

Assignment Discovery Online Curriculum

Lesson title:

Astronomical Scales

Grade level:

9-12

Subject areas:

Mathematics

Astronomy/Space Science

Duration:

One to two class periods

Objectives:

Students will

1. understand how scaling factors can be used to make representations of astronomical distances;
2. learn how to write and solve equations that relate real distance measurements to scaled representations of the distances; and
3. understand how the use of scientific notation makes calculations involving large numbers easier to manage.

Materials:

- Calculators
- Pencils and paper
- Ruler
- Reference materials about the universe, such as books, magazines, and the Internet
- Copies of Classroom Activity Sheet: Understanding Sizes and Distances in the Universe
- Copies of Take-Home Activity Sheet: Comparing the Sizes of Planets

Procedures:

1. Begin by discussing the vastness of the universe. For example, tell students that light travels at the unimaginably fast speed of 300 million meters per second, and yet light takes years to travel to us from the stars and takes thousands or even *millions* of years to travel the depths of space between galaxies. When we're dealing with those kinds of distances, it's no wonder that we often think of them as being beyond our grasp. One way to put these distances into perspective is to think of them as multiples of smaller-scale distances. By putting these quantities in the context of a well-understood frame of reference, they begin to have more meaning.

2. Help students grasp our place in the enormous universe by reviewing your school's “galactic address”—beginning with its street address and ending with its place in the universe. Discuss the different units of measurement that are used to describe distances in each part of the galactic address. Give students examples for each step, or have them use reference materials to provide their own examples. Review any unfamiliar units of measurement, such as light-years and astronomical units. By thinking about their location on a small scale first and then moving out to a much larger scale, students begin to get a sense of how distance is measured at each scale.

Place	Units of measurement	Example
[Street address]	Feet, meters (within a house)	A room might be 10 _ 14 feet.
[City]	Miles, fractions of miles	You might drive _ mile to the grocery store; a town might be about 10 miles wide.
[State]	Tens to hundreds of miles	The distance from Austin to San Antonio is a little more than 50 miles; Texas is about 600 miles across.
United States	Hundreds to thousands of miles	The distance from New York to Los Angeles is 3,000 miles.
Earth	Tens of thousands of miles.	Earth's circumference is 25,000 miles.
Solar System	Millions to billions of miles, or astronomical units (AU). (An AU is the average distance from Earth to the sun, or 93 million miles.)	Neptune is 30 AU, or 2.79 trillion miles, from the sun.
Milky Way Galaxy	Hundreds of thousands of light-years. (A light-year is the distance that light travels in one year, or about 6 trillion miles.)	The Milky Way is about 100,000 light-years across.
Local Group (a cluster of about 20 galaxies, including the Milky Way)	Millions of light-years	The Andromeda galaxy is about 2.2 million light-years away from our Milky Way galaxy.
Supercluster (a group of clusters)	Hundreds of millions of light-years	The Virgo supercluster of galaxies is about 150 million light-years across.
Universe	Billions of light-years	The farthest known galaxy (the edge of the observable universe) is 13 billion light-years away.

3. Explain that one way to put the enormous sizes and distances of space into perspective is to compare them to smaller scales that are easier to grasp. In this activity, students will convert distances and sizes in space to smaller units. To begin, distribute the Classroom Activity Sheet: Understanding Sizes and Distances in the Universe, and have students work in pairs to answer the questions.

4. To help students understand how to solve these problems, you may wish to do the following problem together as a class:

Problem: Using a scale in which a quarter represents Earth, what would the distance from Earth to the moon be?

Solution: Three pieces of information are needed in order to determine this scale distance to the moon: the diameter of the quarter, Earth's diameter, and the actual distance from Earth to the moon. Measuring the quarter reveals that it has a diameter of 1 inch. Earth's diameter is about 8,000 miles. The actual distance from Earth to the moon is an average of 240,000 miles, although this distance can vary with the moon's orbit around Earth. For these calculations, though, the average can be used. Now that we have these three pieces of information, we can find the fourth piece (the scale distance d) by setting up the following ratio:

$$\frac{\text{a diameter of quarter}}{\text{diameter of Earth}} = \frac{\text{scale distance } (d)}{\text{average Earth-moon distance}}$$

This is equivalent to the statement “The diameter of a quarter is to Earth's diameter as our scale distance is to the actual average Earth-moon distance.”

