THE UNIVERSE IN THE CLASSROOM

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Getting Ready for the All American Eclipse!

An NGSS Storyline Approach to Classroom Instruction

by Brian Kruse (Astronomical Society of the Pacific)

The release of the *Framework for K–2 Science Education*, and the adoption of the Next Generation Science Standards, has created a shift in the way teachers approach their instruction. For students to demonstrate their understanding, they must now engage more actively in investigating phenomena rather than passively learning about a set of topics. Next year, on August 21, 2017, teachers and students across the nation will have an opportunity to witness one of the most awe-inspiring phenomena on earth: a total solar eclipse. Taking place mid-day on what is for many schools a school day, everyone in the contiguous United States will experience at least a 60% partial solar eclipse. Those fortunate enough to live in the path of totality will, weather permitting, see up to two minutes and forty seconds of a total solar eclipse. The partial phases of the eclipse will last much longer, ranging from two and a half up to three hours duration from start to finish. Even the partial eclipse is a wonderful phenomenon for students to observe! A teachable moment, without compare.

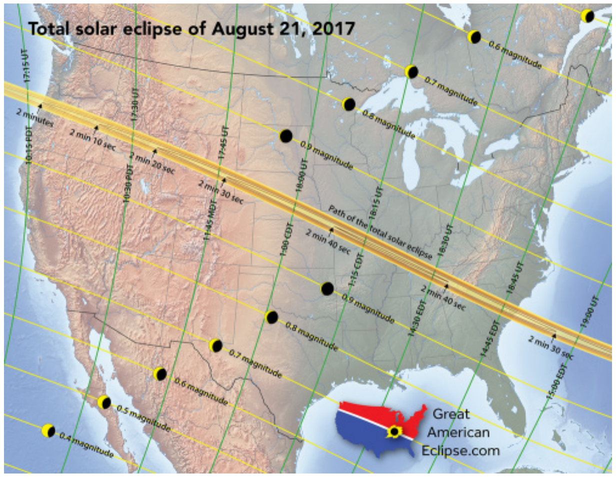

Figure 1: The Great American Eclipse of 2017
Illustration courtesy of Michael Zeiler: Great American Eclipse.com

To take advantage of this teachable moment, there are two primary considerations for teachers:

- Incorporating the eclipse into their instructional sequence, and
- Safely viewing the eclipse

For the first, a solar eclipse provides an opportunity to engage students in an NGSS storyline, with a coherent sequence of investigations that give them an in-depth understanding of the phenomenon of eclipses. Basically, an NGSS storyline incorporates an Anchoring Phenomena, something students are able to observe for themselves, which can lead to a Driving Question for the overall investigation. A set of sub-questions lead to investigations which move into student development of an initial model to explain the phenomena, which can then prompt further questions and investigations to refine the model. Eventually, the students come to a point where they can form a final consensus model. At any time during the instructional sequence, it is recommended to probe for student understanding using a variety of formative assessment strategies. The book *Uncovering Student Ideas in Astronomy: 45 New Formative Assessment Probes* by Page Keeley and Cary Sneider (2011, NSTA Press) contains a number of probes useful at any grade level.

This is what such a storyline may look like:

Anchoring Phenomena and Driving Questions

Anchoring Phenomena:

- The Sun appears partially covered, and eventually appears dark.
- The Moon turns dark or blood red.

Potential Driving Questions for a Solar Eclipse:

- Why do solar eclipses happen?
- Why is the appearance of the Moon the same size as the Sun in our sky?
- How are lunar phases and a solar eclipse related?
- How often do solar eclipses occur?
- Why don't we see an eclipse every month?
- Why are solar eclipses not visible to every location on Earth?

Potential Driving Questions for a Lunar Eclipse:

- Why do lunar eclipses happen?
- How is a lunar eclipse different than a solar eclipse?
- Why do lunar eclipses last longer than solar eclipses?
- How are lunar phases and a lunar eclipse related?
- How often do lunar eclipses occur?
- Why can we not see an eclipse every month?
- Who is able to see a lunar eclipse?
- Why don't we see lunar eclipses during the day?

Sequence of Investigations

Investigation 1: When is the Moon Visible in the Sky?

