorola Foundation
Produced by Cosmic Voyage Incorporated with additional support from the National Science Foundation.

Cosmic Voyage

A Travel Guide for Educators

Educational Services Department
National Air and Space Museum
Smithsonian Institution
Washington, DC

Cosmic Voyage is presented as a public service for the advancement of science education by the National Air and Space Museum and the Motorola Foundation with additional support from the National Science Foundation. The film is a production of Cosmic Voyage, Inc. and is distributed by Imax Corporation.

Cosmic Voyage, which premiered in the summer of 1996, is a special commemorative program of the Smithsonian Institution's 150th and the National Air and Space Museum's 20th anniversaries.

The film was shown at the Museum's Samuel P. Langley Theater (renamed the Lockheed-Martin IMAX Theater) and is being shown in other IMAX/IMAX Dome (OMNIMAX) theaters worldwide. To locate an IMAX format theater near you log on to <http://www.imax.com>. Enter the site and go to theaters. To find a listing of large-format non-IMAX theaters showing *Cosmic Voyage* contact MacGillivray-Freemen Films at (949) 494 1055.

Cosmic Voyage: A Travel Guide for Educators was produced in conjunction with the film to provide educators with information and activities to enhance the educational content of the film. It was developed by the Educational Services Department of the National Air and Space Museum. For more information about educational programs at the Museum visit: <http://www.nasm.si.edu>

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COSMIC VOYAGE

“With *Cosmic Voyage*, the National Air and Space Museum continues its tradition of presenting high-quality educational films in large format. *Cosmic Voyage* reveals the wonders of the universe from the tiniest building blocks of matter to superclusters of galaxies. The National Air and Space Museum hopes that young viewers will be inspired by the film to join the next generation of explorers and scientists who will investigate the challenges of the 21st century.”

Donald Engen
National Air and Space Museum
Director (1996 - 1999)



Acknowledgments

Cosmic Voyage: A Travel Guide for Educators is dedicated to the next generation of voyagers and to those committed to helping them get started on the journey. The following people contributed to the development and production of this publication.

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“Career Connections” was written by Leslie O’Flahavan.

“Get the Picture” was adapted from *Space-Based Astronomy: A Teacher’s Guide with Activities* (National Aeronautics and Space Administration, 1994).

“Inner Space” was adapted from ideas and activities found in *Beauty and Charm at Fermilab: A Teacher’s Guide* (Fermi National Accelerator Laboratory, 1993).

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ICONS

Our Space

In a scene from the film, a young girl sits within a miniature city in Holland. ©1996 BY SMITHSONIAN INSTITUTION & THE MOTOROLA FOUNDATION.

Outer Space

Primordial Earth is seen from space in *Cosmic Voyage*. ©1996 BY SMITHSONIAN INSTITUTION & THE MOTOROLA FOUNDATION.

Inner Space

Cosmic Voyage takes viewers into the double helix of a DNA molecule. ©1996 BY SMITHSONIAN INSTITUTION & THE MOTOROLA FOUNDATION.

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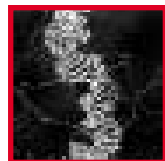


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OBJECTIVES AND GRADE LEVELS

			
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THE MAKING OF COSMIC VOYAGE

So, naturalists observe, a flea
Hath smaller fleas that on him prey;
And these have smaller still to bite 'em;
And so proceed ~~ad infinitum~~.
—Jonathan Swift, 1733

It is not surprising that the author of *Gulliver's Travels* composed this amusing view of an infinite regression from the tiny to the infinitesimal. Swift had an obvious fascination for questions that philosophers and ordinary people alike have pondered for millennia: How big is big? And how small is small?

Cosmic Voyage, a large-format film from the Smithsonian's National Air and Space Museum, attempts to answer these age-old questions with an unprecedented portrait of the universe, from the unimaginably small to the incomprehensibly large. Along the way the film covers a spectrum of the sciences—astronomy, physics, geol-

ogy, chemistry, and biology. The film provides students with a unique experience that will give them new insight into our place in the universe.

Lemuel Gulliver stood halfway between the miniature Lilliputians and the gigantic Brobdingnagians. Today, our most sophisticated scientific instruments show us that humans seem to be similarly positioned between the tiniest subatomic particles and the most immense galactic structures. The range of scale of the known universe extends across some 42 orders of magnitude, or powers of ten.

To explore this mind-boggling range, *Cosmic Voyage* uses a concept employed nearly 40 years ago by a Dutch school

teacher. In his 1957 book, *Cosmic View; The Universe in 40 Jumps*, Kees Boeke created a "cosmic zoom" with a series of pictures, each of which shows a scene that is ten times broader than the one before. *Cosmic Voyage* extends this concept in the powerful IMAX medium. In the words of writer/director Bayley Silleck, "The film addresses two questions of profound interest to all of us on the planet: Where are we in the vast cosmos? And how did we get here?"

Starting on the surface of Earth in a scene that is a meter wide and seen from a meter away, we move ten times farther away and increase the width of our view tenfold every few seconds, to ten meters,

Director Bayley Silleck, right, and
Cinematographer Ernie McNabb,
with the IMAX camera,
filming on location in Greece.



©1996 BY SMITHSONIAN INSTITUTION & THE MOTOROLA FOUNDATION. PHOTO CREDIT: STEVE FORD

then one hundred, a thousand, and so on. In a surprisingly short time we have zoomed far from Earth, past other planets and stars and out to the most distant reaches of the cosmos, where groups of billions of galaxies, each containing billions of stars, appear as individual points of light. Returning to Earth, we take a similar journey inward, each step magnifying the previous scene by a factor of ten. Looking into a drop of pond water, we find new worlds hidden: single-celled microorganisms such as paramecia, and inside them, the complex molecules of life, DNA. From there we enter a single atom and its components: electrons, protons, neutrons; and beyond to the quarks that may be, according to our current understanding, among the fundamental building blocks of all matter.

Cosmic Voyage also examines the fourth dimension by taking a trip through time, from the formation of the universe in the big bang to the present. Viewers will witness the development of stars and galaxies, the birth of our own solar system, and the development of life on the young Earth.

Cosmic Voyage contains a significant amount of computer animation created from actual scientific data and theoretical models. For instance, the starfields seen in the film are derived from the Smithsonian Astrophysical Observatory's detailed star catalogs, and accurately show the correct position, the apparent brightness, and even the color temperature of tens of thousands of stars. A spectacular collision of two galaxies was rendered from computer models developed by astrophysicists at the University of California, Santa Cruz.

To animate some sequences, Donna Cox of the National Center for Supercomputing Applications (NCSA) used a virtual reality system called Virtual Director, which she developed with

colleagues Bob Patterson and Marcus Thiebeaux at NCSA. Standing in a 10-foot cubical room, known as a "Cave," the operator wears a head-mounted tracker and electronic 3-D glasses, similar to those used in some IMAX 3-D theaters. Three-dimensional video images are rear-projected on the walls of the Cave, immersing the operator in the starfield (or other data set) that is to be animated. By moving through the room, the operator controls the motion of a virtual "camera" through the data set's virtual universe.

As impressive as high tech can be, everyone involved in the project was dedicated to seeing that *Cosmic Voyage* achieved an appropriate mix of education and entertainment. An advisory board composed of some of the world's leading scientists ensured the accuracy of the scientific content. A comment by John Grower, president of Santa Barbara Studios, on the challenges he faced sums up what the whole team hopes will be students' reaction to *Cosmic Voyage*: "It's been an incredible ride, and we've learned a lot."

© UNIVERSITY OF ILLINOIS, URBANA-CHAMPAIGN (UIUC). PHOTO CREDIT: JEFF CARPENTER, NCSA/UIUC



To create images for the film, Dr. Donna Cox and Bob Patterson use Virtual Director, a three-dimensional graphics software.

THE TRAVEL GUIDE

If you have ever tried to describe the big bang or attempted to explain how scientists study the internal structure of an atom, you will appreciate what *Cosmic Voyage* can offer your students. The film summarizes our current understanding of the universe from galaxies to quarks. Supercomputers and scientific visualization techniques make it possible to portray events in an exciting visual format, and at the same time, remain faithful to contemporary scientific models and theories. Students will be able to see on the big screen phenomenon that are difficult, if not impossible, to demonstrate in the classroom.

This film transports students beyond the realm of normal human experience to the limits of scientific knowledge—from the edge of the known universe to

inside the nucleus of an atom. Before embarking on the journey, students will benefit from experience with metric measurements and scale. The activities found in “Our Space” provide this essential background. To better understand how scientists know what they know, students can do the activities in “Outer Space,” which looks at astronomy and in “Inner Space,” which looks at the nature of matter. Through simulated experiences, students examine research techniques employed by scientists in their work. The “Objectives and Grade Levels” chart will help you select the activities best suited for your students.

The activities have been designed for, and tested in, middle school classrooms, but they can easily be adapted for other circumstances. The materials needed for the activities are inexpensive and, for

the most part, easy to acquire. The background information gives content and practical advice for the teacher. If you are interested in integrating mathematics and science, there is plenty of opportunity. Check out the “Curriculum Connection” at the end of each activity for suggestions. “Career Connections” at the end of the guide offers paths for students who want to continue their journey of discovery in science and mathematics. An astronomer, an engineer, and a model builder talk about their work and their lives. Used alone or in conjunction with the film, the activities in this guide provide students with concrete experiences to help them understand measurement, scale, and how scientists work. Equipped with the information in this guide, you are prepared to take your students on a cosmic voyage.

Bon Voyage!

*Maureen Kerr
October, 1996*



A man next to a miniature passenger jet challenges our perception of size in a scene from the film.



POWER VIEWERS

ActivityOne

Purpose: Students examine the relationship between the apparent size of an object and distance from which that object is viewed.

Overview

H

How does the apparent size of an object change as we move away from it? In this activity students predict how tall a fellow student will appear when viewed through a transparent grid at three different distances: 1 m, 10 m and 100 m. Students then make observations at each of these distances with the transparent grid. Students compare their predictions to their observations and discuss how changing distances affects the apparent size of an object.

Preparation

Make the Power Viewers. Copy the student worksheet onto transparencies. Each transparency will have three grids and can be used to make three Power Viewers. Cut out the grids leaving a border around each one. Make frames from poster board.

Copy the student worksheets. Copy two for each student. One will be used for prediction, and the second will be used for observation.

Set up the viewing area. Find a location with an unobstructed view at least 100 m long. (This will probably be outside.) Ideally the area will be wide enough for half the students to line up facing the other half of the students. If not, students

can take turns making their observations. Mark a starting line. Measure and mark three lines: 1 m from the starting line, 10 m from the starting line, and 100 m from the starting line. Locate landmarks that are approximately 1,000 m from the starting line to be referenced later during the discussion.

Procedure

Introduce the activity. Hold up a Power Viewer and explain to the students that they will use the viewer to observe another student from three different distances: 1 m, 10 m and 100 m.

Make predictions. Give the students one worksheet each and have them circle “prediction” at the top of the page. Tell them to draw a stick figure or outline showing how tall they think a student will appear when observed through the grid from each of the three distances: 1 m, 10 m and 100 m.

Get ready for observations. Give each pair of students a viewer and a clipboard. Give each student a second worksheet and have them circle “observation” at the top. Emphasize the importance of keeping the viewer the same distance from the eyes for each observation. Remind students to draw what they see through the grid.

Make observations. Have the students move to the viewing area, with half of the students standing at the starting line

facing the 1-m line. Instruct the other half of the students to stand at the 1-m line facing the starting line. Have partners stand next to each other on the same line, so they can share a clipboard and viewer. Have students draw an outline or stick figure showing the apparent height of the student standing opposite them 1 m away. When everyone has finished, have the students standing at the 1-m line move to the 10-m line, and again, have all students record their observations. Repeat for 100 m.

Compare the predictions and observations. Have the students compare their predictions to their observations.

MATERIALS

For each student team:

- Power Viewer
- Clipboard or a heavy piece of cardboard with a clip

For the Power Viewers:

- One transparency sheet for every three Power Viewers
- Poster board or file folders (12 cm x 14 cm for each frame)
- Utility knife or scissors to cut frames
- Cellophane tape

For each student:

- Two copies of the “Power Viewers” student worksheet

Reflection and Discussion

1. How did your observation differ from your prediction?
2. How does the apparent size of an object change as you move farther away? (As you move farther from an object, the object appears to get smaller. When you move 10 times farther away the object appears to be about $1/10$ th its previous size.)
3. Each time you made an observation you moved 10 times farther away. If you continued, the next observation would be 1,000 m away. If your view was not blocked by anything, do you think you could see the student from this distance? How tall do you think the student would appear to be?

Extension

1. Students can develop a data chart or graph comparing distance and apparent height.
2. Students can use the PowerViewer to do a perspective drawing.
3. Students can investigate related astronomy topics, such as angular size and inverse square law.



In the film the journey starts in St. Mark's Square in Venice where the acrobat's ring is 1-m wide while the crowd is 10-m wide.