Substituting what we know shows us that:

$$\frac{1 \text{ inch}}{8,000 \text{ miles}} = \frac{d}{240,000 \text{ miles}}$$

Remember that it's important to keep track of the units. If Earth's diameter had been given in kilometers, it would be incorrect to use 240,000 miles for the Earth-moon distance. We would need to convert that distance to kilometers, too. Because both diameters are given in miles, they cancel each other and can be crossed out of the equation. In this problem, we should expect our result to be in inches, the same unit as the quarter's diameter. By multiplying both sides of the equation by 240,000 miles to isolate d , we find that

$$d = (240,000 \text{ miles}) \times (1 \text{ inch}/8,000 \text{ miles}) = 30 \text{ inches}$$

So, at this scale, the distance between Earth and the moon would be 30 inches.

5. Before students start working on the problems, it may be useful to go over scientific notation, which is a helpful way to deal with large numbers. Use the following examples to illustrate the powers of 10:
- 1 can be written as 10^0 (because anything to the power zero is 1).
 - 10 can be written as 10^1 (because anything to the first power is itself).
 - 100 can be written as 10^2 (because 10 multiplied by itself, or 10×10 , equals 100).
 - 1,000 can be written as 10^3 (because 10 multiplied three times, or $10 \times 10 \times 10$, equals 1,000).

Explain that we can use these powers of 10 to represent decimal places, too:

- 3.4 can be written as 3.4×10^0 .
- 99.1 can be written as 9.9×10^1 .
- 4,526 can be written as 4.526×10^3 .

Review the properties of exponents to make scientific notation even more useful:

- When multiplying two numbers with exponents, if the base numbers are the same, just add the exponents. For example, $10^5 \times 10^3 = 10^8$.
- When dividing two numbers with exponents, if the base numbers are the same, subtract the exponents. For example, $10^4/10^2 = 10^2$.

6. Have each pair of students solve the problems listed below, which also appear on the Classroom Activity Sheet: Understanding Sizes and Distances in the Universe. Also included for students are constants that provide helpful information to be used in scaling. Students must figure out which information is needed to solve each problem. Students can work with partners to solve the problems, but each student should fill out his or her own sheet. All the questions from the Classroom Activity Sheet and the answers are listed below. Questions on the Classroom Activity Sheet: Understanding Sizes and Distances in the Universe

If Earth were the size of a penny...

- ...how large would the sun be? (*81 inches, or 6.7 feet, in diameter*)
- ...how far away would the sun be? (*8718.75 inches, 726.5 feet, 242 yards*)
- What is located about that distance from your classroom? (*Answers will vary.*)

If the sun were the size of a basketball...

- ...how far away would Neptune be from the sun? (*3237 feet, or 0.6 miles*)
- ...how far away would the nearest star, Proxima Centauri, be from the sun? (*5,538 miles*)
- Find two places on a world map that are about this distance apart. (*Answers will vary.*)
- ...how far would it be to the center of the Milky Way? (*36,538,218 miles*)
- About how many trips to the moon does this distance equal? (*152*)

If the Milky Way were the size of a football field...

- ...how far away would the Andromeda galaxy be? (*6,600 feet, or 1.25 miles*)
- ...how far would it be to the farthest known galaxy? (*39 million feet, or 7,386 miles*)
- Find two places on a world map that are about this distance apart. (*Answers will vary.*)

Helpful Measurements

- A penny is about $\frac{3}{4}$ inch in diameter.
- Earth is 8,000 miles across.
- The sun has a diameter of 861,000 miles.
- One mile equals 5,280 feet.

- The average distance from Earth to the sun is 93 million miles.
- A basketball is roughly 12 inches in diameter.
- Neptune is 30 AU from the sun, or 2.79 trillion miles.
- One light-year is 6 trillion miles.
- The nearest star, Proxima Centauri, is 4.2 light-years away.
- The sun's distance from the center of the Milky Way is about 30,000 light-years.
- A football field is 100 yards (300 feet) long.
- The Milky Way is about 100,000 light-years across.
- The distance to the Andromeda galaxy is 2.2×10^6 light-years.
- The farthest known galaxy is 13 billion light-years away.

7. Assign the Take-Home Activity Sheet: Comparing the Sizes of Planets for homework. If time permits, discuss the answers in class. You could have students draw the planets to scale to compare the sizes of different planets visually.

Adaptation for younger students:

Complete the Classroom Activity Sheet as a whole-class project. Instead of completing all seven problems focus on four or five. Students may also enjoy completing the Take-Home Activity Sheet together as a class.

