THE AUGUST 2017 TOTAL SOLAR ECLIPSE

The Perfect Opportunity to Highlight Three-Dimensional Science Learning

BY DENNIS SCHATZ AND ANDREW FRAKNOI

On August 21, 2017, 500 million people across North America will experience one of the most beautiful astronomical phenomena: an eclipse of the Sun. If you are lucky enough to be in the 60-mile-wide path of totality (Figure 1), you will see the Moon completely cover the Sun. When only a sliver of sunlight is visible, your surroundings will begin to darken, as if the Sun were setting. Temperatures will drop and birds will go to roost, thinking that night is coming. Finally, the Sun will be totally covered and the beautiful solar atmosphere (the *corona*) will become visible. Totality will last two minutes or less for this eclipse, and then the Sun will slowly be uncovered.

Although only people in the narrow path of totality will see a total eclipse, everyone in the United States (as well as Canada and Mexico) will see a *partial eclipse*, during which a "big bite" is taken out of the Sun (the entire area outside the path of totality in Figure 1). Teachers, students, and families will want to enjoy its beauty, and they will need to be prepared to safely observe the event. More information regarding where and when the eclipse will be visible, as well as safe viewing strategies, can be found in the *Solar Science* insert in this issue of *Science Scope*. The insert can also be accessed for free online (see Resource).

By August, we expect that there will be enormous media and public interest in the eclipse and how to observe and understand it. Science teachers will be a key group for helping students and communities with eclipse preparation. Eclipses are rare and exciting events that generally produce a feeling of cosmic awe and mystery, but people's sense of wonder can be further enhanced through a clear understanding of what causes eclipses. The 2017 eclipse provides a great hook to engage students in learning what causes the phases of the Moon (essential to understanding eclipses), how and when solar and lunar eclipses occur, and why people travel thousands of miles and spend thousands of dollars to see a total solar eclipse.

FIGURE 1: August 2017 eclipse path of totality

CONTENT AREA

Lunar phases; solar and lunar eclipses

GRADE LEVEL

6–8

BIG IDEA/UNIT

The position of the Moon in its orbit relative to the Sun and Earth causes lunar and solar eclipses.

ESSENTIAL PRE-EXISTING KNOWLEDGE

None; the set of learning experiences begins with an activity that reveals students' existing knowledge of lunar phases, and builds from there.

TIME REQUIRED

Each individual learning experience involves 45 minutes or less, but the series of activities should be done over a number of days (10 to 30).

COST

Under $50, not including any copying costs

The eclipse and three-dimensional science learning

For educators, the eclipse and its associated concepts provide the perfect opportunity to incorporate three-dimensional (3-D) into your teaching, as recommended by *A Framework for K–12 Science Education* (NRC 2012) and the *Next Generation Science Standards* (*NGSS*) (NGSS Lead States 2013). These documents describe three key dimensions of effective science learning:

1. Disciplinary core ideas (DCIs): The most important science and engineering ideas that students should know.
2. Science and engineering practices (SEPs): Behaviors that students need for investigating and building models and theories about the natural world.
3. Crosscutting concepts (CCCs): Science concepts that have applications across all domains of science.

Traditional teaching strategies often focus only on conveying a specific DCI or using a particular SEP. The goal of 3-D learning is to interweave the dimensions, so students see them as a connected whole. Not every individual activity lends itself to incorporating all three dimensions; it is only when you look at a sequence of learning experiences that you can identify effective ways to incorporate 3-D learning.

Helping students understand what causes solar eclipses provides an ideal opportunity to connect a number of learning experiences over several weeks. These not only incorporate 3-D learning, but also include other essential learning strategies, such as assessing prior student understanding of the subject and the learning that occurs during and after instruction.

The learning experiences described in this article use 3-D learning activities that focus on the middle school performance expectation associated with *NGSS* DCI MS-ESS1.A, "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" (NGSS Lead States 2013). At the same time, students engage with the following key SEPs:

- analyzing and interpreting data during their efforts to predict the order of the lunar phases and as they make regular observations of the Moon in the sky;
- using a model of the Earth–Moon–Sun system (light bulb, foam balls, and their heads) to describe the relationship between its components and develop an understanding of what causes the Moon's phases and eclipses; and
- engaging in argumentation based on evidence as they compare their predictions for the order of lunar photographs and their daily observations of the Moon.

The experiences we describe also allow educators to identify CCCs embedded in the learning:

- Patterns observed during the experiences allow students to identify cause-and-effect relationships as they observe how the relative positions of the

Earth, Moon, and Sun produce the Moon's phases.