Background Information

This activity is recommended for fourth grade and up. Students begin their observations at a distance of 1 m and move ten times farther away for each subsequent observation. The distances can be expressed as a “power of ten.” A power of ten refers to the number of times 10 is multiplied by itself. For example, 100 m is equivalent to 10^2 m, while 10^3 is read as “10 to the third power” and is equal to $10 \times 10 \times 10$ or 1,000. The number 3, in this example, is an exponent. The exponent is equal to the number of zeros after the one. A negative power of ten indicates the number of times to divide by 10 which means that 10^{-3} is equal to 0.001. Powers-of-ten notation is used to express very large and very small numbers.

Powers of Ten

10^3	1,000
10^2	100
10^1	10
10^0	1
10^{-1}	0.1
10^{-2}	0.01
10^{-3}	0.001

If students have not studied exponents, there is no need to address powers-of-ten notation to benefit from this activity. Refer to the distances in meters and point out that each step is ten times farther than the last one. Students will still be able to investigate the relationship between the apparent height of an object, in this case another student, and distance.

The Power Viewer is designed to help students observe and record the apparent

size of another student by helping them overcome the tendency of the mind to make adjustments to what the eye sees. During the

Renaissance,

Albrecht Dürer developed a device, an upright wire grid to help artists master perspective drawing. The Power Viewer is similar to this device.

The Power Viewer is not designed for precise measurement, but using it should help students begin to understand the relationship

between apparent size and distance. If you move ten times farther away from the object, the object will appear to be 1/10th its previous size. During the activity monitor student observations and encourage them to keep the Power Viewer the same distance from their eyes and to draw what they actually see through the grid.

Curriculum Connections

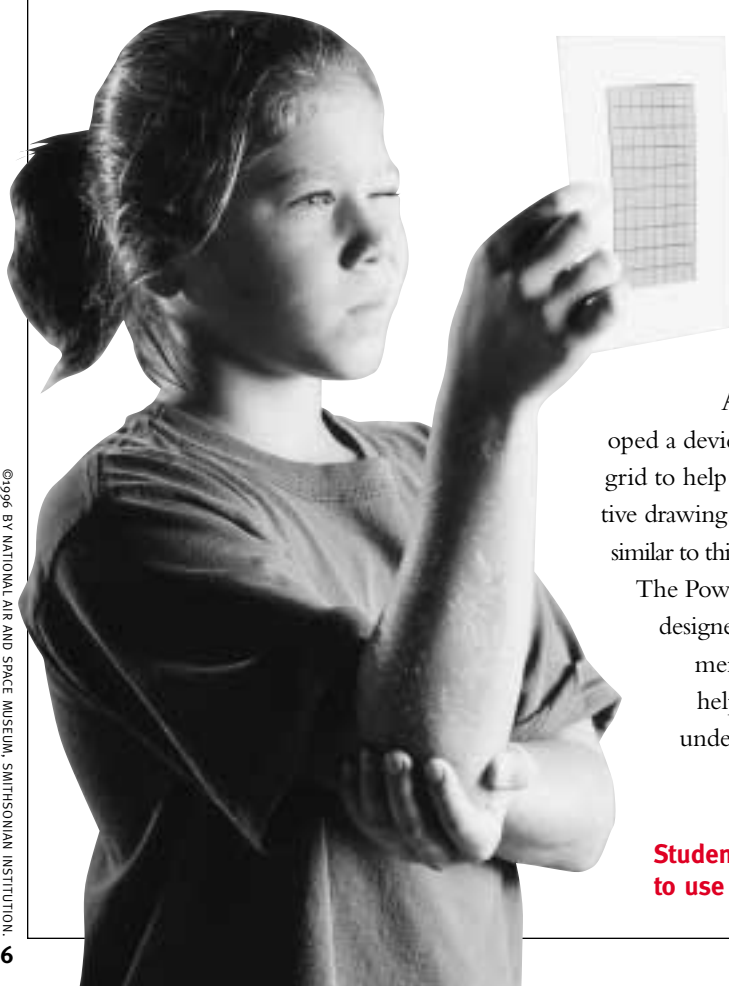
Powers of ten

Place value concepts

Exponents (exponential notation)

Film Connection

In the film the camera will zoom out by powers of ten and then zoom in by powers of ten. The narrator sometimes refers to these as steps. For example, “Eight steps on our outward journey, eight powers of ten...” Although the distances traveled in *Cosmic Voyage* are far beyond human experience, this activity will help students begin to appreciate the meaning of distances measured by “powers of ten” and to understand the steps they will see in the film.



Student demonstrates how to use the Power Viewer.

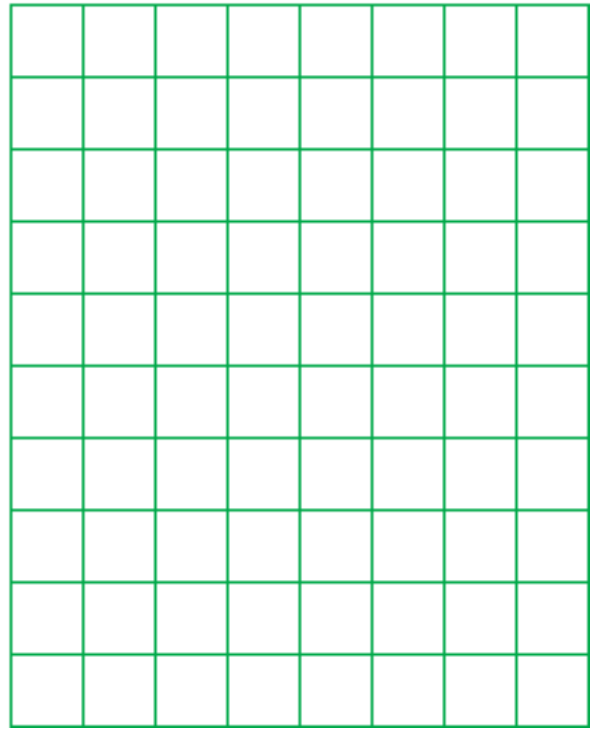
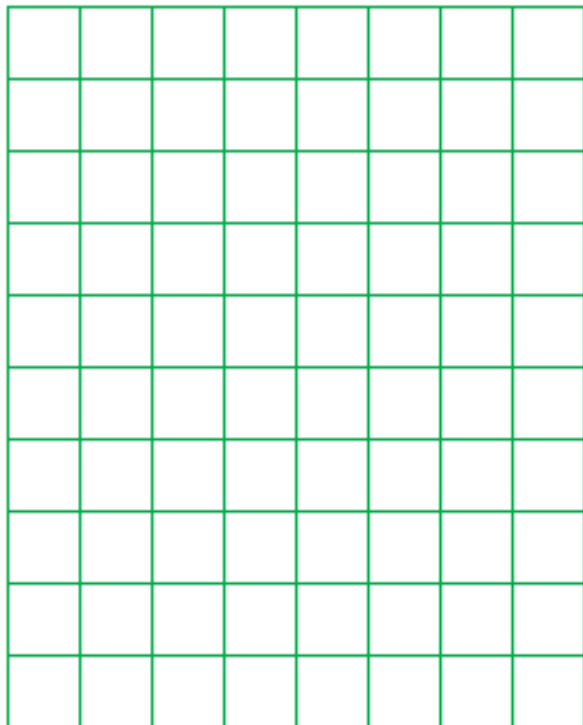
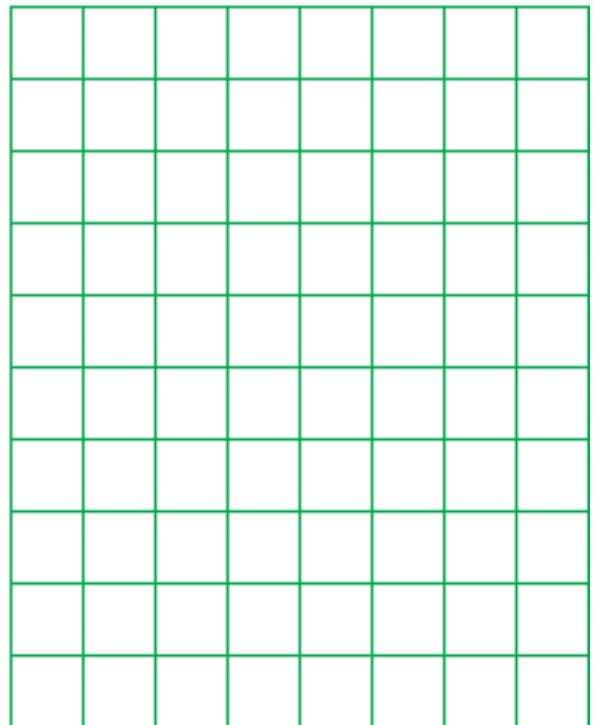


Name _____

Circle One: Prediction or Observation

Directions for Prediction: Draw an outline or stick figure that shows how tall a student would appear if observed through a grid at each of the distances.

Directions for Observation: For each grid on the worksheet, move to the correct viewing line. Look through the transparent grid at another student and draw what you see. Make sure you draw it in the correct grid for that distance. Remember to hold the PowerViewer the same distance from your eyes for each observation.

**Grid 1** Distance = 10^0 or 1 meter**Grid 2** Distance = 10^1 or 10 meters**Grid 3** Distance = 10^2 or 100 meters



METRIC ME

ActivityTwo

Purpose: Students use nonstandard measurement tools to become familiar with metric units of length.

Overview

How can we improve our ability to think about measurements in metric units? In this activity students learn how to use personal rulers—hand span, height, and pace—to make approximate measurements. Students also practice estimating and measuring metric lengths and distances.

Preparation:

Identify objects to measure. Select a variety of objects between 10 cm and 10 m for students to estimate and measure.

Locate an area. Students will need about 10 m to walk 10 paces. Mark a starting line with masking tape.

Set up a location to measure height. Tape blank paper to walls or doors where students can mark and measure their heights.

Procedure

Set up data tables. Have students set up data tables in their journals or on data sheets.

Object	Estimation no tools	Approximation personal rulers	Measurement standard rulers

MATERIALS

For the class:

- Blank paper
- Masking tape

For each pair of students:

- Metric ruler
- Meter stick
- Objects to measure

Estimate metric lengths. Have students use metric units to estimate three measurements of varying length. For example, they could estimate the width of a book, the height of a doorway, and the width of the classroom. Have students record their estimations.

Measure span. This is the distance between the tip of the little finger and the tip of the thumb when the hand is fully extended. Have each student place a hand on a metric ruler with fingers extended. Record this measurement and label it “hand span.”

Measure height. Have the students work in pairs to measure one another’s height. Record this measurement and label it “height.”

Find average pace. A pace is measured from the point that a heel leaves the ground until the point that this same heel touches the ground again. The student stands with both heels on the starting line. Have the student start walking with the left foot first and then the right. Have the student count one pace each time the right heel hits the ground. The student walks ten paces and then measures the distance from the starting line. Divide this distance by ten to get the average pace. Record this measurement and label it “average pace.”

Use personal rulers. Have students use their personal rulers—hand span, height, and average pace—to help them make approximate measurements of the objects. Have them record their approximations.

Measure with standard rulers. Have students measure the objects using standard metric rulers or meter sticks. Have them record their measurements.



Reflection and Discussion

1. Without looking at your data, give the span of your hand, your height, and your average pace in metric units.
2. Describe a situation where knowing these measurements may be helpful.
3. Compare the advantages and disadvantages of personal rulers and standards rulers.

Extension

1. Students use height measurements for the activity “Big and Small” and pace measurements for “Zoom Out” found in this guide.
2. Students can create a map of the school campus or neighborhood by determining approximate distances using paces.
3. Students can investigate the history of measurement and compare the earlier methods of measurements to the modern standards.

Background Information

This activity is recommended for fourth grade and above. By applying metric units of measurement to themselves, students develop a personal connection to the meaning of the units and apply this to the world around them. If a student knows she is 1.5 m tall, she can then compare her height to the height of a doorway and make a reasonable estimate. If a student knows his hand span is 15 cm, he can picture a plant that is 30 cm tall. Students should recognize that the advantage of personal rulers is that you always have one. Standard metric rulers, however, are more accurate.

Metric Units

kilometer (km) = 1,000 m
meter (m) = 1 m
centimeter (cm) = 0.01 m
millimeter (mm) = 0.001 m

Curriculum Connections

Estimation
Metric measurement

Film Connection

Metric measurements are used throughout the film. Familiarity with these units and their meaning will increase students' understanding of the film. Specifically, the film refers to meters, kilometers, and millimeters. In addition, the film mentions light year, the distance light travels in a year (9.5 trillion km).

BIG AND SMALL



Activity Three

Purpose: Students explore big and small in the normal realm of human experience and use scale drawings to compare size.

Overview

How big is big? Before students can appreciate relative size on a cosmic or atomic scale, they must be familiar with big and small in their world. In this activity students begin by guessing the name and size of the largest and smallest objects in specific categories. Students then use scale drawings to compare the relative size of some of the objects.