The beginning of an investigation of eclipses may begin months before an eclipse, and then culminate with the observation of the eclipse. As with any new unit, it is best to start with an assessment of what prior ideas students are bringing to the table, such as with a probe for student ideas about when the Moon is observable in the sky. Many people, including adults, hold the misconception the Moon is only observable at night, so probing for this idea is important. Choosing a time when the Moon is up during the day, and observable at this point is quite valuable. For planning purposes, the US Naval Observatory is able to provide data for daily Sun and Moonrise and set times. See the list of resources at the end of this booklet for the link.

Once establishing the Moon is observable in the daytime sky, useful questions for follow-up include:

- Is the Moon always in the same place at the same time?
- Does the Moon always have the same shape?

Returning outside to observe at the same time on subsequent days can lead to students keeping their own Moon Journal for recording their observations. Alternatively, show a month's worth of images of the Moon and its changing phases, having students record their observations. (see Supplementary Document A for a sample Moon chart) Group discussions at this point can help students identify patterns in their observation.

Sun and Moon Data for One Day

U.S. Naval Observatory
Astronomical Applications Department

San Francisco, San Francisco County, CA (Longitude W122° 26', Latitude N37° 46')

Thursday, July 27, 2017 — Pacific Daylight Time

Sun	
Begin civil twilight	5:40 a.m.
Sunrise	6:09 a.m.
Sun transit	1:16 p.m.
Sunset	8:23 p.m.
End civil twilight	8:52 p.m.
Moon	
Moonrise	10:50 a.m.
Moon transit	5:09 p.m.
Moonset	11:20 p.m.

Closest Primary Moon Phase: First Quarter on July 30, 2017 at 8:23 a.m. (local daylight time)

Phase of the Moon on July 27, 2017: Waxing Crescent with 23% of the Moon's visible disk illuminated.

Figure 2: Complete Sun and Moon Data for One Day
Image from the United States Naval Observatory Astronomical Applications

Investigation 2: How Large Does the Moon Appear?

A related item for investigation is the Driving Question:

- Does the Moon always appear the same size in the sky?

It is important to note there are only a few things that astronomers can actually measure about astronomical phenomena. One essential measurement is angular size, or the amount of space an object appears to occupy in the sky. Using their fingers and hands, students can make approximate measurements of the angular size of the Moon in the sky. The width between an outstretched thumb

Figure 3: Sequence of lunar phases
Images by Jay Tanner - N/A, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php

and pinkie covers approximately 20° of the sky, and a clenched fist about 10°. A thumb covers 2° of sky, and a pinkie about 1°. The Moon has an angular diameter in the sky of about 0.5°, or half a pinkie. Students can measure the Moon in the sky with their pinkie every time they make an observation. Students may mention noticing how much larger the Moon appears when it is near the horizon. Having them measure the Moon when it looks larger near the horizon will help convince them of the unchanging apparent size of the Moon. This "Moon Illusion" is explained as an optical illusion due to our mind's comparison with objects of known size in the foreground, combined with our perception of more distant objects appearing smaller the farther away they are.

Figure 4: Measuring the angular size of the Moon. The Moon appears 0.5 degrees in diameter, about the same as half of a person's small finger. Image: Brian Kruse/ASP

This investigation leaves out the actual minor changes in the size of the Moon due to the elliptical nature of its orbit around the Earth. Recent years have seen the term "Super Moon" coined to refer to the Moon appearing larger when it is at perigee, the closest point in its orbit to the Earth.

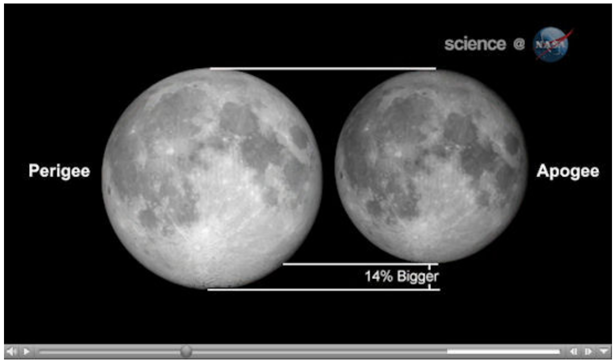

Figure 5: the difference in angular size of the Moon at perigee compared to apogee. Image from NASA Science News, http://science.nasa.gov/science-news/science-at-nasa/2011/16mar_supermoon/

Investigation 3: How Much of the Moon Does the Sun Illuminate?

