**Eclipse Science: Modeling Eclipses in the Solar System**

Inspired by *The Physics Teacher*’s

“Using the Solar Eclipse to Estimate Earth’s Distance from the Moon” by Mikolaj Sawicki

**Description:** Students create a proportional physical model of the Earth and Moon system and model eclipses.

The inspiring article presents an activity to estimate the Earth’s distance from the Moon during a solar eclipse. The following activity is a hands-on lesson to help students understand both the geometry of the Earth and Moon during eclipses (and can be performed on any sunny day), as well as the relative distances and sizes of the Earth and Moon. This activity supports conceptual understandings presented in the inspiring article.

This work is a modification on the resource developed by AAPT and Temple University, a project funded by the NASA Heliophysics Education Consortium (HEC) to support learning about space science in college-level physics and astronomy courses. Visit **aapt.org/resources/eclipse2017** for additional research-based teaching resources about eclipses, or **eclipse2017.nasa.gov** for further information about the 2017 Total Solar Eclipse.

**Purpose:** Demonstrate an understanding of solar eclipse geometry of the Earth, Moon, and Sun.

**NGSS Connections:**

Performance expectations: MS-ESS1-1

Disciplinary Core Ideas:

* Earth’s Place in the Universe: MS-ESS1.B, HS-ESS1.B

Crosscutting Concepts:

* Cause and Effect
* Scale, Proportion, and Quantity
* Systems and System Models

Science and Engineering Practices:

* Developing and using models
* Constructing explanations

**Materials** (per group)**:**

* Cardboard (8.5” x 11”)
* T-pins or nails (2)
* Modeling clay
* String
* Ruler
* Bright, diffuse light (this activity is best done outdoors during a bright day with clearly directed sunlight, but can also be accomplished indoors using an LCD projector).
* White paper

**Activities** (in brief):

* Students build a scale model of the Earth and Moon using the cardboard as a base. The Moon and Earth should be proportional both in their distance from each other and the relative size of the balls of clay representing them. A string is tied at the base of each ball of clay, which is made parallel to the cardboard. When the string is parallel to the board, it represent a long along the plane of the ecliptic.
* Students observe the shadows produced by a “total solar eclipse” using the model when all objects are perfectly aligned by placing a piece of paper behind the model (opposite the light source).
* Students reflect on the possible reasons why total solar eclipses are not observed every month (or during every new Moon).
* Students model how the Moon leaves the plane of the ecliptic by pushing the T-pin or the nail supporting the Moon either up or down through the cardboard paper. When the string connecting them is no longer parallel to the cardboard, this represents that the Moon is not in alignment with the plane of the ecliptic.
* Students observe the shadows produced by the Earth and Moon as the Moon passes between the Earth and Sun either above or below the plane of the ecliptic.
* Students reflect on the difference between the shadows observed on the paper and the actual perspective of people viewing the eclipse from the Earth or from the surface of the Moon facing the Earth.
* Students compare relative proportions of the size of the shadow of the Moon on the Earth using the model and comparing it to a NASA video of the shadow crossing the Earth.
* Students sketch possible observations of the total eclipse from viewers on Earth at points located near the center and at various edges of the umbra.