MATERIALS

For each student:

- “Big and Small” student worksheet
- “Scale Drawing” student worksheet
- Plain paper (1 sheet)
- Metric rulers

Preparation

Make copies. Copy the “Big and Small” and “Scale Drawings” student worksheets for each student.

Procedure

Complete “Big and Small” student worksheet. Distribute “Big and Small” student worksheets only. Do not let the students see the photographs before they complete the worksheet. Have the students work in small groups to guess the name and size of the object for each category. There is no need for the students to come to consensus. Each student will write his or her answer on the worksheet. Remind them to use metric units to record the size.

Discuss the answers. Ask the students to share their answers. Allow time for discussion of big and small things.

Compare a hummingbird to your hand.

Let students know that they will continue to explore big and small things by using scale drawings to help them compare size. Distribute the “Scale Drawing” student worksheet and one sheet of plain paper to each student. Have each student use a pencil to trace the outline of his or her hand on the paper. Tell them to stay as close to the hand as possible when they trace so the outline is the same size as the actual hand. The photograph of the hummingbird is full scale, the same size as an

actual hummingbird. Have students cut out the picture of the hummingbird and place it on the outline of the hand. This is a full scale comparison of the hummingbird and the student’s hand.

Compare the height of a giraffe to your height.

Tell the students that because some things are too big to put on paper full size, we will use a scale drawing to study the giraffe. A scale is a ratio between two sets of measurements. In this case, the scale is the ratio between the height of the giraffe in the picture and the height of the real giraffe. The giraffe in the picture is 15 cm tall. The real giraffe is 6 m or 600 cm tall. To calculate scale you must use the same units of measurement. In this case we will use cm. The scale is 15:600 or 1:40 ($15/600 = 1/40$). Each cm on the paper represents 40 cm in the real world. Have each student figure out his or her height at this scale. (Divide height in cm by 40). Have each student draw a stick figure or outline next to the giraffe showing his or her height at this scale.

Compare the height of the giraffe to the height of a redwood tree. Let the students know that you have to change scale for objects of different sizes. Challenge the students to figure out how large the redwood tree would be at a 1:40 scale. The redwood would be 275 cm (11,000 cm/40), which is too large to fit on the

paper. Have the students calculate the scale for the picture of the redwood tree. The scale is the ratio of the height of the tree in the picture (20 cm) to the actual height of the redwood (110 m or 11,000 cm). The scale is 20:11,000 or 1:550. Have the students calculate the size of the giraffe at this scale. Divide the actual height of the giraffe in cm by 550. (600 cm/550) At this scale the giraffe would be just over 1-cm tall. Have the students draw the giraffe next to the redwood. Challenge the students to figure out how tall they would be at this scale. (Divide the student's height in cm by 550.)

Reflection and Discussion

1. Did anything surprise you about the drawings?
2. Explain how drawings give you a better understanding of size than the measurements alone.
3. Give some other examples where scale drawings can be used.

Extension

1. To explore much bigger and much smaller scales, students can do the “Zoom Out” and “Zoom In” activities found in this book.
2. To continue their investigation of relative size, students can do additional scale drawings or three-dimensional models.
3. Students can see the effect of changing scale by looking at, or drawing, maps of the same area at different scales.

Background Information

This activity is recommended for middle school students who have studied ratios. If students are not familiar with ratios, they can complete the “Big and Small” worksheet and only do the hummingbird comparison.

The answers to the “Big and Small” worksheet are subject to debate, so be prepared for an interesting discussion. The authority for this information is *The Guinness Book of World Records 1996* (Guinness Publishing Ltd., 1995).

The **smallest fish** is the dwarf goby (*Trimmatom nanus*), which averages 9 mm (0.34 in). Found only in the Indian Ocean, this fish is also the smallest vertebrate (animal with a backbone).

The **tallest mammal** is a giraffe (*Giraffa camelopardalis*), which can be as tall as 6 m (20 ft). The largest mammal is the blue whale (*Balaenoptera musculus*), which can be as long as 34 m (110 ft).

The **tallest living tree** is a redwood (*Sequoia sempervirens*) in California. It is 111 m (365 ft). In 1872 an Australian eucalyptus tree (*Eucalyptus regnans*) was reported to measure 133 m (435 ft).

The **tallest office building** in the world, according to *The Guinness Book of World Records 1996*, is the Sears Tower in Chicago at 443 m (1,454 ft) with 110 stories. The tallest building and freestanding tower is the CN Tower in Toronto at 553 m (1,815 ft). Since the Guinness Book went to print, the Petronas Twin Towers in Kuala Lumpur, Malaysia, have been completed. The 88-floor building stands 452 m (1,483 ft). The World Financial Center in Shanghai, which is planned to be completed in 1999, will be 460 m (1,509 ft).

The **highest mountain** in the world is Mt. Everest in the Himalayas at 8,854 m (29,029 ft). Mt. McKinley in Alaska is the highest mountain in the United States at 6,198 m (20,320 ft). The tallest mountain in the world, measured from its submarine base, is Mauna Kea on the island of Hawaii at 10,211 m (33,480 ft). Only 4,208 m (13,796 ft) of it are above sea level.

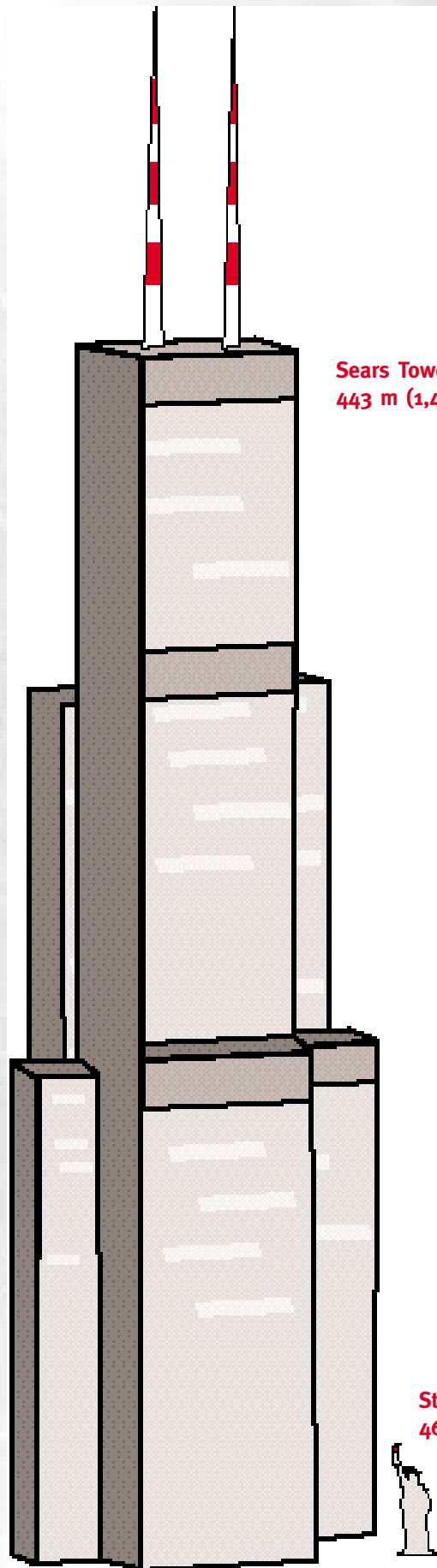
The **smallest bird** is the bee hummingbird (*Mellisuga helenae*) found in Cuba and the Isle of Pines. An average adult male measures 6 cm (2.4 in) while the female is slightly larger.

Curriculum Connections

Relative size
Estimation
Metric measurement
Ratio and scale

Film Connection

Before students leave familiar surroundings to begin their cosmic voyage, they can benefit from looking at the relative size of objects found in “our space.” In the film, the journey outward begins at St. Mark’s Square in Venice with acrobats holding a ring that is 1-m wide. They are surrounded by a ring of spectators that is 10-m wide. The journey inward begins along the waterways of Holland. A student studies a drop of water. As the camera moves in, paramecia fill the screen. The field of view is only 1 mm across. During the film students will also have a chance to see Mauna Kea, the tallest mountain in the world and the location of the Keck Observatory.



Sears Tower in Chicago
443 m (1,454 ft)

Statue of Liberty
46 m (152 ft)

Average Teenager
1.5 m (5 ft)



Big and Small

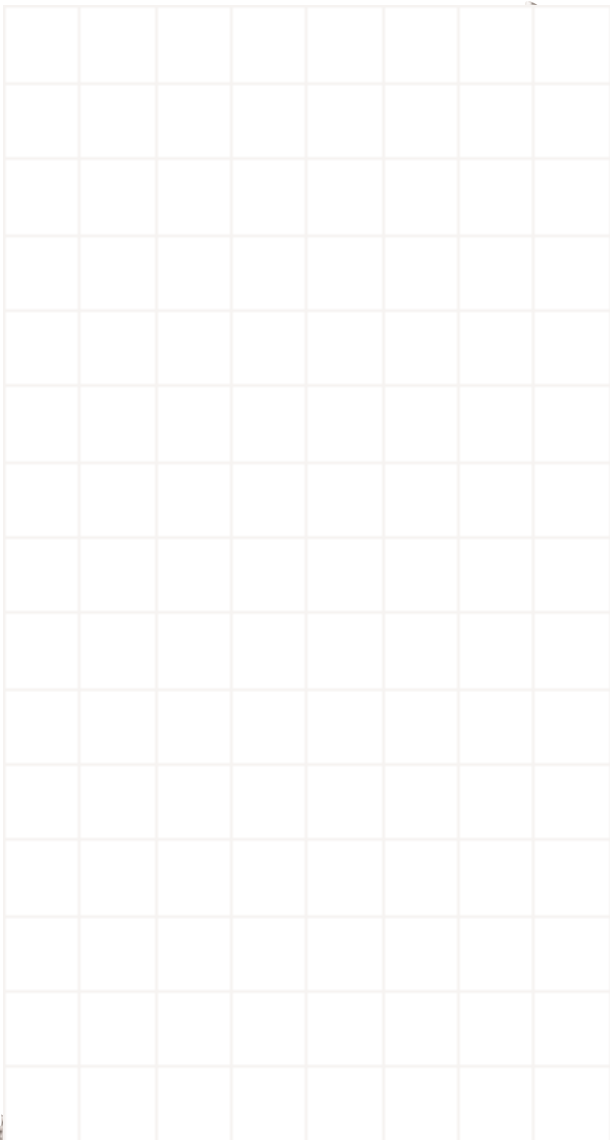
Student Worksheet 1

Name _____

What are some of the biggest and smallest things in the world around us? Look at the chart below and try to guess. You may discuss them with group members, but you do not have to come to an agreement. Write your own guess for the names and sizes on your paper, and remember to use metric units for the size.

BIG AND SMALL	MY GUESS		ACTUAL	
	Name	Size	Name	Size
smallest fish	goldfish	2 cm	dwarf goby	9 mm
tallest mammal				
tallest tree				
tallest building in the world				
highest mountain in the world				
smallest bird				

Scale Drawing





GET THE PICTURE

ActivityFour

Purpose: Students simulate how instruments aboard spacecraft collect and transmit digital images to Earth-based computers.

Overview

Have you ever wondered how scientists get images from spacecraft? In this activity students learn how instruments on spacecraft measure the amount of light (electromagnetic radiation) reflected or emitted by objects in space and how this information is transmitted to Earth. Working in pairs, one student places a transparent grid over a picture to simulate pixels (picture elements). The student then uses a gray scale to assign a brightness value to each pixel and coordinates to indicate location. The student transmits the data to another student who represents an Earth-based computer that converts the data to an image.

Preparation

- Make the folders.** Copy the “Pixel Grid” onto transparencies. Copy the sample picture onto regular paper. Place one transparent “Pixel Grid” and one sample picture into each folder. Label the folder “transmitter.” These folders can be reused for other classes.
- Copy the Pixel Grid.** Make paper copies of the “Pixel Grid” for the receivers. The paper grids cannot be reused, so copy one for each pair of students in each class.
- Make a transparency.** Copy the “Effect of Changing Pixel Size” on a transparency for class discussion.