One of the essential conceptions necessary for a full understanding of both lunar phases, and eclipses, is knowing how much of a spherical object, such as a planet or moon, is lit up when the illumination comes from a single light source, such as a star or sun. Keeley and Sneider's book mentioned earlier contains a formative assessment probe useful at this time to ascertain student understanding of this important concept. The probe asks students to pick one choice:

- If you observed a crescent Moon in the night sky, how much of the *entire* Moon's surface is actually lit up by the Sun?
    - Quarter or less of the entire Moon
    - Half of the entire Moon
    - Three quarters of the entire Moon
    - The entire Moon
- Explain your thinking. Provide an explanation for your answer.

Have the students record their responses, then ask the whole class to vote quietly in response to the question to help you gauge where students are with their understanding. You might consider using a variety of strategies to help students remain anonymous rather than voting with a show of hands. Thumbs up next to their chests, an A-B-C-D voting card, or even a clicker system can help in this instance.

Working in pairs, give students a polystyrene ball impaled on a pencil or stick. With only a single light source in the room, have students observe the ball to determine how much of it is lit at any one time. Allow students to exchange places so each individual has a chance to witness the phenomena. In their explorations, have the students explore the following questions after they know how much of the ball is lighted at any time:

- Where is the ball when you can see the entire lighted side?
- Where is the ball when you cannot see any of the lighted side?
- Where is the ball when you can see only the right side lighted?
- Where is the ball when you can only see the left side lighted?

Figure 6: a waxing crescent Moon. Image from the United States Naval Observatory Astronomical Applications

- What happens to the size and shape of the lighted side you can observe when you move the ball counterclockwise around your head?
- At any time, how much of the ball is illuminated?
- Is there ever a time when no light is illuminating the ball?
- At any time was another object interfering with the light and casting a shadow on the ball?

This brief investigation will lead directly into the next.

Investigation 4: What Causes the Pattern of Lunar Phases?

Asking students to suggest ways to explain the patterns noted in Investigations 1 and 3 leads into this next investigation.

An introduction to this investigation could include the whole-class kinesthetic activity where students' imagine themselves to live on "Mt. Nose." In this simulation/demonstration, the ideas of rotation and revolution are reinforced, along with incorporating time: one rotation of the Earth equals one day, one revolution (or orbit) of the Moon around the Earth is one month, one revolution (or orbit) of the Earth around the Sun equals one year. One can also use this kinesthetic activity to model the rotation of the Moon. It is a common misconception the Moon does not rotate, mainly due to the fact the same side is always turned towards Earth, so there is almost an entire half of the Moon we never see. It is easily demonstrated through modeling the period of rotation of the Moon is for all practical purposes the same as its period of revolution.

Having students use their hands as "horizons" held perpendicular to their head at the same position as their ears will enhance their ability to visualize sunrise and sunset, as well as discovering the times of moonrise and moonset when the Moon is in its various phases.

With analysis of the moon tracking chart, and a pattern of lunar phases along with the Moon's position in the sky described, students are now ready to use the model to explain their observations. Provide materials such as a light source and polystyrene ball to student groups, and ask them to position the ball until the pattern of light and shadow on the ball

Figure 8: sunrise on Mt. Nose as you rotate towards the left; the hands represent the horizon lines. Image: Brian Kruse/ASP

matches what they observed with the Moon. They can then reposition the ball to recreate the pattern of lunar phases.

With students working in groups:

- Have them start using the model to replicate the Moon's shape as observed the first day.
- Using the materials, have them develop a model to demonstrate the positions of the Earth-Moon-Sun system that can recreate and explain their sequence of observations.

Figure 7: exploring the illumination of a sphere. Images: Brian Kruse/ASP

Figure 9: exploring the phases of the Moon. Images: Brian Kruse/ASP

- Consider having students create a poster that includes data from their Moon Journal and modeling using text and diagrams to explain their understanding of what causes Moon Phases.
    - A variety of strategies at this point can help students with engaging in the science practice of Arguing from Evidence. In particular, the Round Robin strategy, with one or two students from each group circulating around the room to see what other groups are proposing. This student then returns to their group to report their findings, which may result in a refining of ideas and presentation.