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation, as students observe the Moon and Sun to understand when solar and lunar eclipses occur.
- System models provide an opportunity for understanding and testing ideas, which occurs when a student uses his or her head, a foam ball, and a light bulb to model the Earth–Sun–Moon system.

Note that it is not sufficient to just have students engage with these SEPs and CCCs. It is critical that the teacher explicitly point them out as the kinds of concepts and practices involved in being a scientific thinker.

FIGURE 2: Six lunar photographs

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3-D learning in action

So, how does 3-D learning actually work in the classroom? The following set of learning experiences ask students to demonstrate their current understanding of lunar phases, before they learn what causes these phases, and then finally gain a full understanding of solar and lunar eclipses. These activities come from our book, *Solar Science: Exploring Sunspots, Seasons, Eclipses and More*, available from NSTA Press (Schatz and Fraknoi 2016). Although step-by-step instructions are provided in *Solar Science*, some of these teaching strategies can be found in other resources, such as the Astronomical Society of the Pacific's *The Universe at Your Fingertips 2.0* (Fraknoi 2011). Many use simple items that are easy to obtain.

Initial engagement and preassessment: Predicting how the Moon will look

In this activity, students analyze and interpret data as they work in groups of three to five to examine and predict the order of six photographs of the Moon that show different phases (Figure 2). (Usable classroom versions of Figures 2, 3, and 7 are available on the NSTA website; see Online Supplemental Materials at end of this article.) Students then develop their scientific argumentation skills by using evidence to explain their reasoning for the sequence they produced. Students' predictions are posted on a wall of the classroom for ongoing reference as they make actual observations of the Moon over the next 10 to 30 days. Students' predictions are then compared to their observations.

FIGURE 3: Lunar observing record chart

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Date Time Location	Date Time Location	Date Time Location	Date Time Location	Date Time Location	Date Time Location	Date Time Location
Date Time Location	Date Time Location	Date Time Location	Date Time Location	Date Time Location	Date Time Location	Date Time Location

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Observing the Moon to discover the order of the lunar phases

A major outcome of the previous experience is that students want to know who has the right sequence for the lunar phases, so they are motivated to go outside to observe the Moon. To determine the appropriate sequence—and orientation—of the photos, students must be able to identify a number of features on the lunar surface, so this activity also allows for a study of lunar craters and maria.

This experience should ideally begin a few days before the Moon is at first quarter. The Moon will be in the western sky in the afternoon and evening, which will allow educators to take students outside near the end of the school day to make their first observation together. This daytime observation allows educators to review with students what each lunar observation should consist of, and gets them into the routine of making daily observations.

Students continue to gain experience analyzing and interpreting authentic data during their daily observations of the Moon. They use a simple observing chart (Figure 3) to identify the phase of the Moon, any surface features they can see, the time, and the location of the Moon in the sky. If time constraints or the weather do not allow students to observe the Moon for a full month, they should be able to begin determining the pattern of the phases after about 10 observations. Daily observations are not necessary, so some days without observation should be fine.

After observing the Moon for 10 to 30 days, students discuss what their observations reveal about the phases of the Moon (Figure 4). Some of the key ideas that emerge are:

- The phases start with a crescent Moon with sunlight on its right side (assuming you started a few days before first quarter).
- More and more of the Moon's surface that faces Earth becomes lit by the Sun over the next week to two weeks, until it is all in sunlight (full Moon).
- After the full Moon, less and less of the Moon's surface that faces Earth is illuminated by the Sun, and the lit part is now on the left side.
- If students observed for a full month, they should be able to conclude that the time it takes one particular phase to appear again is approximately one month (29.5 days).
- Although the amount of light on the Moon's surface that faces Earth changes throughout the month, the features on the Moon appear to stay in the same location.

A good evaluation experience is to give students another set of the lunar phases to put in order based on the new knowledge they have acquired (see Schatz and Fraknoi 2016, p. 326).

Students can now see that objects and events in natural systems occur in consistent patterns, a CCC of the *NGSS*. They are also at the first step of understanding the cyclic patterns of lunar phases, as indicated in *NGSS* DCI MS-ESS1.A.

