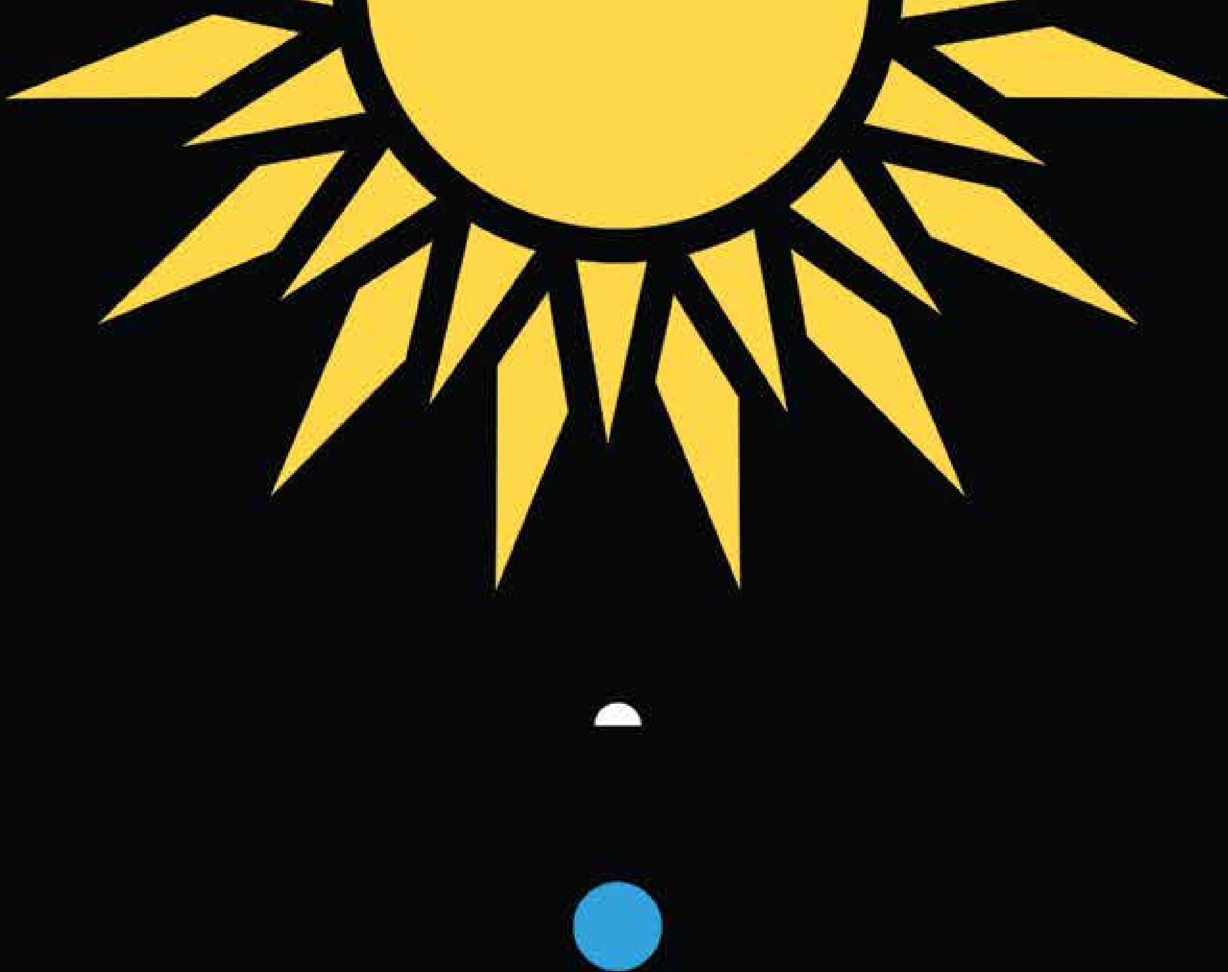


TOTAL ECLIPSE

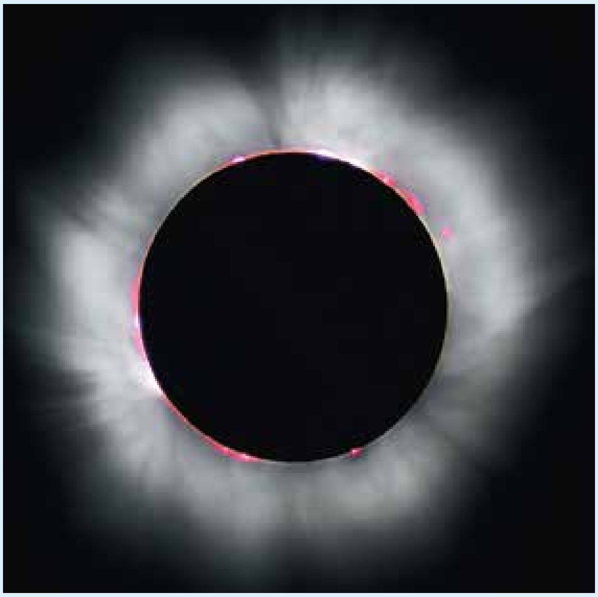
The solar eclipse this August is an ideal opportunity to practice three-dimensional science learning

Dennis Schatz and Andrew Fraknoi

TOTALITY2017

FIGURE 1

Total solar eclipse *(left)* and partial eclipse showing sunspots *(right)*.



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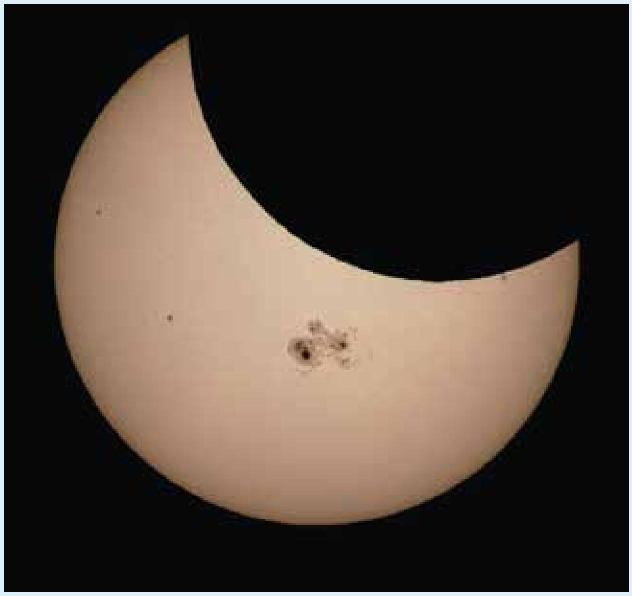


NASA

This summer, on August 21, 500 million people across North America will experience one of the most beautiful astronomical phenomena: an eclipse of the Sun. It will be a "must teach" moment, when all students will want to know the "what, when, and why" of the event. In addition, many high school science teachers are likely to be asked about it, not only in their classes, but in discussions with colleagues, family, and community members. Research shows that many high school students—and adults—fail to correctly understand the Earth-Sun-Moon system (Hermann and Lewis 2003).

If you are lucky enough to be in the 100-kilometer-wide path of totality, you will see the Moon completely cover the Sun. When only a sliver of sunlight is visible, your surroundings will 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 (Figure 1). Totality will last about two minutes for this eclipse, depending on location, and then the Sun will slowly be uncovered.

While only those people in the narrow 100-kilometer-wide band will see a total eclipse, everyone in the United States (as well as Canada and Mexico) will see at least a partial eclipse (Figure 1), where a "big bite" is taken out of the Sun. Teachers, students, and families will want to enjoy its beauty and will need to be prepared to safely observe the event. More information regarding where and when the eclipse is visible, plus safe viewing strategies, are in the insert in this issue of *The Science Teacher*. The insert can also be accessed online (see "On the web").