As they created their model, they will have realized that they needed to lift the full moon up so as to not allow it to sit in the shadow of their head.

Investigation 5: How Big and How Far is the Moon?

In the previous investigation, students were able to create a model explaining the cycle of lunar phases. This is tremendously important since the pattern of both solar and lunar eclipses is tied to the pattern of lunar phases. Probably the second most important factor in having a complete mental model for eclipses involves an understanding of the size and distance scale for the Earth-Moon system.

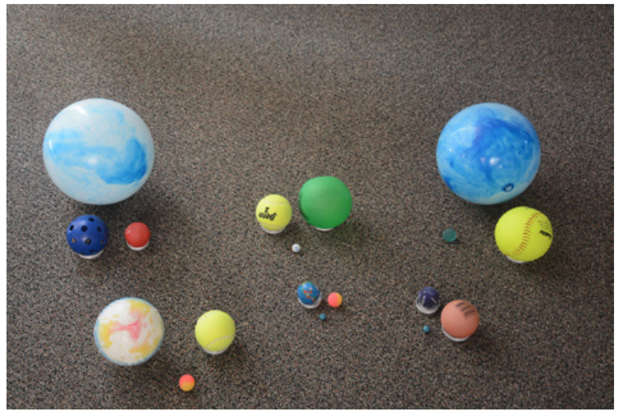

Figure 10: sets of balls with two in each set representing the Earth and the Moon. Image: Brian Kruse/ASP

As with any investigation, it is important to determine the prior conceptions students' have about the Earth-Moon size and distance scale. Give each group a set of three balls of miscellaneous sizes, making sure that one of the balls has a diameter four times that of one of the other balls in the set. Giving each group a set of three balls different from the other groups will help each group come to their own conclusions.

With students working in pairs:

- Tell them you would like to make a scale model of the Earth and Moon using balls, but you are unsure which ones to use.
- Ask each pair of students to select the two balls they recommend you use. Ask them to explain their reasoning, and why they believe their selected pair most closely represents the Earth and the Moon.
- As a whole group, have each pair of students show the pair of balls they selected, and discuss the similarities and differences between the model pairs.
- Give the students the following information:
    - Earth Diameter: 8,000 miles (12,800 km)
    - Moon Diameter: 2,000 miles (3,200 km)
- Allow students to reevaluate their selections above in light of the newly provided data.
- Have each pair of students select the pair of balls that most closely matches with the provided data. They should use the provided measuring devices to check the ratio of the diameter of the Earth and Moon (4:1). Encourage them to use whatever technique and materials are available to measure and

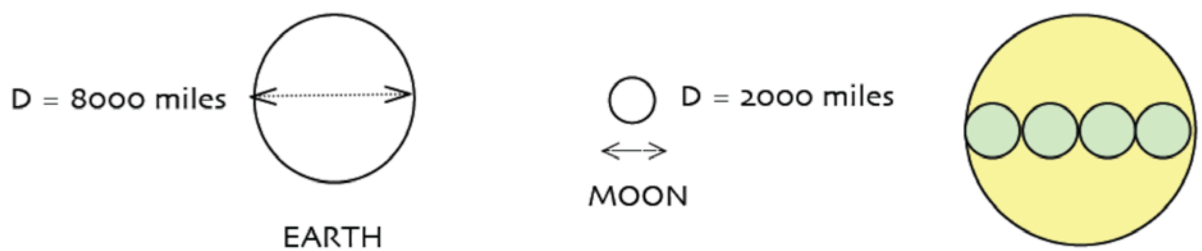

Figure 11: the scale size of the Earth and Moon. Image courtesy of Linda Shore/ASP/Exploratorium

find the correct balls to represent the Earth and Moon.
- As a whole group, discuss and explain how their models changed when given the actual data.

With a new understanding of the scale difference in size between the Earth and Moon, we can turn our attention to the distance between them, both in reality, and in their scale model.