Procedure

- Introduce the activity.** Ask students to explain how they think scientists get images from spacecraft that do not return to Earth. Let students know that they will simulate how instruments aboard spacecraft collect and transmit images to Earth.
- Explain the simulation.** Instruments aboard spacecraft divide an image into tiny squares called pixels (picture elements). Each pixel is assigned a number that represents the brightness of that square. In this simulation the squares on the grid represent pixels. Show the “Pixel

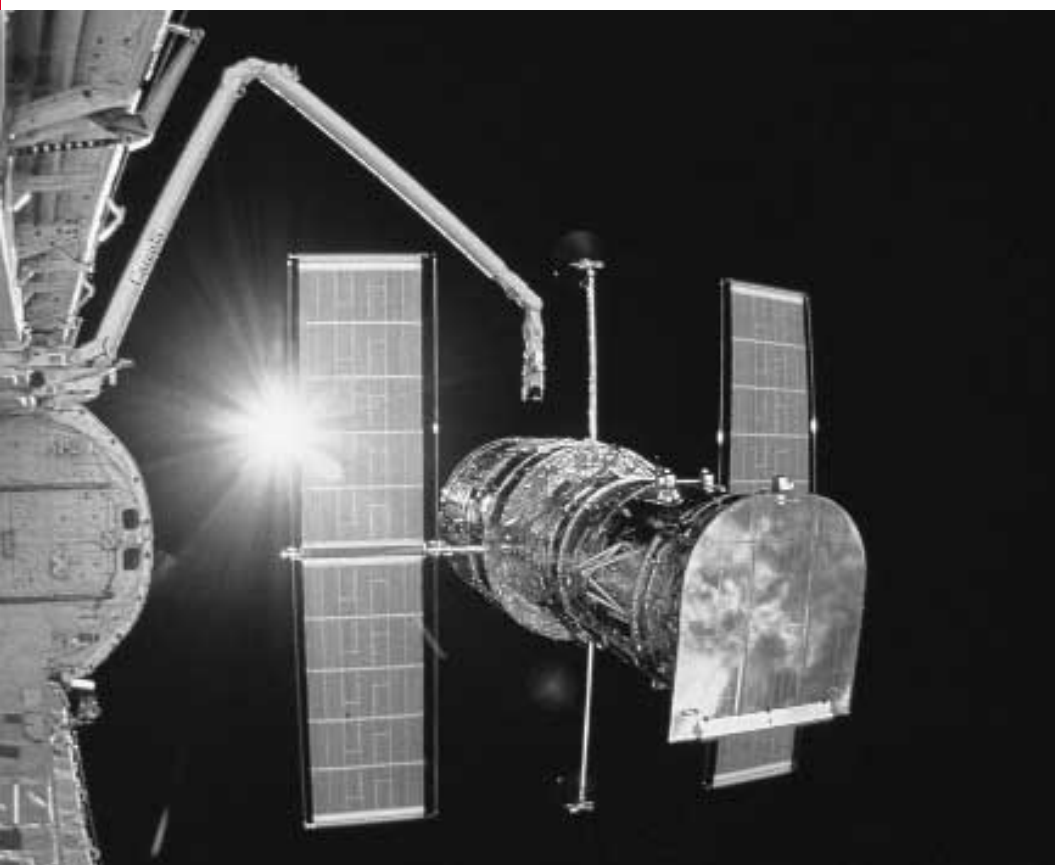
MATERIALS

For each pair of students:

- Transparent “Pixel Grid”
- Paper “Pixel Grid”
- Sample picture
- Folder to conceal sample picture
- Pencil for shading

For the class:

- Transparency: “Effect of Changing Pixel Size”



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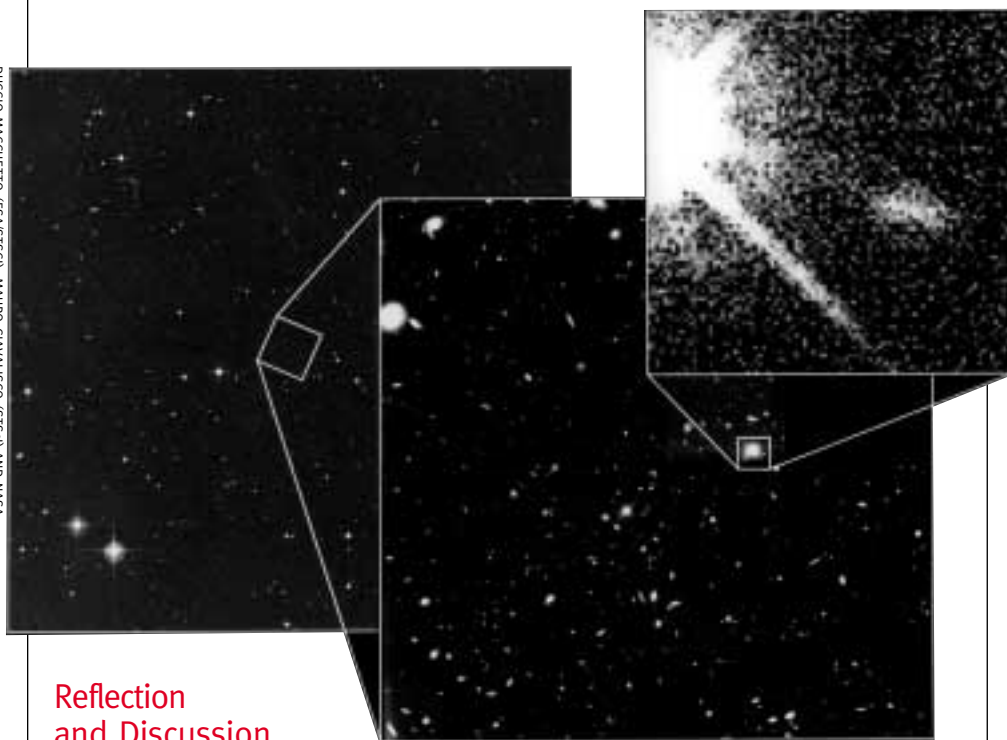
The Hubble Space Telescope suspended in orbit near the Space Shuttle.

Grid” to the students and explain that the student transmitter will place the transparent grid on the sample picture. (Do not show the sample picture.) The transmitter states the location (e.g., A1) and assigns a brightness value from the gray scale (Black is 0, gray is 1 and white is 2). Each pixel can have only one value, so if a square covers light and dark areas, the transmitter estimates total brightness and assigns one number from the gray scale. The receiver shades the square on the paper grid according to the gray scale at the bottom. The transmitter begins in the upper left-hand corner (A1) and reads from left to right for each row.

Complete the simulation. Assign students to work in teams of two. One student will be the transmitter; the other student will be the receiver. Give a folder with

the sample picture and transparent grid to each transmitter with directions not to show the sample picture to the receiving partner. Give a paper grid to each receiver. If you have an odd number of students, one transmitter can work with more than one receiver. Have students complete the transmission simulation.

Close the activity. Have students compare the sample picture to the image transmitted. Ask the students what could be done to improve the quality of the image. Show the transparency, “Effect of Changing Pixel Size.” Ask students what would happen if the squares kept getting smaller.



A very distant galaxy (white blob center right) lies in front of quasar (large blob with spike on left).

Reflection and Discussion

1. Describe what a pixel is?
2. Describe any place where you have seen or heard about pixels.
3. We saw how smaller pixels improved the images. What else could be done to improve the images?

Extension

1. Pixels, which look like tiny squares or dots, can often be seen in photographs. Look for pixels in photographs in magazines or newspapers. Examine them closely with a magnifying glass.
2. This activity demonstrates how simple black-and-white images can be transmitted. Find out how data for color images are collected.
3. Visible light is only one form of electromagnetic radiation. Astronomers examine radio waves, infrared light, ultraviolet light, x-rays, and gamma rays to learn about the universe. Find out how scientists use these other forms of electromagnetic radiation to study the universe.
4. The Hubble Space Telescope has several sophisticated instruments for collecting

images. Find out more about the instruments on the Hubble Space Telescope.

Background Information

This activity is recommended for fourth grade and up. If students have not used coordinate systems, review how to name a location with a letter and number. If students have difficulty following directions and communicating with one another, the teacher can act as the transmitter for the entire class.

A digital image is composed of pixels (picture elements) that are arranged in rows and columns. Each pixel is assigned a numerical value that represents its relative brightness in the image: the larger the number, the brighter the pixel.

Spacecraft use charge-coupled devices (CCDs) to collect these images. A CCD is a computer-run system that measures the amount of light falling on an area. The surface of a CCD is a grid with light-sensitive squares called pixels. The light that falls on each pixel is converted to an electric signal which is given a numerical value representing the brightness of the light. The Hubble Space Telescope uses four

CCDs. Each CCD has a grid consisting of 640,000 pixels for a total of 2,360,000. In this simulation the grid has only 72 pixels. The Hubble uses a gray scale that ranges from 0 (black) to 255 (white) for a total of 256 shades. To simplify the simulation in this activity, the pixels have only three possible values (0, 1 and 2).

Digital images can be transmitted by radio waves. The numerical values from digital images are converted to a data stream of binary numbers. These are transmitted, via radio signals, to a satellite and then relayed to Earth. Computers on Earth convert this data stream back to the original numbers, which can then be processed into images or spectra.

Curriculum Connections

Binary code
Coordinate graphs and maps

Film Connection

The film contains images from the Hubble Space Telescope, including the Eagle Nebula and the Orion Nebula.

(Adapted from *Space-Based Astronomy: A Teacher's Guide with Activities*, NASA, August, 1994).



Name _____

Pixel Grid

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2												
3												
4												
5												
6												

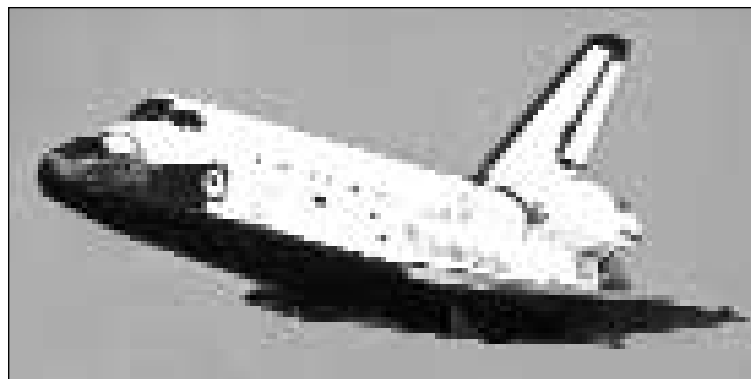
0 1 2



Gray Scale



Sample Picture





Effects of Changing Pixel Size

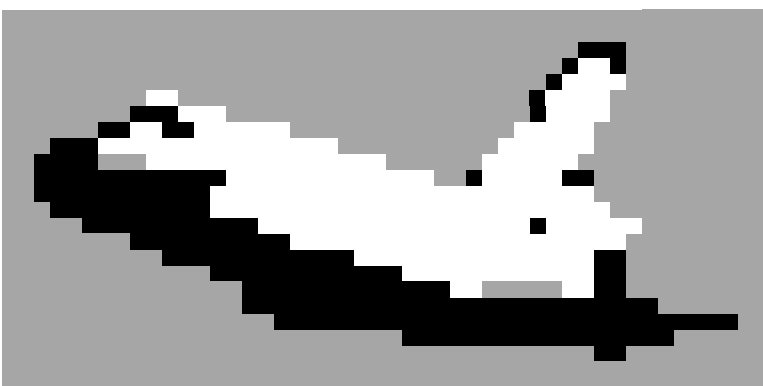
Student Overhead



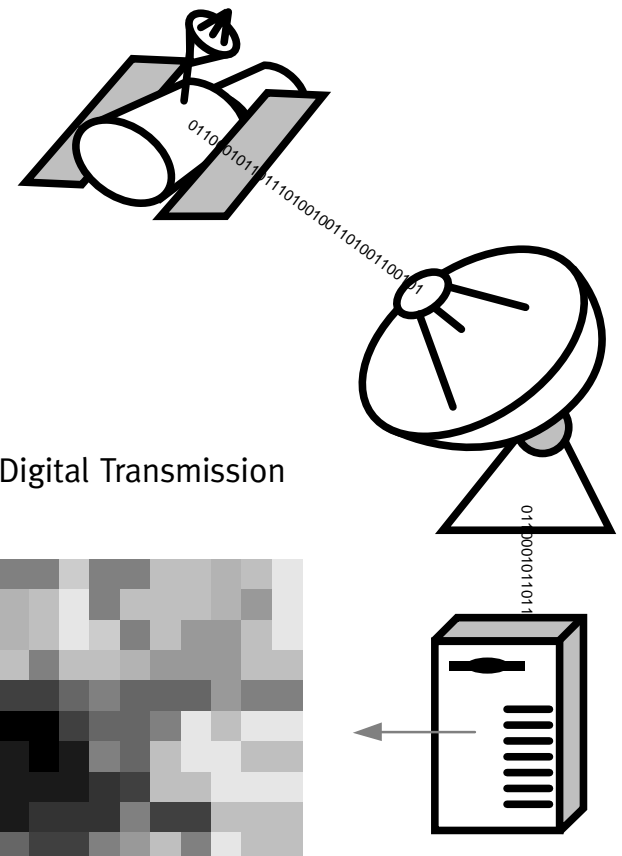
12 x 6 grid



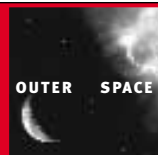
24 x 12 grid



48 x 24 grid



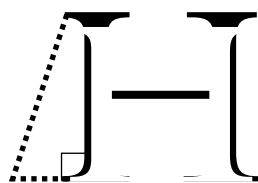
MEASURE UP



Activity Five

Purpose: Students use the properties of right triangles to make an indirect measurement of a tall object and then compare this technique to parallax.

