

Dear Teachers:

The following pages contain a set of activities that I wrote on scale. Although they are written for college students, they should work fine at other levels, though in some cases you may need to modify them a bit. You'll find four activities in this file, each building up a different level of scale:

1. Scale of the Earth-Moon system.
2. Scale of the solar system and nearby stars.
3. Galaxies and the Local Group.
4. Stars and Grains of Sand.

Each activity is preceded by a set of instructor notes that might be of some use; note that the chapter references are to my astronomy textbooks, so you can ignore them.

Hope they are useful.

Jeff Bennett
jeff@bigkidscience.com

Scale Activity 1: The Earth/Moon System

Instructor Notes

Chapter: Chapter 1, though it could also be used with Chapter 2 or when discussing the Moon.

Note: This is the first of a 4-part set of activities that lead students through ideas of scale, from the Earth/Moon system outward.

Estimated Time for Completion: 10-15 minutes.

Objective(s):

- Develop a sense of scale for the Earth/Moon system, and how it relates to the scale of Earth's orbit around the Sun.
- Practice basic computational skills in doing the scale calculations.

Group Size: This activity is meant to be done in pairs, though larger groups are possible, and it can be done individually with minor modifications.

Materials Required: Each student will need:

- two balls approximately 3-inches and 1-inches in diameter, respectively, to represent Earth and the Moon. Note: Styrofoam balls come standard in these sizes and work well, especially if mounted on wood skewers. Alternatively, almost any balls of the right approximate sizes will do; students could even make them by balling up paper or cloth, secured with rubber bands.
- an approximately 1-inch diameter ball to represent the Moon
- a ruler or tape measure
- a calculator

Activity Overview:

Students work in pairs to learn about the Earth/Moon scale. Generally, one student should hold the balls while the other measures; they can trade off so both get a turn on each part, especially on Part A in which they make a guess. As with most scaling activities, students are usually very surprised to see the true scale of anything astronomical.

Scale Activity 1: The Earth/Moon System

Before you begin:

- You will need two balls, with diameters of approximately 3-inches and 1-inch, to represent Earth and the Moon, respectively. (The actual ratio of Earth diameter to Moon diameter is 3.7 to 1.)
- You will need a ruler or tape measure.
- You will need a calculator.

Part A. Use your 3-inch ball to represent Earth and your 1-inch ball to represent the Moon. *Without doing any calculations*, make a guess about how far apart Earth and the Moon are on this scale; hold your Earth and Moon (one in each hand) to show your guess. Have your partner measure the distance you are holding them apart, and fill-in your name and the measurement of you guess below. Then trade off so that your partner also gets to make a guess.

Student _____ Measurement of guess _____
Student _____ Measurement of guess _____

Part B. The actual average Earth–Moon distance is about 384,000 kilometers, and Earth’s diameter is about 12,800 kilometers. How many “Earth diameters” is the distance from Earth to the Moon? Show your work.

Part C. Based on your answer to Part B, what is the correct scaled distance of the Moon, using the 3-inch ball as Earth?

Part D. Measure out the distance you found in Part C. How does it compare to the guesses you and your partner made in Part A? Write a couple sentences describing the comparison and what you have learned from it.

Part E. The Sun’s actual diameter is about 1,400,000 kilometers. How many “Earth diameters” is this? Given your 3-inch Earth, how large of a ball would you need to represent the Sun? Give your answer in feet, and show your work.

Part F. The Earth–Sun distance of 1 AU is about 149,600,000 km. To represent this distance to scale, how far away would you have to place your 3-inch Earth from your Sun? Give your answer in feet, and show your work.

Part G. Write a few sentences summarizing what you’ve learned from this scaling exercise. Be sure to explain why this scale, although very useful for visualizing Earth and the Moon, is much less useful for visualizing the solar system.

Part H (Bonus). The Hubble Space Telescope orbits Earth at a maximum altitude of about 600 km. Given your 3-inch Earth, how far above the ball’s surface would the Hubble Space Telescope be located? Based on your answer, what can you say about the common belief that Hubble is useful because it is “closer to the stars”?

Scale Activity 2: The Solar System

Instructor Notes

Chapter: Chapter 1.