With students working in their same pairs, and with the same balls they determined represented the Earth and Moon:

- Ask the pairs of students to place the balls they selected before at the distance apart they think the model Earth and Moon should be on this scale.
- As a whole group, ask a group to explain their thinking and why they chose the distances

Figure 12: measuring the scaled Earth and Moon. Image: Brian Kruse/ASP

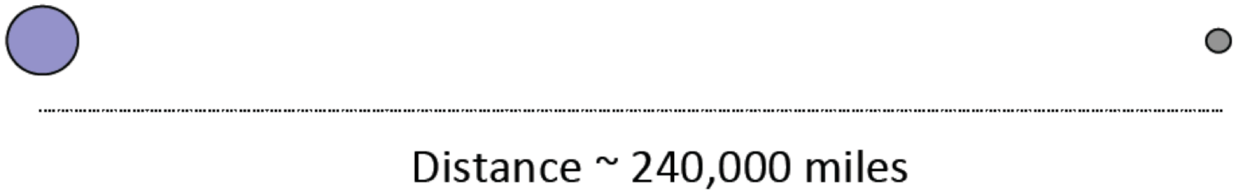

Figure 13: the distance between the Earth and the Moon (image not to scale!) Image courtesy of Linda Shore/ASP/Exploratorium

they did. Ask another pair of students if they agree or disagree with their estimate, and to explain their thinking. Seek other groups' opinions and estimates.

- Give the students the following information:
  - Distance from Earth to the Moon: 240,000 miles (385,000 km)
- Using this information, and that provided in the previous section, ask students to use any technique they want to determine the scale distance between the pair of balls representing the Earth and Moon.
- As a whole group, have students explain how they determined the scale distance between the Earth and Moon.
  - With a variety of different sizes of balls, the distances will vary, however, if students have accurately portrayed the scale distance, will form similar ratios when comparing individual models.
- Probe for student understanding and their new ideas about the size and distance comparison between the Earth and Moon. Were they surprised at the results of their investigation?

Investigation 6: Why Do Eclipses Happen?
Students have now modeled both lunar phases and the size and distance scale for the Earth and Moon. They are now ready to discover the Sun-Earth-Moon system geometry that leads to solar and lunar eclipses.

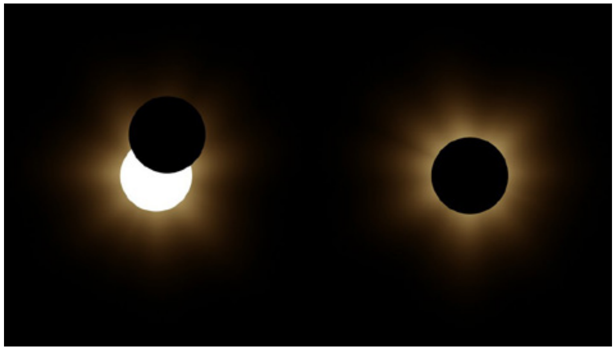

Figure 14: a partial (left) and total (right) solar eclipse. Image: NASA's Scientific Visualization Studio

Show students images of a variety of solar eclipses, including YouTube videos. Ask students to summarize the pattern of what they see in each solar eclipse. Provide at least one sequence of 6 to 8 photos of a solar eclipse as a set of data to work with. With students working in groups, provide them with a new scale model of the Earth-Moon system.

In their groups, ask students to try to reproduce the phenomena they observe in the eclipse images and sequences. You can provide each group with their own flashlight for illumination, or you can use a bright, centrally located light much as you did