Overview



How do scientists measure distances to celestial objects? In this activity students learn to use an astrolabe to measure an angle. They then apply the special properties of right triangles to determine the height of a remote object. They compare this technique to parallax, one of the methods used by astronomers to measure distances to nearby stars.

Preparation

Find an object to measure. Find a tall object to measure, such as a flagpole, light post, or telephone pole.

Make overhead transparencies. Make overhead transparencies or large drawings of Figures 5.1, 5.2, 5.3, and the Tangent Table from the student worksheet to facilitate discussion and explanation.

Copy the astrolabe template and student worksheet.

Procedure

Introduce the challenge of measuring remote objects. Show Figure 5.2 to the students. Ask them to suggest ways to measure the height of the flagpole without going near it.

Identify the right triangle. Let the students know that right triangles have special properties that make them useful for determining distances. Ask students to suggest how a right triangle can be made in Figure 5.2. Outline the triangle formed by the flagpole (See Figure 5.3). Ask students to indicate the right angle and to identify the hypotenuse. Show Figure 5.3 and relate it to Figure 5.2.

Set up the ratio. Ask students to identify the side that can easily be measured from the ground (distance from student to base of flagpole). Have students identify the acute angle that can be measured from the ground in Figure 5.2. (The angle near the student.) Let students know that if they can measure the angle and one side, they can use a ratio called a tangent to find the other side.

$\text{tangent } \angle B = \text{opposite side} / \text{adjacent side or}$

$\text{tangent } \angle B = \text{flagpole height} / \text{distance to flagpole}$

$\text{flagpole height} = \text{tangent } \angle B \times \text{distance to flagpole}$

Introduce the tangent table. Let students know that for an acute angle of a given measurement (e.g., 30°) the ratio of the opposite side to the adjacent side is always the same. The ratio does not depend on

MATERIALS

For each student:

- Copy of the astrolabe template
- Cardboard for mounting
- 20-cm string
- Weight (hex nut or fishing weight)
- Drinking straw
- "Indirect Measurement" student worksheet

For each student team:

- Calculator
- Cellophane tape
- Glue sticks
- Scissors
- Meter stick or metric tape measure

the length of the sides, only on the size of the angle. Show the Tangent Table.

Make the astrolabes. Tell the students that to measure this angle, they will use an instrument from astronomy called an astrolabe. Distribute the astrolabe templates, cardboard backing, scissors, straws, tape, glue, string and weight. Go over the instructions for making the astrolabe with the students. When the astrolabes are finished, distribute the student worksheet and discuss how to use astrolabes (Step no. 1) to measure an angle.

Measure the height of the flagpole. Move to the flagpole or other tall object. Students should have their astrolabes and worksheets on “Indirect Measurement.” Each student team should have a meter stick or metric tape. Have the students complete the worksheet.

Discuss the findings. Have students share their results. Go over the calculations. Have the class determine what they believe to be the best approximation for the height of the flagpole. Give the actual height of the flagpole, if it is known.

Reflection and Discussion

1. Can you use this method on smaller triangles? On larger triangles? What does the tangent ratio depend on? (The tangent depends on the size of the angle, not the length of the sides. The special properties of right triangles can be applied to large and small triangles. If you can measure the angle and the length of the adjacent side, you can use the tangent to find the length of the opposite side.)

2. Have students extend one arm in front of them with a finger pointing up. Have them cover one eye and then the other eye as they view the finger against a distant background such as a wall. (A blank wall will not work—students will need some visual cues in the background.) Ask students to describe what appears to happen as they blink back and forth. (The finger should appear to change position in respect to the background. It seems to shift from side to side depending on which eye is used.)

3. This apparent change in position is called parallax, and it can be used to measure distances to the stars. Scientists calculate the position of a star against the background of more distant stars. As Earth moves in orbit around the Sun, the apparent position of the star changes. Show students Figure 5.1. Scientists can measure the angular shift in the star’s position from the first sighting to second sighting. Half of this angular shift is the parallax angle. Since we know the parallax angle and the distance from the Sun to Earth, we can use our knowledge of triangles and ratio to calculate the distance to the star.

4. Would a star that was farther away than the star in Figure 5.1 have a smaller parallax or larger parallax? (A star that was farther away would have a smaller parallax.) Have students repeat the exercise in number 2 to see how moving the finger closer or farther from the eyes affects the apparent shift.



A student uses an astrolabe to measure an angle.

Extension

1. Students can use shadows and similar triangles to measure the height of the flagpole.
2. Students can investigate the history of measuring remote objects.
3. The astrolabes can be used to measure the altitude of celestial bodies.

Background Information

This activity is recommended for middle school students who have studied ratios. If they understand ratios, they should understand the mathematics involved in this activity, even if they have not been introduced to trigonometry. The students would benefit from previous experience measuring angles and working with triangles, especially similar triangles.

The students will need to know the following: A triangle has three angles and three sides. In a right triangle, one angle is 90° . The side opposite the right angle is called the hypotenuse. The square symbol in the diagram indicates a right angle. An acute angle is less than 90° . The side opposite an acute angle is called the opposite side for that angle. The side next to an acute angle (that is not the hypotenuse) is called the adjacent side for that angle.

A ratio is an expression that compares two quantities by division. BC/AC shows a ratio between two sides. If $BC = 14$ cm and $AC = 20$ cm, then $BC/AC = 14/20 = 0.70$.

Students can use a protractor instead of an astrolabe to do the measurement. They can also use a string and tie the string with the astrolabe directly to the protractor at the vertex. However, there is some benefit in having students construct an astrolabe that they can keep to use later.

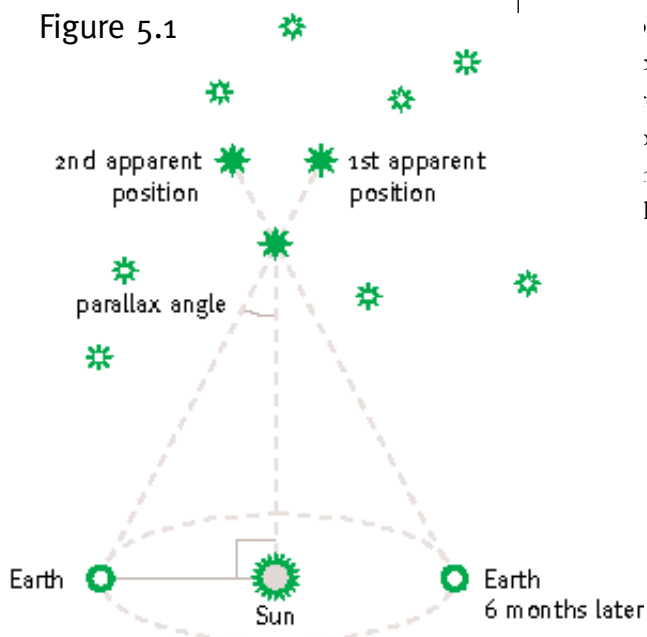
Curriculum Connections

Similar triangles
Right triangles
Ratio

Film Connection

The film looks at distances in our universe. The camera goes by our nearest neighbor stars, almost five light-years away. How do scientists know how far it is to the stars? This activity helps students understand how scientists use indirect measurements to determine distance.

Figure 5.1

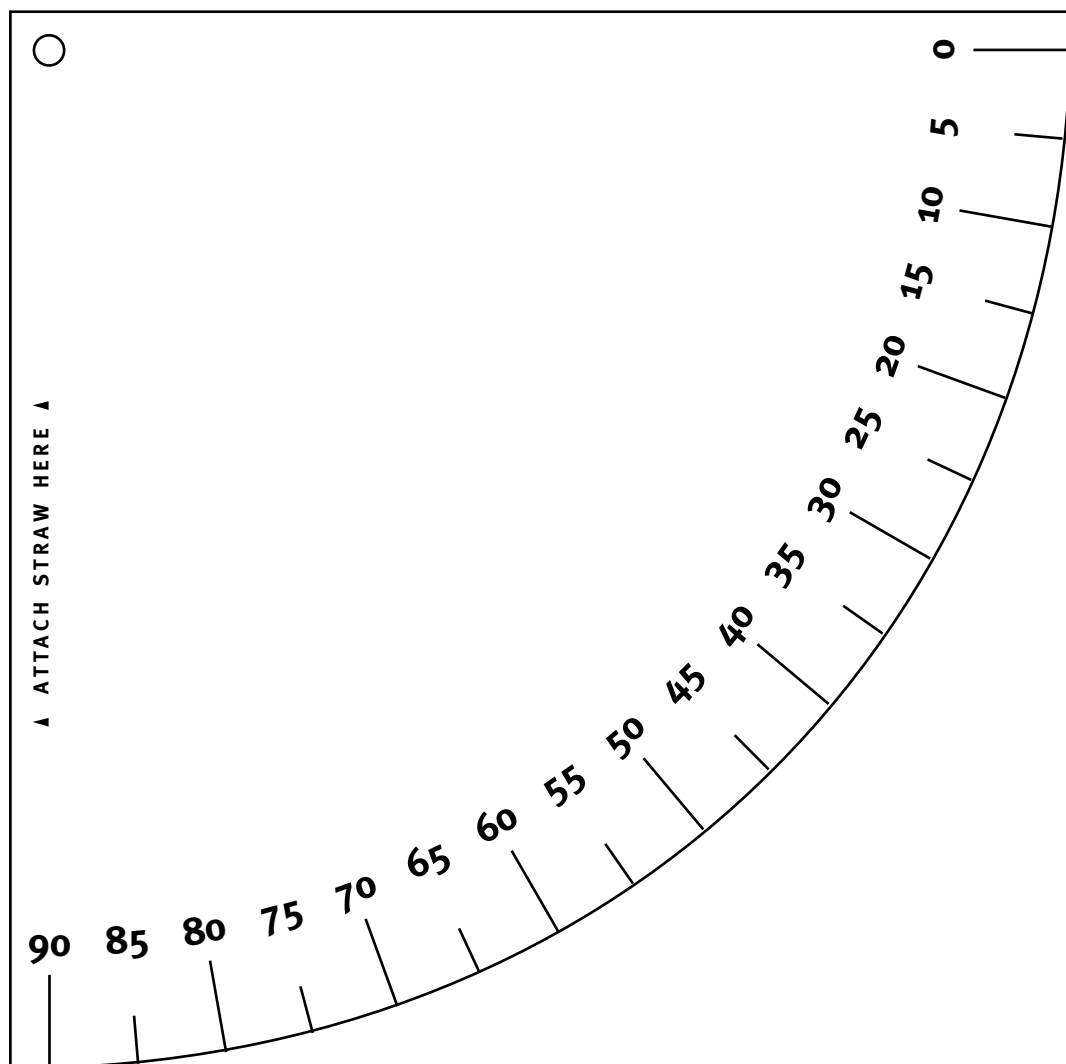


Making an Astrolabe

Student Worksheet 1

Directions:

- Cut out astrolabe template.
- Glue it to the cardboard.
- Cut out cardboard.
- Tape a straw to top of astrolabe.
- Poke a hole at the ○ in the center of the astrolabe at the top.
- Put string through the hole.
- Tape the string on the back side of the astrolabe, so that the string hangs freely on the front side.
- Tie the weight to the end of string, so it hangs well past the end of the astrolabe.





Name _____

Here's how to use the astrolabe to find the height of a tall object.