Questions:

1. Parallax is the apparent change in position of an object when it's viewed from two different places. Astronomers use this phenomenon to measure the distances to some stars. They assume that the stars are fixed, and as the Earth moves in orbit they take measurements of the apparent shift in position. Then they calculate the distance based on a trigonometric relationship between the parallax angle and the “baseline” (the radius of Earth's orbit). Considering that the more distant an object is, the smaller the angle it will make, why would parallax measurements be better suited for stars than for galaxies?
2. What is the value of using exponents? Give some examples of when they are commonly used. (*Exponents are used to express and calculate large numbers. For example, if you needed to multiply 1,000,000,000,000,000 by 1,000,000,000, instead of dealing with all those zeros, you could write the equation as $10^{15} \times 10^9$ and add the exponents to get the answer, 10^{24} . Exponents are also used in business to express large sums of money and in science to express pH levels, the magnitude of earthquakes, and the brightness of stars.*)
3. Vast distances in space are often measured in light-years. A light-year is the distance that light travels in one year, or about 6 trillion miles. Altair, a star in the constellation Aquila, is 16.6 light-years away, which means that the light we see now from that star left its surface 16 years and 219 days ago. Describe what was happening in the world when the light we are seeing from Altair first left that star. How far away is Altair in miles?

4. Explain why it would be impossible for scientists to measure stellar distances that are accurate to within a few feet. Why is it not critical to attain such accuracy when dealing with astronomical distances?
5. Does knowing how to use a scale on a map help you understand how to use scale to measure distances in the universe? How are they similar? How are they different?
6. Describe how you could measure the height of a mountain without having to climb it. (Hint: Imagine that you're standing 10 miles from the base of the mountain.)

Evaluation:

You can evaluate students using the following three-point rubric:

Three points: active participation in classroom discussions; cooperative work within groups to complete the Classroom Activity Sheet; ability to answer more than three questions correctly

Two points: some degree of participation in classroom discussions; somewhat cooperative work within groups to complete the Classroom Activity Sheet; ability to answer three questions correctly

One point: small amount of participation in classroom discussions; attempt to work cooperatively to complete the Classroom Activity Sheet; ability to solve one problem correctly

Extensions:

How Many Miles Are There in a Light -Year?

Tell students that we know that light travels at a speed of 186,000 miles per second. Have them use that information to figure out how many miles are in a light-year. Then have them try to figure out a scaling factor to help make the large distance easier to understand.

Answer: Multiply the speed of light by the length of time in one year. The tricky part, however, is that the speed of light is expressed in miles per second. Because you have to keep the units the same, you must figure out the length of time in one year in seconds. To do that, multiply the number of days in one year (365) times the number of hours in one day (24) times the number of minutes in one hour (60) times the number of seconds in one minute (60). The answer is 31,536,000 seconds. To find out how many miles are in a light-year, multiply 186,000 miles per second by 31,536,000 seconds. The answer is about 6 trillion miles. To understand what this means, think of Earth, which has a diameter of 8,000 miles, as being the size of a pea, which has a diameter of 1/4 inch. Using that scale, a light-year would be about the distance across the United States.

Selecting the Right Units

Explain to students that establishing the most appropriate unit of measurement is critical when it comes to measuring distances. The right choice of unit can make calculations simpler and help ensure accuracy. Have them imagine trying to measure a mountain in centimeters or an ant in miles. Ask students to research the items in the list below and arrange them in order of scale from smallest to largest. Then have them write down, next to each item, the unit best suited for measuring it. When the list is complete, have the class discuss the tools and procedures that could be used to make each measurement.

- an electron
- the Olympus Mons (a volcano on Mars)
- the Amazon River
- the Great Red Spot (a hurricane like feature in Jupiter's atmosphere)
- a #2 pencil
- Mt. Everest
- a school flagpole
- the Ring Nebula (estimated to be 1/2 light-year across)
- an EP-3E reconnaissance plane
- Ganymede (the largest moon of Jupiter)
- the Empire State Building
- a grain of wild rice

Suggested Reading:

The Astronomy Café: 365 Questions and Answers from "Ask the Astronomer"

Sten Odenwald. W. H. Freeman, 1998.

Using a question-and-answer format, the author covers a wide range of information about space. Each chapter is preceded by a short description of the questions most people have about astronomy. Many questions relate to the distances between the stars and planets and their relative sizes. A few color plates, along with charts and graphs, add to the text.