By August, we expect enormous media and public interest in the eclipse and how to observe and understand it. Science teachers can help students and communities prepare. 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 by a clear understanding of what causes them. Indeed, the 2017 eclipse provides a great hook to engage students in wanting to know what causes the phases of the Moon (key to understanding eclipses), how and when we get solar and lunar eclipses, and why people travel thousands of miles and spend thousands of dollars to see a total solar eclipse.

The eclipse and three-dimensional science learning

For educators, the eclipse and its associated ideas provide the perfect opportunity to incorporate three-dimensional learning (3-D learning) into your teaching, as recommended by the *Next Generation Science Standards* (NGSS Lead States 2013; see box, p. 38), covering science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCs). 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 one can identify effective ways to incorporate 3-D learning.

Helping students to 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 assessing the learning that occurs during and after instruction.

3-D learning in action

So, how does 3-D learning actually work in the classroom? The following set of learning experiences asks 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). Some of these teaching strategies can also 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

One might expect high school students to already know the phases of the Moon and what causes them. But many don't. In the first activity, students 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 shows the sorted, labeled phases; for unsorted, unlabeled images, see "On the web"). Students 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.

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

FIGURE 2

Correct order of the lunar phases.

FRED ESPENAK, *WWW.ASTROPIXELS.COM*

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.

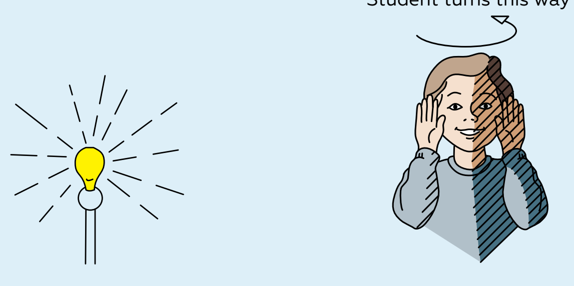
Students continue to gain experience analyzing and interpreting authentic data during their daily observations of the Moon. They use a simple observing chart (see "On the web") to identify the phase of the Moon, any visible surface features, the time, and the location of the Moon in the sky. If time constraints or the weather do not allow students to observe the Moon daily for a full month, about 10 spaced observations should be adequate to determine the pattern of the phases. After observing the Moon for 10 to 30 days, students discuss what their observations reveal about the phases of the Moon (Figure 2, see p. 35). Key ideas that emerge include:

- 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 (see "On the web") to reorder based on their new knowledge.

FIGURE 3

Earth-Sun model with horizon blinders.