1. Stand where you can easily see the top of the flagpole through the straw on the astrolabe. Make sure the string and the weight hang freely. As you look through the straw at the top of the flagpole, the string will move alongside the astrolabe. Once you have sighted the top of the flagpole, let the string come to rest. Hold the string against the side, and read the angle to the nearest five degrees.

$$\angle B = \underline{\hspace{2cm}}^\circ$$

2. Use the Tangent Table to find the tangent for the angle measured.

$$\text{tangent } \angle B = \underline{\hspace{2cm}}$$

3. Measure the distance in meters from where you are standing to the base of the flagpole. On the diagram this distance is the side next to the angle you measured, so it is the adjacent side in the tangent ratio.

$$\text{distance to flagpole or adjacent side} = \underline{\hspace{2cm}}\text{m}$$

4. Find the height of the flagpole. In the diagram the flagpole height is the side opposite the angle you measured. For the tangent ratio, it is the opposite side.

tangent $\angle B$ = opposite side/adjacent side, so

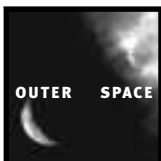
tangent $\angle B$ = flagpole height/distance to flagpole

$$\text{flagpole height} = \text{tangent } \angle B \times \text{distance} = \underline{\hspace{2cm}} \times \underline{\hspace{2cm}}\text{m} = \underline{\hspace{2cm}}\text{m}$$

5. Since you did not lie on the ground to measure the angle, you will have to add the height to your eye level to the calculation in Step 4 to get the actual height of the flagpole.

actual height of flagpole = answer in Step 4 + your height to eye level.

$$\text{actual height of flagpole} = \underline{\hspace{2cm}}\text{m} + \underline{\hspace{2cm}}\text{m} = \underline{\hspace{2cm}}\text{m}$$



Tangent Table/Angle Diagrams

Figures 5.2, 5.3

Measurement $\angle B$	Tangent $\angle B$
5°	.09
10°	.18
15°	.27
20°	.36
25°	.47
30°	.58
35°	.70
40°	.84
45°	1.0
50°	1.2
55°	1.4
60°	1.7
65°	2.2
70°	2.8
75°	3.7
80°	5.7
85°	11



Figure 5.2

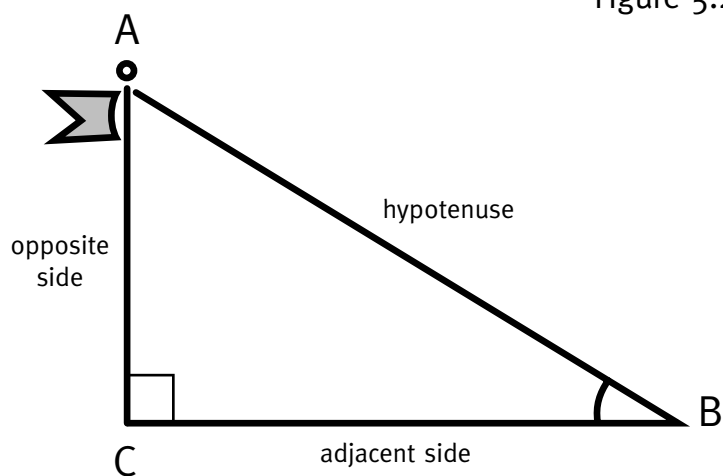
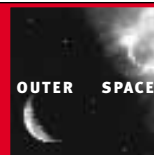


Figure 5.3

ZOOM OUT



Activity Six

Purpose: Students develop a scale model of the solar system from common objects and use this scale to investigate distances beyond the planet Earth.

Overview

How can we begin to appreciate the size of the planets and the vast distances between them? In this activity students compare the relative size of the planets and use a ratio to calculate scale distances from the Sun. The discussion extends this experience to more distant members of the universe.

MATERIALS

For the class:

- One balloon, preferably yellow, about 10-in (250 mm) diameter

For each student group:

- Several poppy seeds
- Several dry chick peas
- Ping-Pong ball
- Several radish seeds
- Three filbert nuts in shell
- Small ball (≈ 20 mm)
- Ten index cards
- Caliper (optional)

Preparation

Gather materials. The materials section lists suggestions for objects to represent the planets in the scale model, but substitutions may be made. The sizes are only approximations.

Select a site. The total length needed to lay out the scale model is about 850 m (900 yd). It does not have to be in a straight line. The perimeter of the schoolyard may work, or you can double back.

Prepare information for student use.

Students need the scale diameters for the planets from Table 6.1 to check their scale model selections. Students need the ratio, "Distance from Sun Compared to Earth," from Table 6.2 to calculate scale distance for each planet.

Prepare for group work. Have students work in small groups of three to five. Have each group list the names of the members on an index card. On each of the remaining nine cards, have them write the name of one of the planets. After the name of the planet, have them write the following labels:

- Scale diameter
- Scale object
- Scale distance from Sun
- Number of paces from Sun
- Fact

Select planet Earth. Inflate a balloon to approximately 200 mm in diameter. Tell the students, "If the Sun were the size of

this balloon (approximately 200 mm diameter), select the object that best represents the Earth." When the groups have completed their selections, ask each group to tell which object was selected to represent Earth and why it was selected. Let students know the Sun's diameter is about 100 times larger than Earth's diameter. At this scale Earth's diameter would be about 2 mm, the size of a radish seed.

Pick the Planets. Tell the students to use the same scale to select an object to represent each of the planets and place the object on the appropriate index card. Let students know they do not have to use all the objects, and they may use some objects more than once.

Check your scale model. Let the students use metric rulers and the scale diameter information from Table 6.1 to check their planet selections and change them, if necessary. Students may have difficulty measuring the diameter of the objects. Provide calipers, if they are available. When the students have finished, discuss their selections. Have students glue or tape their final selections to the index cards and fill in the name and size of the scale-model object selected for each planet.

Predict Earth's distance from the Sun at this scale. Now that students know the scale size of the Sun and Earth, ask them to predict how far Earth would be from the Sun. Ask them to think about how many

A group of students select model planets.

suns could be lined up between the Sun and Earth. Allow some time for discussion, and then, let each group tell its prediction and how it was determined. (Earth's average distance from the Sun is about 150 million km. The Sun's diameter is about 1.4 million km. If you divide distance by diameter, the result is 107 Suns. In the scale model, the Sun has a diameter of 200 mm, so if you multiply the diameter by the 107, the result is 21,400 mm or about 21 m.)

Calculate the distance from the Sun for each of the planets. Let the students know that Earth's distance from the Sun at this scale is 21 m. Have the students use the ratio given in "Distance from Sun Compared to Earth" from Table 6.2 to calculate the distance to each planet (ratio \times 21 m = distance to planet). Have each group copy the scale distance on the index card for each planet.

Find an interesting fact for each planet.

Have the students research and write one fact about the planet on the index card. This can be done anytime before the tour. Some suggestions include finding a unique characteristic for each planet, listing the spacecraft that have surveyed or landed on the planet, or learning about the origin of the planet's name or other names for the planet.

Tour the scale-model solar system. Go to the starting point for the scale-model solar system and place the balloon that represents the Sun. Tell students they will be pacing off distances for the scale

model. A pace is measured from the place that the heel leaves the ground until that same heel touches the ground again. Each pace measures about one meter. Let each group take turns leading the class while they pace off the distance and read the facts about each planet. The distances will only be approximate, but the students will begin to appreciate the scale. As you walk, look back on the solar system.

Reflection and Discussion

1. Describe how you felt about the size of the planets and the distances between them, as we laid out the scale-model solar system.

2. Using this scale how far do you think the nearest star, Proxima Centauri, would be from our Sun? (Proxima Centauri would be more than 45,000 km away. At the equator the circumference of the Earth is about 40,000 km)

3. How fast do you think you traveled as you walked the scale model of the solar system? (Divide distance from the Sun to Pluto, 5,914 million km by the time it took for the walk. If you completed the walk in 30 minutes, you were traveling approximately 10 times the speed of light. The speed of light is 300,000 km per second.)

4. At this speed how long do you think it would take to reach Proxima Centauri? (Proxima Centauri is over four light years away. A light year is the distance light travels in one year. If we could travel 10 times faster than the speed of light, it

would take 0.4 years or almost 5 months to reach Proxima Centauri. Of course, we can only travel that fast in our scale model. According to current scientific theory, nothing can travel faster than the speed of light.)

5. The spacecraft that went to the Moon could travel almost a million km in a day (11 km/sec). How long would it take this spacecraft to travel from the Sun to Pluto? (5,914 days or more than 16 years)

6. Do you think travel to other solar systems will ever be possible? Explain your answer.

Extension

1. Have the students give the solar system tour to their families or other students.

2. Develop a more permanent scale-model solar system. Mount the scale planets and the information on posters. Protect them from weather and place them around the school yard at the appropriate distances.

Background Information

This activity is appropriate for middle-school students who are familiar with ratios. If students are not familiar with ratios, or if time is limited, skip the calculations and give the students the scale distances they need to complete the model solar system.

Students begin to work with the scale objects and discuss relative sizes and distances before they are given specific measurements. This will allow time to develop the concept of the scale before they focus on the numbers and calculations. Even when they work with the measurements, the purpose is not accurate measurement but reasonable approximations.

Curriculum Connections

Scale

Ratio

Speed/distance calculations

Film Connection

In the film the camera zooms out to the very edge of the known universe. The experience of working on the scale-model solar system will begin to give students an appreciation of the vastness of space and how small our own planet is in relation to the rest of the universe.

Table 6.1 Diameter scale 1:7,000,000,000

	Diameter (km)	Diameter Compared to Earth	Scale Diameter (mm)	Scale Object
Sun	1,392,000	109.13	218	balloon
Mercury	4,879	0.38	1	poppy seed
Venus	12,104	0.95	2	radish seed
Earth	12,756	1.00	2	radish seed
Mars	6,794	0.53	1	poppy seed
Jupiter	142,984	11.21	22	small ball
Saturn	120,536	9.45	19	filbert
Uranus	51,118	4.01	8	chick pea
Neptune	49,528	3.88	8	chick pea
Pluto	2,302	0.18	>1	poppy seed

Data for the diameters is from the *Astronomical Almanac* for 1995. (E88 Washington: GPO, 1994). "Diameter Compared to Earth" is the ratio of the Sun's or planet's actual diameter divided by the Earth's actual diameter. The scale diameter is the ratio, "Diameter Compared to Earth" multiplied by the Earth's scale diameter. The result is rounded to the nearest mm. The scale objects are recommendations. There is variation in the sizes of the objects, and students may suggest other choices, if they can defend them.

Table 6.2 Distance from Sun scale 1:7,000,000,000

	Average Distance from Sun (millions of km)	Distance from Sun Compared to Earth (AU)	Scale Distance from Sun (m)
Sun	0	0	0
Mercury	57.9	0.39	8 m
Venus	108.2	0.72	15 m
Earth	149.6	1.00	21 m
Mars	227.9	1.52	32 m
Jupiter	778.2	5.20	109 m
Saturn	1,428	9.55	201 m
Uranus	2,884	19.28	405 m
Neptune	4,522	30.23	635 m
Pluto	5,957	39.82	836 m

Data for average distance is from the *Astronomical Almanac* for 1995 (E3, Washington: GPO, 1994). "Distance from Sun Compared to Earth" is the ratio of the planet's distance from the Sun divided by the Earth's distance from the Sun. This is equivalent to the distance from the Sun measured in astronomical units (AU). The "Scale Distance from Sun" is the ratio of the Sun or planet's distance compared to the Earth's distance multiplied times the Earth's scale distance (AU x 21 m). The result is rounded to the nearest m.

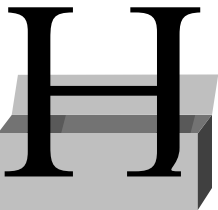


MYSTERY BOX

ActivitySeven

Purpose: Students make inferences about the contents of a sealed box and compare their experience to the process of developing scientific models.

Overview



How do scientists develop theories or models to explain phenomenon that humans cannot see or manipulate directly,

such as atoms and black holes? In this activity students investigate the contents of a sealed box. They make inferences and use a variety of methods and tools to test their inferences. Students discuss their conclusions with other students and compare their experience to that of research scientists.

Preparation

Determine the mass of an empty box.

Post the result in the classroom.

Assemble the mystery boxes. Place a different object in each mystery box. Seal the boxes with masking tape, so the students cannot open them.

Assign students to work in teams of three or four. Even though students work with partners, each student records his or her own observations.

Procedure

Introduce the activity. Explain that scientists often investigate objects that cannot be observed directly. Hold up a mystery box and explain to the students that their challenge will be to describe the object

in the box by making indirect observations. They cannot open or in any way damage the box or seal.

Prepare for the investigation. Have the students prepare their science journals or data sheets. First have them record the mass of the empty box, then they can set up two columns: “What we did” and “What we found out.” As students investigate the box, they will record the results in the two columns.

Investigate the mystery boxes. Distribute the boxes and equipment. Remind students not to open or in any way damage the box. Students may use nonintrusive, nondestructive methods to investigate the contents of the box. They may use the tools (magnet, compass, and scale) to collect information about the objects. Students may hold the box and gently shake or move it, while they use their senses to gain additional information. As they investigate, students should record what they do and what they find out. Allow five to ten minutes to investigate the box, then have students write a conclusion describing what they think the box contains and why.

Prepare for the mystery box conference.

Distribute chart paper or overhead transparencies and tell students they have ten minutes to prepare a presentation for other “mystery box researchers.” Tell students to prepare

a persuasive presentation that provides solid evidence for the group’s conclusion about the contents of the mystery box.

Hold the conference. Allow two or three minutes for each group to present their findings. When the presentations are done, poll the students to see if they have come to any agreement about the contents of the mystery boxes. You may want to confirm the identity of the objects during the discussion, or you may want to delay revealing the contents to simulate scientists’ inability to find all the answers.

MATERIALS

For each student group:

- Mystery box
- Directional compass
- Magnet
- Chart paper or overhead transparency for presentation

For each mystery box:

- Sturdy box (school supply box works well)
- Mystery object (piece of steel wool, rubber stopper, cedar ball, steel ball bearing, wooden block, cinnamon stick, magnet or marble.)

For the class:

- One or two metric scales or balances

Reflection and Discussion

1. What is indirect observation?
2. When and why do you think scientists use indirect observation?
3. As you investigated the mystery boxes, what other methods or instruments would have helped you determine the contents of the box.
4. Did the presentations by the other groups change your ideas about the contents of the boxes?

Extension

1. The activity can be repeated with different mystery objects and additional tools or with more than one object in a box.
2. Students could read a mystery story, keep a written record of the evidence or clues as the story unfolds, and try to guess the ending before it is revealed.