**Prior Conceptual Understandings Required**

* Formation of shadows
* Phases of the Moon

**Modifications**

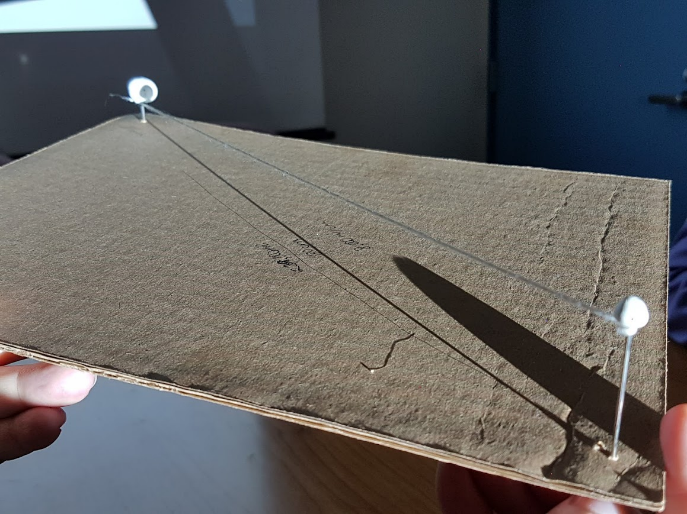
* Light source: A 300-W directional flood light works reasonably well.
* If available, use calipers to measure diameters of Earth and Moon balls.
* Clay tends to work a little better than Play-Doh. In either case, the lighter the color, the better, at least for Earth.
* Use cardboard or black foamboard; white foamboard will be too reflective.
* If you can get the light source parallel to the desk or table, so the cardboard can sit on the surface, it makes alignment a bit easier. Then set the cardboard on something like a book with smaller dimensions to allow for movement of the pins up and down for part X.2.
* Blacken, cover, or otherwise dim any light sources as much as reasonable.
* If you don’t have block periods of more than an hour, you’re likely to need a second day. Consider where you’ll store the setups between lessons.
* Starting with X.3.B, these items do not require the setup and so could be done as homework.

**Star Spectra Science: Using Balloons and Buttons to Model Spectroscopy**

Student Worksheet

**Purpose:** Demonstrate an understanding of solar eclipse geometry of the Earth, Moon, and Sun.

**Guiding questions:**

To understand how solar eclipses occur, we will build off of what we already know about the phases of the Moon. In essence, we will expand our model to think about how the Sun, Earth, and Moon are aligned in order for an eclipse to occur.

PART 1

Build a scale model of the Earth-Moon system using a piece of letter-sized piece of **cardboard** with two **pins** or nails inserted at opposite corners of the cardboard. (Insert the nails from the bottom, so that the sharp ends are pointed upward).

Place small balls of **clay** on top of the pins or nails to represent Earth and the Moon. The size of each piece of clay will be determined below.

1. Determine the scale of your system by determining the distance between the two pins or nails. Explain how you did this in words or with math. (The average distance between Earth and the Moon is 238,900 miles).



1. Using the scale for your model, make Earth and the Moon proportional sizes. Explain how you did this in words or with math. (Earth radius = 3,959 miles; Moon radius = 1,079 miles).

Connect Earth and the Moon with a taut piece of **string**. Ensure that the string always remain attached right at the base of the clay. The cardboard will represent the orbital plane of Earth as it goes around the Sun, and the string will represent the orbital plane of the Moon as it goes around Earth.

Begin with the string parallel to the cardboard. Using a diffuse, bright **light** such as the Sun or a projector beam, place the model so that the Moon is closest to the light, and Earth is farthest away. The Sun, Earth, and Moon should be perfectly aligned so that they all fall in the same line. Observe the shadow that falls onto a piece of **paper** held vertically just beyond Earth.

1. Where does Earth’s shadow appear? What does it look like?
2. Where does the Moon’s shadow appear? What does it look like?
3. Identify any similarities and differences between Earth’s and the Moon’s shadows.
4. Create a sketch below showing what this setup looks like from a side-view of the Sun, Earth, and Moon system. Include a sketch of how the shadows are produced and where they fall. Label each object.

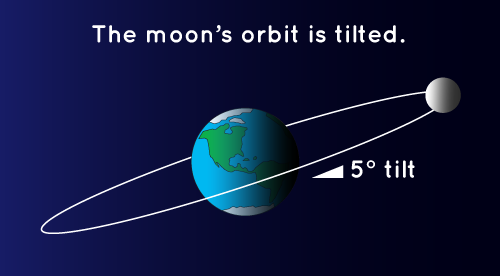
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1. Create a sketch below show what this setup looks like from a top view of the Sun, Earth, and Moon system. Include a sketch of how the shadows are produced and where they fall. Label each object.

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1. What is the phase of the moon during a solar eclipse? Explain how you know.
2. You might be aware that it is fairly rare to see a total solar eclipse. (Total solar eclipses can only be observed at the same location about every 375 years, with typically 2 total solar eclipses visible at some point on Earth each year). Elaborate on one or two possible reasons why you might not see total solar eclipses each month.

PART 2



Credit: NASA

As was noted in Part 1, total solar eclipses do not occur each time there is a New Moon. This is due, in part, to the fact that the Moon does not lie on the same plane as the Sun and Earth (the Plane of the Ecliptic).