Note: This is the second of a 4-part set of activities that lead students through the scale of space.

Estimated Time for Completion: 20-30 minutes.

Objective(s):

- Develop a sense of scale for the solar system, and how it relates to the much greater distances to other stars.
- Practice basic computational skills in doing the scale calculations.

Group Size: This activity works well in pairs, though larger groups are possible, and it can be done individually with minor modifications.

Materials Required: Each student will need:

- A ball or piece of fruit (grapefruits work well) approximately 14 cm in diameter, to represent the Sun.
- (optional) clay or a set of ball bearings ranging to represent planets, which will range in diameter from about 0.5 mm to 1 cm.
- a ruler and tape measure
- a calculator
- *Note:* For best effect, this activity should be done outside so that students can actually measure out Earth's orbit around the Sun with a 15-meter radius.

Activity Overview:

In the activity Scale 1, students used a 3-inch ball to represent Earth and a 1-inch ball to represent the Moon. While that scale is very useful for picturing the Earth/Moon system, at the end of the activity students realized it would not work for the solar system, because the Sun is far too large and too far away on that scale. We therefore now “jump scales” by switching to a 1-to-10-billion scale for this activity.

Scale Activity 2: The Solar System

Before you begin:

- Find a ball or piece of fruit (grapefruits work well) approximately 14 cm in diameter, to represent the Sun.
- (optional) You can use clay or a set of ball bearings to use as models for the planets.
- You will need a ruler and tape measure.
- You will need a calculator.

Part A. We will look at our solar system on a scale of 1 to 10 billion, meaning that sizes and distances are all 1/10,000,000,000 of actual sizes and distances. Since the Sun is 1.2 million km in diameter, on this scale it is 14 cm in diameter. You should have a ball or piece of fruit of approximately this size. *Without doing any calculations*, make a guess about Earth's size on this scale, drawing a circle on paper to show your guess. Your partner should then measure the diameter of your guess, and record your name and the measurement below. Then trade off so that your partner also gets to make a guess.

Student _____ Diameter of guess for Earth _____
Student _____ Diameter of guess for Earth _____

Part B. Earth's actual diameter is about 12,800 kilometers. Divide this by 10 billion to find Earth's diameter with our 1-to-10 billion scale model. Show your work. Then draw a dot on paper with the correct diameter. How does the correct answer compare to your guesses from Part A?

Part C. Earth's actual average distance from the Sun is about 150 million kilometers. Divide this by 10 billion to find the distance with our 1-to-10 billion scale model. Go outside and find a place for your model Sun, then measure out the distance to the model Earth. Then, using bits of paper as markers, trace a circle at this distance to represent Earth's orbit around the Sun. Comment briefly on the perspective this gives you about Earth's annual motion around the Sun, viewed to scale.

Part D. The Moon is a little more than $\frac{1}{4}$ the size of Earth, and located at an average distance from Earth of about 384,000 kilometers. Where is the Moon on this scale? Show the scaled distance of Earth and the Moon, and compare to the distance to the Sun. Briefly describe in words how the size of Moon's orbit around Earth compares to the size of the orbit that Earth and the Moon share around the Sun.

Part E. Using data from the Appendices, determine the scaled sizes and distances of the rest of the planets on this scale; make a table of the scaled diameters and distances from the Sun. Identify a few clear trends (such as differences between the sizes and distances of the 4 inner planets compared to those of the 4 outer planets) so that you have a good picture of the solar system.

Part F. The nearest stars besides the Sun are those of the Alpha Centauri system, which are about 4.4 light-years away. Making calculations as needed, find the scaled distance to the nearest stars. Comment on your results.

Part G. The Milky Way Galaxy is about 100,000 light-years in diameter. What would its diameter be on the 1-to-10-billion scale? Is this scale useful for picturing our galaxy? Why or why not?

Part H (Bonus Questions).

- i. How much does Earth/Sun distance vary over course of year on this scale? Comment on why this varying distance does *not* noticeably affect our seasons.
- ii. The *New Horizons* spacecraft — which is traveling faster than any other ship ever built by humans — is taking about a decade to travel the distance from Earth to Pluto. About how long would it take it to reach the nearest stars? Comment on the technological challenge of interstellar travel.
- iii. The distances between stars that you've found in this activity is typical for our region of the galaxy. Comment on the likelihood of collisions among star systems, and on the likely effects on stars and planets when entire galaxies collide.