Figure 15: the basic setup for modeling eclipses. Images: Brian Kruse/ASP

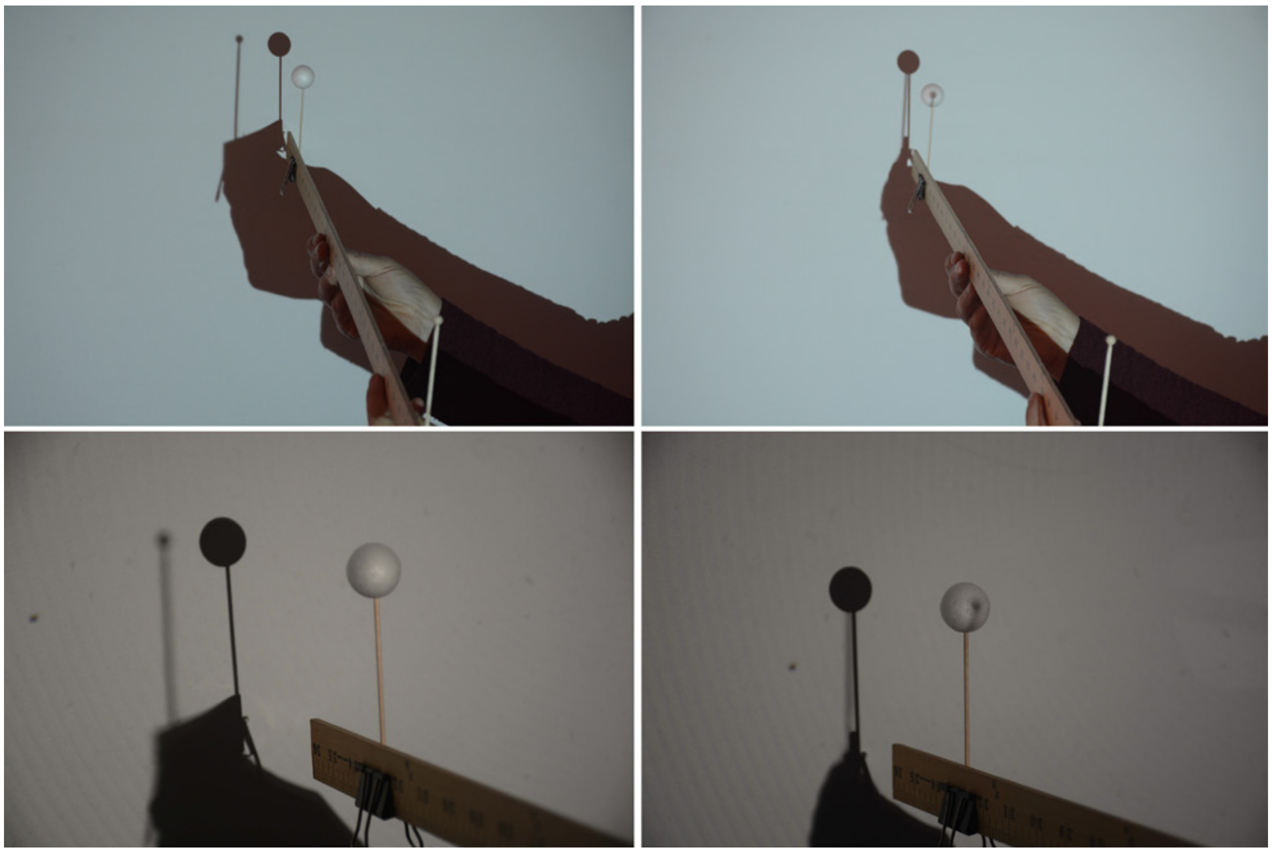

Figure 16: modeling a solar eclipse. Images: Brian Kruse/ASP

earlier in the investigation of lunar phases. Students will find it difficult to align their model to produce an eclipse, so providing some blank, white paper will help them to align the shadows of both objects to form their eclipses. The main concern here is some students will concentrate on the shadow cast by their Earth and/or Moon on the paper, mistaking that for the eclipse seen from Earth.

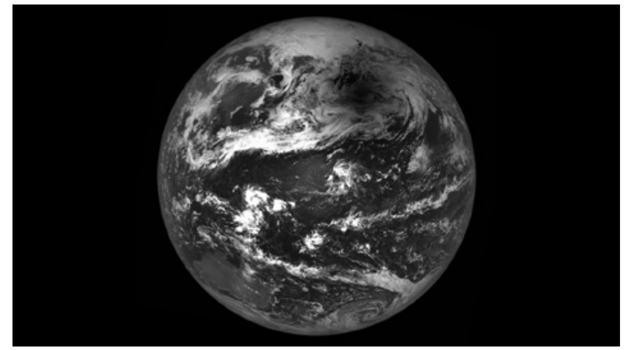

Figure 17: the shadow of the Moon on Earth during the annular eclipse of May 20, 2012. Images: NASA's Scientific Visualization Studio/LRO

At this time it is also possible to have students engage in a Round Robin type activity, much as they did earlier, to see any differences in model there are between groups. Have students make sure they are ready to make a correlation between the phenomena of a solar eclipse with those of lunar phases. What is the relationship? Can they demonstrate the relationship?