Modeling lunar phases and eclipses

During the next experience, students develop their modeling skills to understand what causes lunar phases and eclipses. The model they use consists of students using their heads to represent Earth, a 60-watt light bulb at the front of the room to represent the Sun, and a small foam ball attached to a pencil to represent the Moon. The lamp is placed at the front of a completely dark room, and students stand facing the lamp, spread out enough so the light from the lamp reaches each student. (*Safety note:* Be sure to tell the students to not touch the hot bulb. The teacher should remove any potential trip-and-fall hazards prior to beginning the activity. *Editor's safety note:* Students should wear goggles.)

Students first stand so it is noon in their hometown on their Earth/head. If they disagree about the correct position, students discuss until they agree that noon is when their nose is pointed toward the "Sun." Next, they stand so it is midnight in their hometown.

It is useful to remind students which way is north, south, east, and west for their Earth/head. If their hometown/nose is in the Northern Hemisphere, north is the top of their head, south is their chin, east is to their left, and west is to their right. From prior knowledge and their Moon observations, they should know that the Sun rises in the east. It helps to have students place their open hands on the sides of their heads, acting as horizon blinders (Figure 5). After some trial and error, they will be able to determine that Earth rotates from right to left in their model, with their right shoulder moving forward.

Students first practice rotating their Earth/head to determine how to stand so it is sunrise, sunset, noon, and midnight on their model Earth. They then add a Moon/ball to their model Earth–Moon–Sun system. They hold the model Moon at arm's length and explore how the Sun's light reflects off the model as they place their Moons in different positions around their Earth/head (Figure 6).

FIGURE 4: Order of lunar phases

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FIGURE 5: Earth–Sun model with horizon blinders

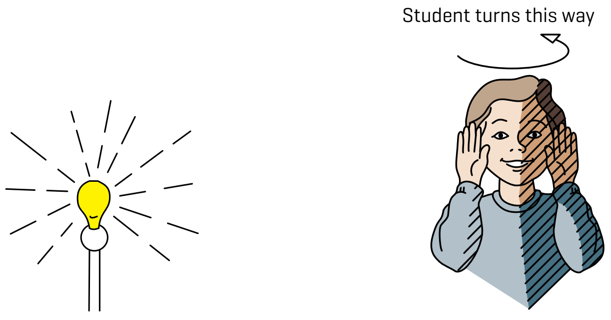


FIGURE 6: Using a Moon model to produce lunar phases

After students explore reproducing the phases with this model, they are asked to determine in what position the Moon must be in its orbit to produce a particular phase. Full Moon is a good one to start with. Students are asked to compare their positions and discuss differences. Students then model other phases (e.g., first quarter, third quarter, new Moon, waning gibbous). When they have had sufficient time to explore producing different phases on their Moon/ball, students work in small groups of three to four students to complete a Moon Phases Activity Sheet (Figure 7).

Once students understand where the Moon has to be in its orbit to see each phase, the modeling continues as students explore where the Moon, Earth, and Sun have to be to produce solar and lunar eclipses. Students move their model Moon in its orbit to determine what phase the Moon has to be in to block the Sun's light from reaching Earth (a solar eclipse) and when Earth can block the Sun's light from getting to the Moon (a lunar eclipse). Through these observations, students discover that solar eclipses only occur when the Moon is in its new phase, and lunar eclipses only occur when the Moon is in its full phase.

Students also continue to develop their ability to analyze and interpret data as they make observations of the phases in their model Earth–Moon–Sun system, and they demonstrate their argumentation skills as they use evidence from the model to compare and discuss their understandings of what causes the lunar phases.

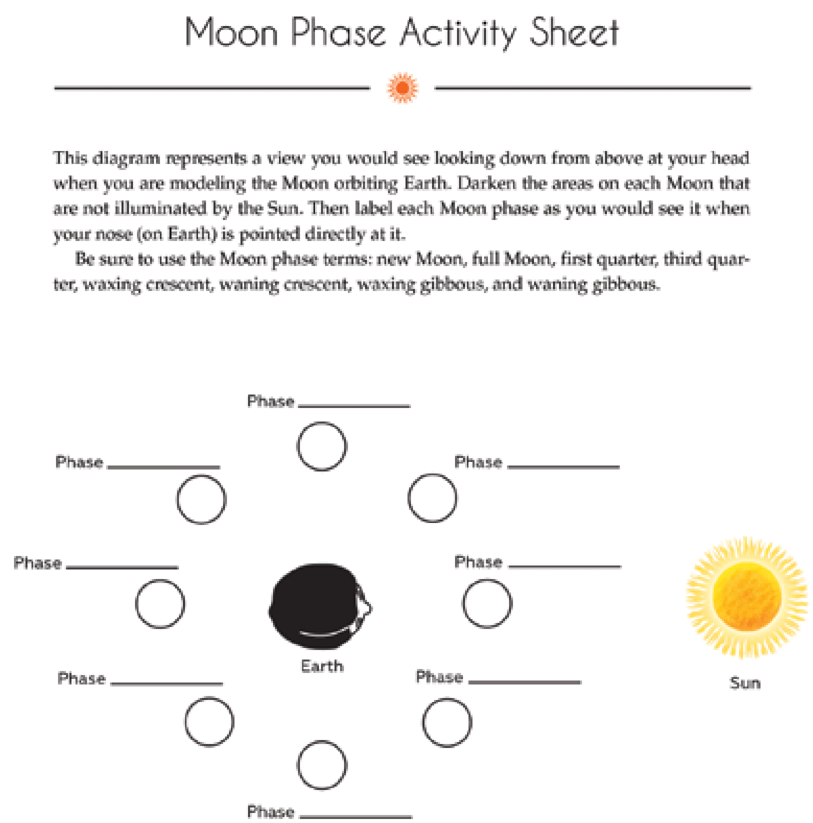
3-D learning and the eclipse: Final comments