Background Information

This activity is recommended for students in fifth grade and up. Students of all ages are fascinated by the mystery of the sealed box. Encourage them to give details when describing the evidence that led to their conclusions. There are many ways to organize the Mystery Conference. All of the groups can have the same, or each can have a different, mystery object. There could be several different types of mystery boxes with different contents (Box A, Box B and Box C), and each group could investigate the different boxes.

Help the students relate what they are doing with the mystery box to scientific research. Scientists often rely on indirect observations to gather information about aspects of the world that are not available to direct inquiry. Particle physicists cannot see or manipulate the inside of an atom. They can, however, study the results of collisions between particles. Astrophysicists



In the film Dr. Kolb tells students that billions of years ago, all matter in the universe was packed in a volume smaller than this marble.

cannot recreate the big bang, but they can study radiation from the event. Scientists invent special tools and techniques to collect information about things we cannot see. From this information they develop models with enough precision and accuracy to make predictions and to describe reality. Through collaboration among scientists and additional testing, the models are refined. If a model continues to explain or predict phenomena, it eventually becomes accepted as a theory.

Curriculum Connection

Speech/persuasive argument
Logic/deductive reasoning

Film Connection

The film surveys what we currently know about the universe from quarks to galaxies. Students will see computer simulations created from actual scientific data and theoretical models. They will also get to see tools of the scientists from the particle accelerator at the Fermilab to the Hubble Space Telescope.

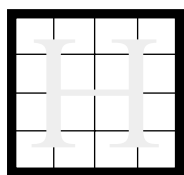


PARTICLE DETECTOR

ActivityEight

Purpose: Students use probes to locate and define an unseen object and compare their investigation to the work of particle physicists.

Overview



How do scientists investigate objects that are so small that manual probes cannot be used? In this activity students use steel ball bearings to locate and describe the shape of a hidden magnet. They compare their investigation to research with high-speed particle probes.

Preparation

Collect the necessary materials and prepare the boxes. Draw and label a grid to fit the top of the boxes. Make copies of the grid for each box and make additional copies of the grid to record data. Tape a grid to the top of each box. Tape a donut-shaped magnet to the underside of the box lid. Put the magnet in a different location for each box. To secure the boxes, tape the lids shut.

Test the equipment. The size of the ball bearing, the strength of the magnet, and the height of the ramp will affect the experiment. Do a trial run and make necessary adjustments.

Post the rules. Make a chart to post, or copy the rules to hand out.

Assign your students to work in teams of three or four students.

MATERIALS

For each team of three or four students

- Box with lid (school supply box)
- Paper grid to cover lid of box
- Copy of the paper grid for data collection
- Lid to catch the steel ball (optional)
- Ramp with stand (ruler with center groove and books to hold the ramp)
- Ceramic magnet (donut-shaped)
- Steel ball bearings (three sizes ranging from 4 mm to 8 mm)

Procedure

Introduce the activity. Let students know that they will use steel ball bearings as probes to locate and describe the shape of a magnet hidden under the box top.

Set up the equipment. Distribute box, ramp (ruler), and stand (box or books). Show students how to set up the box, ramp, and stand.

Give the rules. You may want to post them or hand them out.

- Do not touch the box once it has been set up in your work area.
- The edge of the ramp cannot be placed beyond the heavy black line along the edge of the grid on the box.
- Ball-bearing probes must be released from the top of the ramp each time. Do not place them directly on the grid.

Select the best probe. Distribute a set of ball bearings of various sizes to each group. Have students roll each bearing at three different locations along one side of the box and observe the reaction of the ball bearings. From these trials have students select the probe that they think will help them locate the magnet and describe the shape. Students should note why they selected the probe so they can discuss it later.

Find the location, and shape of the hidden object. Distribute copies of the grid for data collection. Remind students of the rules. Have students place the ramp at the perimeter of the grid on the box and release the ball bearing from the top of the ramp. Have the students draw a line on the copy of the grid (not the box) showing the path of the ball bearing. Have the students repeat this for each square along the perimeter of the grid in a systematic fashion. As long as they follow the rules, students may run additional trials at any square along the perimeter to help them locate and define the object.

Describe location, shape and size of hidden object. Have students interpret their observations by drawing the shape and size of the object at the appropriate location on their copy of the grid.

Discussion and Reflection

1. Which ball bearing did your team select and why?
2. Describe how you conducted your experiment to determine the location, shape, and size of the hidden magnet.

Extension

1. Find out about the tools and research methods used by particle physicists and compare their work to your investigation. How is it similar, and how is it different?
2. Do a similar experiment but use carbon paper to record the path of the ball bearing.



Students use a ball bearing to locate a hidden magnet.



In this scene from *Cosmic Voyage*, scientists at Fermilab view tracks from a high-energy collision.

Background Information

This activity is recommended for middle school students. In this activity students use a steel ball bearing to “probe” a hidden magnet. The ball bearing is deflected from its path, because it is attracted to the magnet. The reaction of the moving ball bearing gives clues about the location, shape, and size of the magnet.

To study the smallest particles of matter, physicists use the largest of scientific instruments, particle accelerators. Physicists use particle accelerators to cause collisions between beams of protons and antiprotons. To observe and record these invisible collisions physicists set up huge detectors on the accelerator ring. The detector’s job is to observe as many collisions as possible and to preserve the information for later study. Physicists look at the data for new parti-

cles and phenomena that can confirm the predictions or refine the models of theoretical physicists.

Film Connection

In the film the camera zooms into a carbon atom revealing the structure, six electrons surrounding a tiny nucleus with protons and neutrons. Inside the proton we see even smaller particles, quarks.

The film shows the Fermi National Accelerator Laboratory where scientists use particle accelerators to explore the particles inside an atom. Rocky Kolb, a scientist at Fermilab speaks to a group of students about the big bang.

ZOOM IN



ActivityNine

Purpose: Students investigate relative size and the nature of matter from humans to quarks.

Overview



How are the building blocks of living things and matter organized? In this activity students

arrange the components of life in a hierarchy based on relative size. Students then take an imaginary journey inside a cell.

Preparation

Copy student worksheets.

Find a large, open area. Make arrangements to use the gym, a large room, or an outside area for the scale-model activities. During the activity students will form a circle with a 10-m diameter.

Procedure

Review powers of ten and vocabulary on the worksheet. Discuss exponents and powers of ten and help students understand their meaning. Students will probably recognize most of the terms listed on the worksheet, but they may not have a good understanding of how they fit together or of their relative size. Keep explanations to a minimum to give students a chance to grapple with what they do know. Their questions will be answered later in the lesson.

Complete the worksheet. Distribute the worksheets. Let students know they will work with a partner or in a small group. Tell the students to arrange the names of the objects in order from largest to smallest, and then determine approximate size to the nearest power of ten. If the students cut out the names, they can organize, discuss, and reorganize until they agree on the hierarchy and approximate size. Allow five to ten minutes for discussion among the students. When the students have finished, ask the groups to present their view on how life is organized.

Prepare for an imaginary journey. Move to a large, open area. Have the class form a 10-m diameter circle. Use a 5-m length of string, as you would a protractor, to organize the circle. Set the stage by asking the students to close their eyes and imagine that they will be going on a fantastic journey inside a cell.

Zoom to 10^{-5} . Have the students open their eyes and tell them they are standing at the edge of a typical cell 10^{-5} m in diameter. Have six students form a 2-m diameter circle inside the 10-m circle. Tell students this circle represents the nucleus of the cell at this scale. In addition to the nucleus, the cell contains cytoplasm and other organelles.

Zoom to 10^{-6} . Tell the students that they are going to zoom in one more power of ten. The diameter of the nucleus which was 2 m is now 10 times wider or 20 m. The students who represent the nucleus move beyond the other students to a location 10 m from the center of the circle, if there is room. The rest of the students are now inside the nucleus of a cell where they would see a tangle of DNA.

Zoom to 10^{-10} . Have all the students return to the 10-m circle. Tell the students that as they continue to zoom in they would begin to see the shape of DNA which is like a ladder twisted in a spiral. At 10^{-9} they would see the molecules that make up the DNA. At 10^{-10} a carbon atom

MATERIALS

For the class:

- Pin (1 mm)
- Cork or rubber stopper
- String
- Three BBs (2 mm)
- “Zooming In” student worksheets

For each team of two to four students:

- Scissors
- Glue or tape

would fill the circle. Stick the pin in a cork and hand it to one student to take to the center of the circle. Tell the students the head of the pin, approximately 1-mm in diameter, represents the nucleus of the atom at this scale. The circle represents the outer edge of the carbon atom. Between the outer layer of the atom, which is occupied by the electrons, and the nucleus at the center of the atom, there is empty space.

Zoom to 10^{-14} . Tell the students that as they zoom into the center of the atom they quickly pass through space occupied by the electrons. At 10^{-12} and 10^{-13} the circle, which is now inside the atom, contains primarily empty space. At 10^{-14} the circle represents the nucleus of the atom, which contains neutrons and protons. Have 12 students enter the circle to represent the 6 protons and 6 neutrons in a carbon nucleus.

Zoom to 10^{-15} . At 10^{-15} the circle now represents the diameter of one proton. Give one BB to each of three students to represent the three quarks that make up a proton. Have the three students stand in the center of the circle at least 1-m apart. Let the students know that the nucleus of the atom that had a diameter of 1 mm at a previous scale is now 100 m. Ask them where they think the electron would be at this scale. (The electron would be about 1,000,000 m or 1,000 km away.)

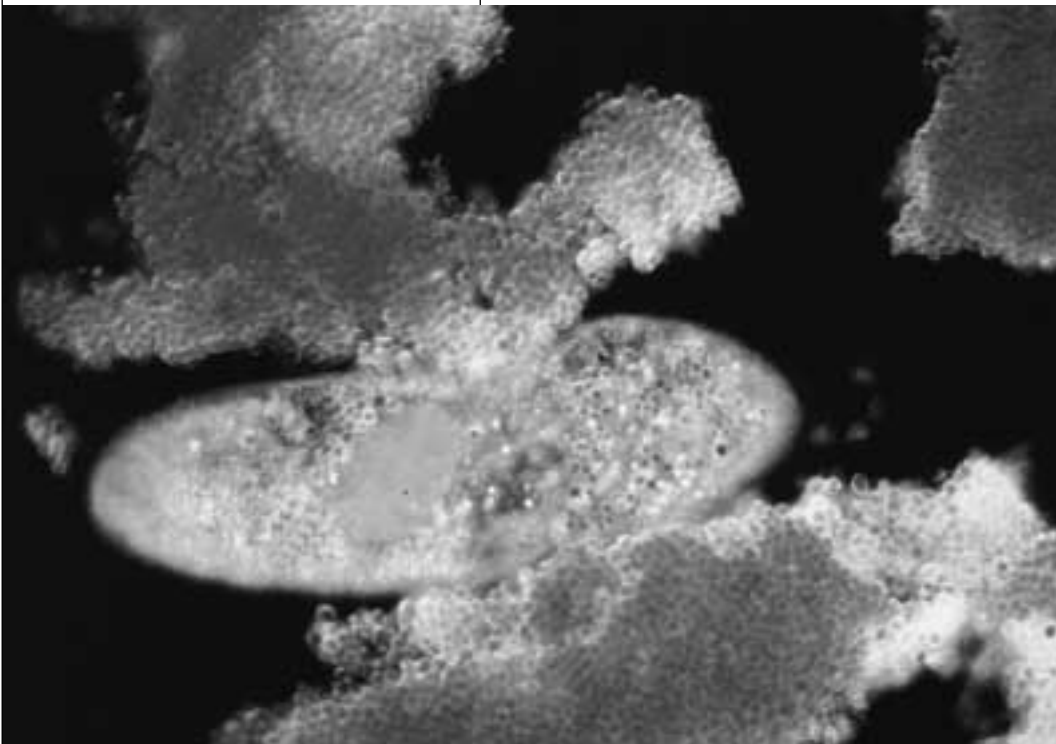
Discussion and Reflection

1. In your own words describe or diagram how life is organized from the largest component, the human organism to the smallest, quarks.
2. Describe what you noticed as you zoomed in. Did anything surprise you?

Extension

Students could choreograph and script the imaginary journey like a play complete with costumes and props.

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Paramecia, single-celled organisms are shown on the giant IMAX screen.

Background Information

This activity is recommended for middle or high school students who have a basic understanding of powers of ten. The imaginary journey requires students to think abstractly and work cooperatively. To simplify the activity and reduce the amount of time required, select one or two steps from the journey and demonstrate them in the classroom with lengths of string to represent distances.

The nucleus of the cell is one of the most important organelles. It contains all the genetic information of the organism and directs the operation of the cell.

10^{-7} m • chain molecule

Chain molecules are made of thousands to millions of molecules linked together. DNA and proteins are examples of chain molecules.

where the electrons orbit, and the nucleus. Atoms are mostly empty space.

10^{-14} m • nucleus

The nucleus at the center of the atom contains the protons and neutrons. Each type of atom contains a different number of protons. Hydrogen has one proton. Carbon has six protons and six neutrons.