Each month, the Moon passes through the Plane of the Ecliptic at an angle of 5° above and below. In Part 1, the string was parallel to the cardboard, and Earth and the Moon were both in the Plane of the Ecliptic. In Part 2, you will make the Moon go above and below the Plane of the Ecliptic.

1. Push and pull on the nail representing the Moon, so that the string is no longer parallel to the cardboard. Orient the Moon so that its shadow appears to the left of Earth (when observing the shadows on a piece of paper, like in the diagrams below). Slowly rotate the system so that the Moon’s shadow moves toward the right. Observe how this changes the shadows produced on the paper. Draw the progression of the projected images seen on the paper for the following scenarios.



* 1. The Moon is “higher” than Earth. The Moon passes above Earth’s plane.

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* 1. The Moon is “level” with Earth. The Moon passes along Earth’s plane.

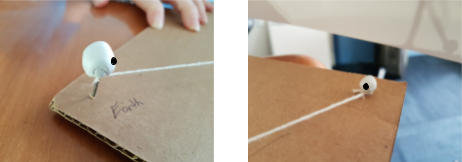
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* 1. The Moon is “lower” than Earth. The Moon passes below Earth’s plane.

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1. Which of the above scenarios is total solar eclipse? Explain.

Consider the scenario you selected that represents a total solar eclipse. Notice, however, that the projected images you drew in all three cases above is *not* what is actually viewed by people during a total solar eclipse. Using your pencil, place a **dot** on the surface of Earth and the Moon where they face one another.



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1. Draw a sketch of what would be viewed from Earth when looking toward the Moon during a total solar eclipse.
2. Draw a sketch of what would be viewed from the Moon when looking toward Earth during a total solar eclipse.

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Part 3

In Part 2, you drew a sketch showing what would have been observed from the Moon when looking toward Earth. NASA has captured images of the shadow on Earth, called the Moon’s umbra. See an animated gif here: <https://goo.gl/HcLXuu>



Credit: NASA

One place that our cardboard and clay model of the Moon and Earth fails is in the size of the shadow on Earth.

Compare the size of the umbra on the clay Earth in your model to the size of the umbra shown in the image above from NASA.

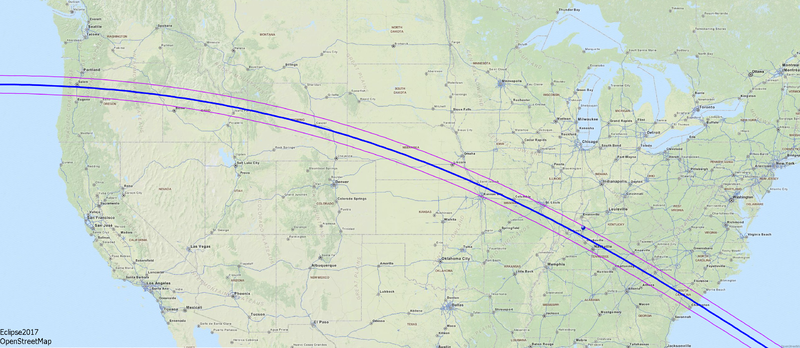
1. How are they different?
2. What do you think might account for this difference in size? If you are unsure, try modeling eclipses in front of different types of light sources, including sources that are point sources (such as a smartphone flashlight), sources that are diffuse, more and less intense, and nearer or farther.
3. Because the umbra does not fully cover the surface of Earth that is facing the Sun during a solar eclipse, not everyone has the same view during the eclipse! On the “pop-outs” on the diagram below, sketch what would be observed by people in boats at various points in the Pacific Ocean at the moment this image was taken. Label the Sun and the Moon in your sketches.



Credit: NASA

Consider the upcoming eclipse! Look at the map on the following page showing the path of the eclipse below.

1. Where will you be on 21 August 2017? What will the eclipse look like to you?
2. Imagine you had a friend in rural Montana. Write a letter to you friend describing what s/he will expect to see on August 21, and why (if s/he remains in Montana during the eclipse). In your letter, include the following:
   1. What a solar eclipse is.
   2. How the Sun, Earth, and Moon must be aligned (including a sketch).
   3. What the eclipse will look from his/her location (including a sketch).



Credit: Wolfgang Strickling