Becoming a proficient science learner is much like becoming a proficient tennis player; it requires practice. An important characteristic of 3-D learning is that the DCIs, SEPs, and CCCs are not transmitted or acquired in a single activity. The dimensions require multiple experiences that introduce and reinforce them over time and in different contexts. Our series of lunar phase and eclipse experiences will expose your students to 3-D concepts, but lasting learning requires many additional science activities that provide 3-D experiences in other areas of science.

When the “Great American Eclipse” (as it is now being called) occurs, we estimate that half the school districts in the United States will be in session, and half will still be on summer break. Many families across the country will be on a vacation. Even those districts that are in session may not have time to do much eclipse-related science in August before the event. This means that the best time to get your students (and their families) thinking about the eclipse will be the spring semester of 2017. We hope the ideas in this brief introduction and the eclipse insert in this issue will inspire you to prepare your students for both the science and the delight of the eclipse.

If you and your students are in the narrow eclipse path, congratulations! Your old friends and relatives will soon be discovering how much they long to visit you in August. But if you are outside the path, there will still be a great partial eclipse to discuss, get ready for, and view safely. We wish you clear skies and clear minds for the event. ●

FIGURE 7: Moon phase activity sheet



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Schatz, D., and A. Fraknoi. 2016. *Solar science: Exploring sunspots, seasons, eclipses, and more*. Arlington, VA: NSTA Press. *www.nsta.org/solarscience*.

RESOURCE

Solar Science insert—*http://bit.ly/2bkGSvA*

ONLINE SUPPLEMENTAL MATERIALS

Lunar photographs, lunar observing record chart, and Moon phase activity sheet—*www.nsta.org/scope1703*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standards

MS-ESS1: Earth's Place In the Universe

www.nextgenscience.org/dci-arrangement/ms-ess1-earths-place-universe

Performance Expectations

MS-ESS1. 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.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Analyzing and Interpreting Data	Students analyze and interpret data as they predict the order of the lunar phases and make regular observations of the Moon in the sky.
Developing and Using Models	Students use a model of the Earth–Moon–Sun system (light bulb, foam balls, and their heads) to describe the relationship between the three objects in space and develop an understanding of what causes lunar phases and eclipses.
Constructing Explanations and Engaging in Argument Based on Evidence	Students develop explanations and compare their predictions for the order of lunar photographs and their daily observations of the Moon.
Disciplinary Core Ideas	
MS-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.	Students determine the order of the lunar phases and understand the cause of the phases.
MS-ESS1.B. Earth and the Solar System • This model of the solar system can explain eclipses of the Sun and the Moon.	Students use their knowledge of lunar phases and what causes them to determine what causes solar and lunar eclipses.
Crosscutting Concepts	
Patterns	Students appreciate the patterns observed in the relative position and motion of the Earth, Moon, and Sun that produce the Moon's phases and eclipses of the Sun and Moon. Students come to realize this through their observations of the Moon and Sun, leading to an understanding of when solar and lunar eclipses occur.
Systems and System Models	Students understand the value of their model of the Earth–Moon–Sun system as a way to test ideas and make predictions..

Connections to the *Common Core State Standards* (NGAC and CCSSO 2010)

ELA

W.7.1. Write arguments to support claims with clear reasons and relevant evidence.

Mathematics

7.RP.A. Analyze proportional relationships and use them to solve real-world and mathematical problems.