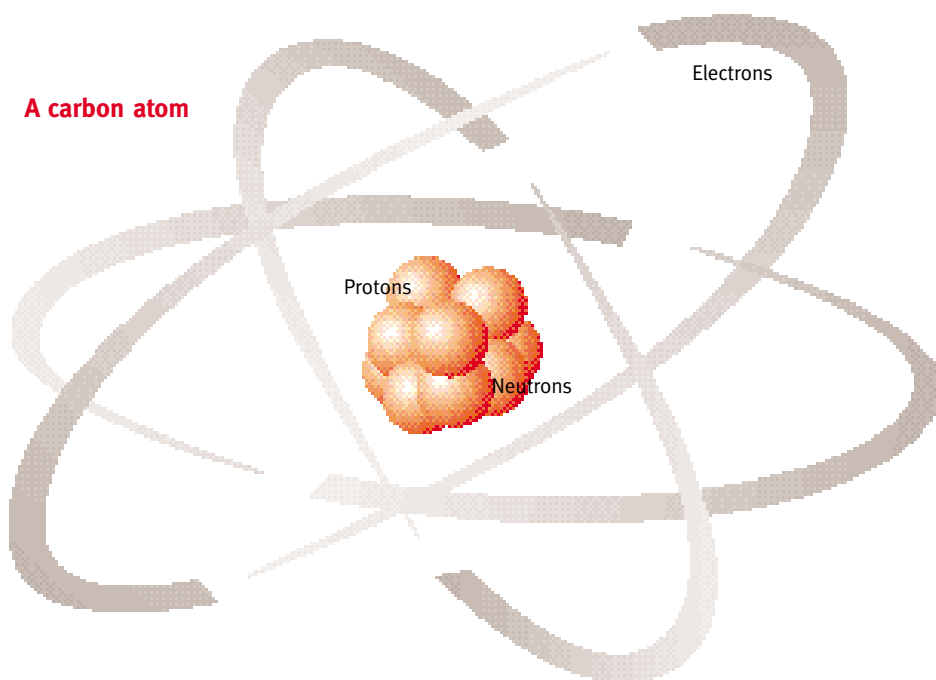
10^{-15} m • proton

A proton is composed of three quarks.

10^{-18} m • quark

Quarks are believed to be in constant motion and held within the proton space by spring-like forces called gluons. The current understanding is that all matter is made of quarks and electrons.

A carbon atom



Curriculum Connections

Powers of ten
Scale
Cell structure
Atomic structure

Film Connection

In the film the camera zooms into a paramecium, a single-celled organism. The zoom continues through the cell nucleus and into a carbon atom. This activity can be used to review and discuss what students saw in the film.

10^0 m • humans

Most humans are taller than 1 m but much shorter than 10 m, so this is the best approximation.

10^{-5} m • large cell

A paramecium is a single-celled organism approximately this size. Most cells in the human body are in this range.

10^{-6} m • organelle

Cells have internal structures called organelles that perform vital functions.

10^{-9} m • molecule

A cell contains about one thousand different kinds of small molecules. Nucleotide molecules link together to form DNA. Sugar is another type of molecule.

10^{-10} m • atom

Carbon, hydrogen, and oxygen are three common atoms found in living things. The outer part of the atom is defined by the electrons. Note the great distance between the outer part of the atom,



Zooming In

Student Worksheet

From humans to the smallest known particles, there are 18 powers of ten. Cut out the names of objects on the left-hand column, arrange them in order from smallest to largest and match them to the closest approximate size on the right-hand column.

	Meters
	10^0
proton	10^{-1}
	10^{-2}
quark	10^{-3}
	10^{-4}
chain molecule (DNA or protein)	10^{-5}
	10^{-6}
	10^{-7}
nucleus of an atom	10^{-8}
	10^{-9}
atom (carbon)	10^{-10}
	10^{-11}
cell (paramecium or human)	10^{-12}
	10^{-13}
	10^{-14}
molecule (nucleotide or sugar)	10^{-15}
	10^{-16}
	10^{-17}
human	10^{-18}

MODEL BUILDER



CareerConnections

DICK KILDAY

Dick Kilday never knows what he will be asked to build next. In his career as a model maker he has built scale models of tanks, bridges, department stores, and helicopters. At the Smithsonian Institution, he builds the models used in exhibitions. Once he constructed a 6-ft (1.8-m) model of an alligator from steel and wood and covered it with thin plastic skin. When the alligator was finished, a co-worker walked into Kilday's studio and said, "If I saw that in my bathtub, I'd have a heart attack!"

Kilday began building models when he was eight. His first models were trains—a Pennsylvania Railroad switcher and a bright orange Great Northern boxcar. He found out early in life that he was a talented model builder and won prizes for his models while he was still in high school. A local architect read about Kilday's prize-winning models of trains and cars and offered him a job making models of buildings. Kilday, who had been earning 63 cents an hour pumping gas at a Sunoco station, jumped at the \$5.00 an hour the architect offered. And so his career began.

After Kilday graduated from high school, he earned a two-year degree in advertising at Dean Junior College in Franklin, Massachusetts. Though he worked for an advertising agency for six



months, he didn't find the work as interesting as model building. He went to work for an exhibit design company, then got drafted into the Army. And how did he serve his country? Building models in the U.S. Army's Exhibits Unit, of course.

In his current position, Kilday sometimes constructs models to fit into a specific space. He built a 5 ft x 9.5 ft (1.5 m x 2.9 m) model of downtown

**"If I saw that
in my bathtub,
I'd have a
heart attack!"**

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Washington, D.C., for the Smithsonian's Visitor Information Center. The model represents an area about 25 blocks long and 8 blocks wide. It includes 100 government buildings and all the capital's museums and monuments. To calculate the scale, Kilday and his co-workers pieced together architectural drawings of the streets and buildings, then photographed the drawings. They enlarged the photograph until it was exactly 5 ft x 9.5 ft (1.5 m x 2.9 m). This photograph provided each building's "footprint," or the space each occupies where it touches the ground. Then, knowing the dimensions of the buildings, they developed the scale model.

One of the most challenging models Kilday ever built was the Zeppelin Staaken R. IV, a World War I bomber nicknamed the "German Giant." The model, which now hangs in the National Air and Space Museum, has a wingspan of 9.5 ft (2.9 m) yet is so light that one person can lift it. Kilday and his team had to construct the model with very little information, as the Allies had burned every Staaken R. IV bomber at the end of the war. The Smithsonian model makers went to great lengths to get the plane's details right. A sculptor modeled the seven crew members; a model maker hand-cut tiny pieces of aluminum to create the bomber's six motors. Kilday researched and painted the camouflage on the wings. He discovered that the Germans had dotted the wings with ten different colors. Each "dot" was no bigger than an inch (2.5 cm) in diameter.

If he has the patience to cover a bomber's wing with 1-in (2.5-cm) paint dots or to install 5,000 miniature trees in a model of the Tennessee Valley, Dick Kilday must love his work. When young people ask Kilday about how to choose a career, he offers them words to live by: "Do what makes you happy."

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The Zeppelin Staaken R. IV, a World War I bomber nicknamed the "German Giant."

ASTRONOMER



CareerConnections

JOHN HUCHRA

When astronomer John Huchra was a child, his aunt gave him a 1-in (2.5-cm) telescope. About all he could see through it was the Moon. Now he's director of the Smithsonian's Whipple Observatory in Arizona, which has the world's fifth largest telescope. At 15-ft (4.6-m) diameter, the Whipple telescope is 180 times the size of his first one. Through it he can "see" most of the way to the edge of the universe.

Believe it or not, Huchra needs to see to the edge of the universe to do his job. He uses the observations he makes through telescopes to help him answer some of the biggest questions we can ask, such as What shape is a galaxy? and How old is the universe?

One big question Huchra and astronomer Margaret Geller have been trying to answer for ten years is how galaxies are distributed. "Astronomers thought they knew that galaxies were distributed in a huge sea with lumps sticking up here and there, but they 'knew' it without looking," Huchra explains. "We decided to make a map." Huchra and Geller's map led to an amazing discovery. "Galaxies are actually distributed on big surfaces surrounding big empty regions. It's as if galaxies were distributed on the surfaces of bubbles." This new way of understanding the distribution of galaxies

changed some accepted ideas in astronomy.

Because Huchra is trying to answer such exciting questions, you might think that every work day would be thrilling. You'd be wrong in two ways. First, Huchra's work day is really a work night. When he's skywatching, he begins his work around 3:00 PM. He sets up his telescope and other equipment, then meets with fellow astronomers to discuss what

they'll be doing that evening and in what order. Second, when the observing begins, Huchra says, it can be "relatively boring." The telescope collects light in the form of photons. Then a computer records the information collected by the telescope and stores it in a file. "Most of the time I'm just sitting there making sure everything is running properly," he says.

But even when Huchra is just "sitting



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there,” unexpected things happen. Once, early in his career, he was looking for supernovae and discovered a comet instead. The result: Huchra has a comet named after him. But don’t rush out to your local observatory to get a glimpse of comet Huchra. It’s a small one, and it comes around once every 912 years. During another observation Huchra couldn’t understand what he was seeing through the telescope. He thought he had made a mistake. “I immediately stopped what I was doing and used a bigger telescope to check out what I was seeing. This “mistake” turned out to be another important contribution to his field. Huchra had accidentally discovered

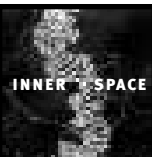
concrete crew. Even while I was doing all of these things I took part of my day to wonder. That’s what separates us from the animals....being curious about things.”

Huchra has a comet named after him. But don’t rush out to your local observatory to get a glimpse of comet Huchra. It’s a small one, and it comes around once every 912 years.

the world’s closest known gravitational lens. (A gravitational lens is a galaxy with a quasar behind it. The gravitational field of the galaxy acts as a lens, distorting the light of the quasar.)

Why does John Huchra make maps of galaxies or try to compute the age of the universe? Because he is interested in “understanding where we come from. Humankind has been doing that forever.” And while he can imagine doing other kinds of work, he cannot imagine a life that doesn’t include asking the big questions. “I’ve been a busboy and a short-order cook. I drove trucks. I worked on a

ELECTRICAL ENGINEER



CareerConnections

BRYNETTE SMITH

It's Thursday night and you have a social studies project due on Friday. It's a group project, but two of your group members were out of school all week with the chicken pox. Don't worry. Just switch on your big screen TV and hold a three-way video conference right there in your living room. Get the project done on time, without catching anyone's germs.

Two-way TV communication in your own home is right around the corner, according to electrical engineer Brynette Smith. So are computers with "smart cards" that will allow you to buy products from as far away as Singapore without even picking up the phone. And Smith knows about the future of electronics.

At Motorola, Inc., she designs computer chips, the tiny "brains" inside electronic devices. Chips do everything from letting your keyboard communicate with your computer to telling the air bag to pop out of the steering wheel during a car crash. Brynette Smith has helped design chips for devices that make everyday living easier, including pagers, cellular phones, and the remote control.

Brynette Smith believes that engineers do more than make life easy for couch potatoes. She says, "Engineers make life better." Her work has made life better for deaf people who want to watch TV. Smith designed one of the chips that makes closed-captioning appear on tele-



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vision programs. With closed-captioning, the words being said during a program show on the screen. Because of this chip, viewers with hearing impairment and people trying to learn English can "read" closed-captioned TV programs.

When Smith designs a chip, she takes it from the idea to the finished product. She interviews the customer by asking them how fast the chip should work and

how much memory it must contain. Then, using computer software, Smith designs the chip. Actually making the chip is tricky. Think of a chip as a slice off a silicon "stick." These dime-sized, wafer-thin slices are so sensitive that they can be destroyed by a single speck of dust. To create the chip that Smith designs, people work in a pure environment, cleaner than an operating room. They must be covered

head-to-foot in a “bunny suit” to prevent even the tiniest particle of dust, makeup, or hair from damaging the chip. After the chip has been fabricated, Smith uses the computer to test it. Before she calls a chip finished she must be sure the chip will work as it was designed.

With so many accomplishments in electrical engineering, it is hard to believe that Brynette Smith once doubted that she could be an engineer. In high school Smith was the only girl in her electronics class. She did not think she could do well enough in physics and chemistry to become an engineer. But in junior college she discovered that “engineering courses weren’t as hard as people had made them out to be.” She continued her education and became an electrical engineer. Now she emphasizes how important it is to think like an engineer. “Don’t

**“You could be the one who asks,
Why don’t we do it this way?
and turns everything around.”**

limit what you think you might do just because of what you see others doing. Realize that you may be thinking of a new way—nobody else may have thought of it. You could be the one who asks, Why don’t we do it this way? and turns everything around.”

Brynette Smith let her curiosity and her abilities take her in a direction she didn’t know she could take. “When I started out I didn’t see this career as something I would end up doing. It’s very satisfying to know that whatever you put your mind to, you can do it, and you can make a big difference as well.”