During a whole group discussion, have student groups demonstrate and defend their model with evidence they gathered through manipulating their models.

After all groups have successfully created a solar eclipse, show them images of a lunar eclipse, then follow the same procedures for student modeling of

Figure 18: a total (left) and partial (right) lunar eclipse. Images: NASA's SpacePlace (left), Brian Kruse (right)

this phenomena.

Related questions for investigation and answerable through modeling with the same setup are:

- Who on Earth is able to observe a solar eclipse? and
- Who on Earth is able to observe a lunar eclipse?

Investigation 7: How Often Do Eclipses Happen?
In investigation six, students were able to model individual solar and lunar eclipses, and explain the relationship between the eclipses and a particular lunar phase. In this investigation, start out with probing for student retention of this relationship:

- Solar eclipses occur during a New Moon
- Lunar eclipses occur during a Full Moon

Ask students to consult their Moon journals.

Figure 19: modeling a lunar eclipse. Images: Brian Kruse/ASP

How often is there a New Moon? How often is there a Full Moon? Students will likely respond once per month ("moonth"). Some students may realize the lunar cycle is a little shorter than a month, or may recall hearing about the possibility of two full moons taking place in the same calendar month (usually referred to as a "Blue Moon," however the exact definition of this phenomena is uncertain), and they may respond and say there are thirteen full moons per year. Further questioning includes asking: how often is there a solar eclipse, and how often is there a lunar eclipse?

The potential Driving Question for this investigation is:

- Why don't we see eclipses every month?

In addition to the science practice of Developing and Using Models, this investigation focuses on Analyzing and Interpreting Data. Using data on lunar phases from the US Naval Observatory (see Supplemental Document D), as well as the dates of solar and lunar eclipses from the NASA Eclipse Page (see Supplemental Documents B and C), students will graphically display the data on a time chart (see Supplemental Document E). This chart will enable students to find patterns in the data to determine any relationship between the two sets of data. Some basic pattern they may observe in the data is:

- Lunar eclipses occur during Full Moons.
- Solar eclipses occur during New Moons.
- Solar and lunar eclipses occur in pairs (and sometimes trios) approximately two weeks apart.
- The pairs of eclipses occur twice per year, approximately 5 and 7 months apart.

Once students have discovered some of these patterns, and with the same modeling setup as before, ask them to return to their Sun-Earth-Moon system models and ask them to try and use the model to explain the observed patterns. This is a potential opportunity to engage them in a sort of scientific symposium, with students making their investigations, and producing a poster presentation explaining their reasoning behind their conclusion regarding the phenomena. They would use evidence from the data, and their modeling to argue for their explanation both on their poster and in a presentation to the class.

Students may come to the conclusion the plane of the Earth-Moon system is tilted with respect to the plane of the Earth-Sun system (as they would have noted already when trying to keep their model Moon out of the shadow of their head during a full Moon, and with the Moon higher or lower than the light bulb during a new Moon). In fact, the tilt is approximately 5 degrees from the plane of the Sun-Earth system. This is just enough so the Moon passes above or below the Sun-Earth plane the majority of the time, thus its shadow, or Earth's shadow touching the Moon, are only in alignment with the Sun and Earth twice per year. These times are referred to as "eclipse seasons," and take place when the Moon is at the nodes, or places where the two planes intersect, and aligned with the Sun and Earth.

Figure 20: two hula-hoops are useful in modeling the tilt of the Earth-Moon plane in relation to the Earth-Sun plane. Image: Brian Kruse/ASP

Optional Investigation: Why Does the Moon Change Color?

One area not investigated directly is the phenomena of the Moon changing color during a lunar eclipse. The media in recent years has characterized a total lunar eclipse as a "blood moon" due to its taking on a coppery red hue, particularly during a total lunar eclipse. This could lead to the potential Driving Questions of:

- Is the Moon always the same color? or
- Why does the Moon change color?

The only other time the Moon is seen to take on a different color is either shortly after it rises, or before it sets, when it can look anywhere from a straw-yellow, to a dusky red color.

The reasons for the color change in both cases, has to do with refraction and scattering of the Sun's light through the Earth's atmosphere.