Milestones of Science

Curt Suple. National Geographic, 2000.

Filled with the luscious photographs that are National Geographic's trademark, this title traces the history of science from prehistory to the present. Each chapter covers a particular time span and the development of man's understanding of the universe. Especially exciting are the chapters that cover the development of modern astronomy, from Galileo to today's space flights.

Vocabulary:

astronomical unit

Definition: A unit of length used in astronomy equal to the mean distance of Earth from the sun, or about 93 million miles (150 million kilometers).

Context: In expressing planetary distances, multiples of the **astronomical unit**—the average distance from Earth to the sun—are often used.

light-year

Definition: A unit of length in astronomy equal to the distance that light travels in one year in a vacuum, or about 5.88 trillion miles (9.46 trillion kilometers).

Context: Many astronomers prefer to use **light-years** to measure stellar distances because they are easier to work with than other units.

parallax

Definition: The angular difference in the direction of a celestial body as measured from two points in Earth's orbit.

Context: After measuring the star's **parallax**, astronomers were able to determine that the star was much closer than previously thought.

scaling factor

Definition: The proportion between two sets of dimensions.

Context: The map indicated a **scaling factor** of 1 inch to every 10 miles.

Academic standards:

Grade level:

9-12

Subject area:

Mathematics

Standard:

Understands and applies basic and advanced properties of the concepts of numbers.

Benchmark:

Understands the properties and basic theorems of roots, exponents (e.g., $[b^m][b^n] = b^{m+n}$), and logarithms.

Grade level:

9-12

Subject area:

Mathematics

Standard:

Understands and applies basic and advanced properties of the concepts of measurement.

Benchmark:

Selects and uses an appropriate direct or indirect method of measurement in a given situation (e.g., uses properties of similar triangles to measure indirectly the height of an inaccessible object).

Grade level:

9-12

Subject area:

Mathematics

Standard:

Understands and applies basic and advanced properties of the concepts of measurement.

Benchmark:

Uses unit analysis to solve problems involving measurement and unit conversion (e.g., between the metric and U.S. customary systems and in foreign currency conversions).

Credit:

Chuck Crabtree, freelance curriculum writer.

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Understanding Sizes and Distances in the Universe

Answer the following questions, using the helpful measurements below. Be sure to use consistent units for each problem and to convert your answer to the largest possible unit. (For example, convert 36 inches to 3 feet, and 5,280 feet to 1 mile.)

Write your answers on the back.

If Earth were the size of a penny...

- ...how large would the sun be?
- ...how far away would the sun be?
- What is located about that distance from your classroom?

If the sun were the size of a basketball...

- ...how far away would Neptune be from the sun?
- ...how far away would the nearest star, Proxima Centauri, be from the sun?
- Find two places on a world map that are about this distance apart.
- ...how far would it be to the center of the Milky Way?
- About how many trips to the moon does this distance equal?

If the Milky Way were the size of a football field...

- ...how far away would the Andromeda galaxy be?
- ...how far would it be to the farthest known galaxy?
- Find two places on a world map that are about this distance apart.

Helpful Measurements

- A penny is about $\frac{3}{4}$ inch in diameter.
- Earth is 8,000 miles across.
- The sun has a diameter of 861,000 miles.
- One mile equals 5,280 feet.
- The average distance from Earth to the sun is 93 million miles.
- A basketball is roughly 12 inches in diameter.
- Neptune is 30 AU from the sun, or 2.79 trillion miles.
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- The sun's distance from the center of the Milky Way is about 30,000 light-years.
- A football field is 100 yards (300 feet) long.
- The Milky Way is about 100,000 light-years across.
- The distance to the Andromeda galaxy is 2.2 – 106 light-years.
- The farthest known galaxy is 13 billion light-years away.

Comparing the Sizes of Planets

Get an idea of the relative sizes of the planets by comparing them with Earth. First, measure the picture of Earth below with a ruler. Use that scale to determine the scaled size of the other planets. Which planet is roughly half of Earth's diameter? Which is four times as large as Earth?



Earth

Actual diameter: 12,756.3 km

Scaled diameter: _____

Planet	Actual diameter	Scaled diameter
Mercury	4,880 km	
Venus	12,103.6 km	
Moon	3,476 km	
Mars	6,794 km	
Jupiter	142,984 km	
Saturn	120,536 km	
Uranus	51,118 km	
Neptune	49,532 km	
Pluto	2,274 km	