Scale Activity 3: Galaxies and the Local Group

Instructor Notes

Chapter: Chapter 1.

Note: This is the third of a 4-part set of activities that lead students through the scale of space.

Estimated Time for Completion: 10-15 minutes.

Objective(s):

- Develop a sense of scale for the Milky Way Galaxy and the Local Group.

Group Size: Since this activity follows the activities Scale 1 and Scale 2, it is best to continue with the same size groups (probably pairs), though you may wish to ask students to switch partners.

Activity Overview:

In the activity Scale 2, students viewed the solar system with a scale of 1 to 10 billion, which does not work well beyond the nearest stars. We therefore now “jump scales” again to visualize the Milky Way Galaxy at about the size of a pancake.

Scale Activity 3: Galaxies and the Local Group

Before you begin:

- Complete Scale Activity 1 and Scale Activity 2 OR carefully read about the Voyage Scale Model Solar System in your textbook.

Introduction. As you have already seen, the 1-to-10 billion scale that we used to visualize the solar system does not work for our galaxy. We must therefore “jump scales” to visualize the galaxy and our Local Group; we will use a scale in which our galaxy the size of a small pancake, about 10 centimeters in diameter. (This means that the scale is now 1-to- 10^{22} .)

Part A. The Milky Way’s disk is about 1000 light-years thick. Given that 10 cm represents the 100,000 light-year diameter of the disk, how thick is the galaxy on this scale? Is it accurate to describe the galactic disk as “flat as a pancake”? Explain.

Part B. The Andromeda Galaxy (the other large member of our Local Group) has about the same 100,000 light-year diameter as the Milky Way and is located about 2.5 million light-years away. If you use a second pancake to represent the Andromeda Galaxy, how far away should you place it from the Milky Way pancake? Draw circles to represent the two galaxies, and place them the correct scaled distance away.

Part C. Using your results so far and what you learned earlier from the scale model of our solar system, explain why collisions between galaxies are relatively common in the universe, but collisions between stars are rare (except in the dense, central portions of galaxies and globular star clusters).

Part D. Using your pancake model of the galaxy (or the circle you’ve drawn to represent it), find the approximate distance of our solar system from the center of the galaxy. How far away are the nearest stars on this scale?

Part E. The observable universe extends about 14 billion light-years in all directions from Earth. Can the pancake scale be used to visualize the universe? Can you come up with another scale that allows you to represent the observable universe in your classroom?

Part F (Bonus Questions).

- i. Based on your answers in Part E, explain what mean by the *observable universe*. What would the observable universe look like from other galaxies?
- ii. Explain the statement “the farther we look out in space, the further back we look in time.” What does it mean about what we see in different parts of the observable universe? How does it relate to your model from Part E?

Scale Activity 4: Stars and Grains of Sand

Instructor Notes

Chapter: Chapter 1.

Note: This is the last of a 4-part set of activities that lead students through the scale of space.

Estimated Time for Completion: 10-15 minutes.

Objective(s):

- Develop a sense of the vast number of stars in the observable universe.

Group Size: Since this activity follows the previous scale activities, it is best to continue with the same size groups (probably pairs), though you may wish to ask students to switch partners.

Activity Overview:

This activity gives less guidance than the prior Scale activities, in hopes that students by now can use the ideas they've been learning to find a way to arrive at the correct answer themselves.

Scale 4: Stars and Grains of Sand

Data. The following data will be useful to you as you do this activity.

- According to the CIA, the total length of sandy beach on Earth is about 360,000 kilometers.
- A typical beach width is about 50 meters, and typical depth of dry sand is about 2 meters.
- Sand grains vary in size from about 0.1 to 2 millimeters in diameter; for this activity, use an average size of about 0.5 millimeters.
- There are about 100 billion galaxies in the observable universe, and you can assume that a typical galaxy has about 100 billion stars.

Activity. Use the given data to calculate the approximate number of grains of dry sand on all Earth's beaches combined. Compare to the number of stars in the observable universe. Show all your work. Comment on your results.