Acknowledgements:

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Next Generation Science Standards Performance Expectations with Disciplinary Core Ideas:

- 1-ESS1-1: Use observations of the sun, moon, and stars to describe patterns that can be predicted.
  - DCI ESS1.A: The Universe and its Stars
    - Patterns of the sun, moon, and stars in the sky can be observed, described, and predicted.
- 5-ESS1-2: Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.
  - DCI ESS1.B: Earth and the Solar System
    - The orbits of Earth around the sun and of the moon around the Earth, together with the rotation of Earth about an axis between its North and South poles, cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the sun, moon, and stars at different times of the day, month, and year.
- MS-ESS1-1: Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.

- DCI ESS1.A: The Universe and its Stars
  - Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.
- DCI ESS1.B: Earth and the Solar System
  - This model of the solar system can explain eclipses of the sun and the moon.

Science and Engineering Practices Emphasized in These Investigations:

- Analyzing and Interpreting Data
- Developing and Using Models
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence

Crosscutting Concepts Emphasized in These Investigations:

- Patterns
- Cause and Effect: Mechanism and Explanation
- Scale, Proportion, and Quantity
- Systems and System Models

Resources

Fraknoi, Andrew, Ed. 2011. *The Universe at Your Fingertips 2.0*. DVD-ROM. Astronomical Society of the Pacific.

Fraknoi, Andrew, and Schatz, Dennis. 2016. *An Observer's Guide to Viewing the Eclipse*. NSTA Press. Arlington, Virginia. http://www.nsta.org/publications/press/extras/files/solarscience/SolarScienceInsert.pdf

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Miranda, Rommel, Kruse, Brian, and Hermann, Ronald. 2016. Exploring Lunar and Solar Eclipses via a 3-D Modeling Design Task. *Science Scope*. 40(2): 26-34.

Morrow, Cherilyn, and Zawaski, Michael. Kinesthetic Astronomy — Sky Time Lesson. http://ngss.nsta.org/Resource.aspx?ResourceID=29 (Sky Time is also found on *The Universe at Your Fingertips 2.0*)

National Research Council. 2011. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K–12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

NASA Eclipse Website: http://eclipse.gsfc.nasa.gov/eclipse.html

NASA Night Sky Network Eclipse 2017 Resources: https://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=588

View a Solar Eclipse Safely: http://eclipse2017.nasa.gov/safety

NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Schatz, Dennis, and Fraknoi, Andrew. 2016. *Solar Science: Exploring Sunspots, Seasons, Eclipses, and More*. NSTA Press. Arlington, Virginia.

United States Naval Observatory Astronomical Applications: http://www.usno.navy.mil/USNO/astronomical-applications

- Complete Sun and Moon Data for One Day: http://aa.usno.navy.mil/data/docs/RS_OneDay.php
- Sun or Moon Rise/Set Table for One Year: http://aa.usno.navy.mil/data/docs/RS_OneYear.php

Discover Your Local Eclipse Circumstances with an Interactive Map: http://xjubier.free.fr/en/site_pages/solar_eclipses/TSE_2017_GoogleMapFull.html

Materials List for the Eclipse Storyline

Materials for each group of two to four learners:

- 1 4-inch diameter polystyrene ball
- 4 2-inch diameter polystyrene balls
- 1 1-inch diameter polystyrene ball
- 1 Earth balloon
- 1 round 0.25-inch diameter white or gray bead
- 4 meters of string
- 1 meter stick with gradations in inches on one side
- 2 medium size binder clips
- 1 tailor's tape
- 1 set of three miscellaneous sized balls, two of which have a diameter ratio of 1:4
- 1 light source on a stand
- 1 mini-mag flashlight
- Chart paper and markers

Supplementary Documents for the Eclipse Storyline

A. Lunar Observing Recording Chart
B. A Decade of Solar and Lunar Eclipses, 2011–2020
C. Correlated Solar and Lunar Eclipses, 2011–2020
D. A Decade of Lunar Phases, 2011–2020
E. Recording Chart for Correlating Lunar Phases with Eclipses

Total Solar Eclipses for North America in the 21st Century

Illustration courtesy of Michael Zeiler: Great American Eclipse.com