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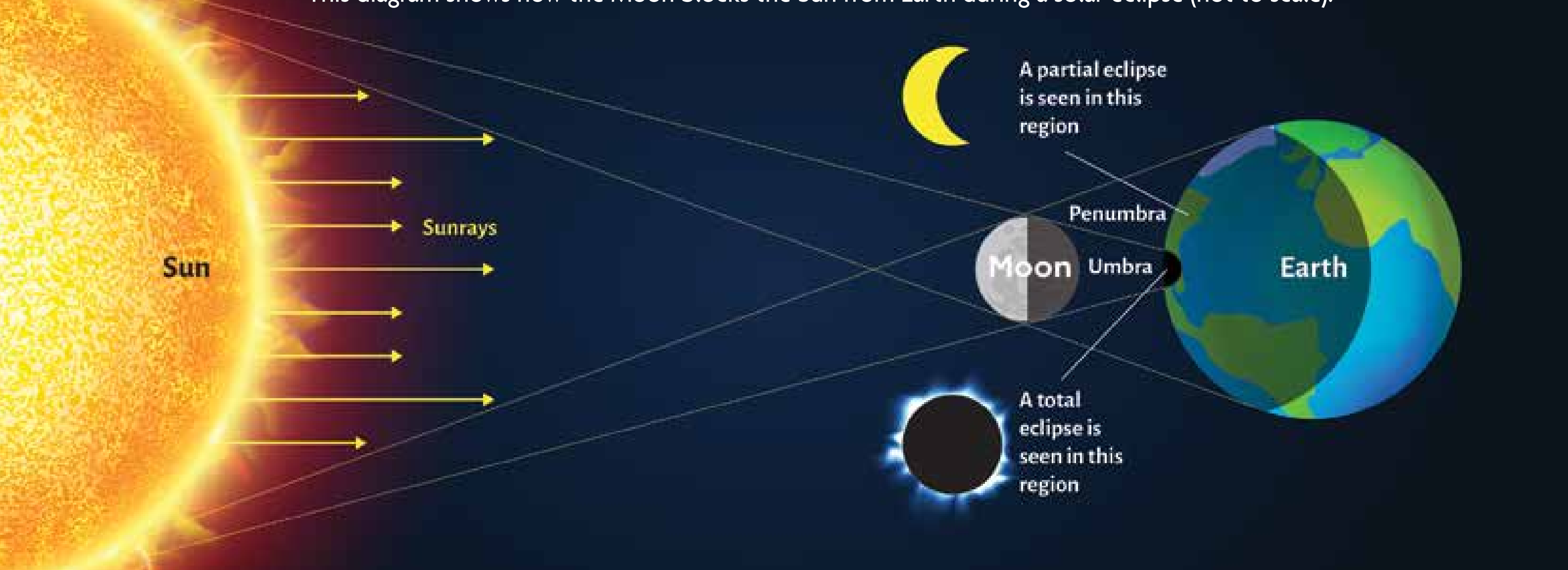
Modeling lunar phases and eclipses

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 lightbulb 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 before the activity.)

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

This diagram shows how the Moon blocks the Sun from Earth during a solar eclipse (not to scale).



students place their open hands on the sides of their heads, acting as horizon blinders (Figure 3). 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.

After students explore reproducing the phases with this model, they are asked to determine 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, third quarter). When they have had sufficient time to explore producing different phases on their Moon/ball, students work in small groups of three to four to complete a Moon Phases Activity Sheet (see "On the web").

Once students understand where the Moon has to be in its orbit to see each phase, the modeling continues as students explore the relative positions of the Moon, Earth, and the Sun 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 use their argumentation skills as they use evidence from the model to compare and discuss their understandings of what causes the lunar phases.

More questions than answers

After this set of experiences, students should have an understanding of what causes lunar phases and what makes eclipses possible, but they are left with more questions than answers. Among these might be:

- If a full Moon and new Moon happen every month, shouldn't we have eclipses every month?
- Why is the 2017 total solar eclipse the first one in the United States in almost 40 years?
- Why do people spend thousands of dollars and travel thousands of miles to see a solar eclipse but aren't as likely to travel to see a lunar eclipse?

Each of these questions can lead to further activities that you can do with your students.

Conclusion

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 CCs 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 this spring semester. We hope the ideas in this brief introduction and the eclipse insert in this issue 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. 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. ■

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On the web

Unsorted lunar photographs, lunar observing record, and Moon phase activity sheet: *www.nsta.org/highschool/connections.aspx*

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

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

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

Standards
MS-ESS1 Earth's Place In the Universe
HS-ESS1 Earth's Place In the Universe

Performance Expectations
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.
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.
HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system (extension activities).

Dimension	Name and *NGSS* code/citation	Classroom connection
Science and Engineering Practices	**Analyzing and Interpreting data** • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims. **Developing and Using Models** • Develop a model based on evidence to illustrate the relationships between systems or between components of a system. **Constructing Explanations** • Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. **Engaging in Argumentation From Evidence** • Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments.	Students analyze and interpret data as they predict the order of the lunar phases and then again as they make regular observations of the Moon in the sky. Students use a model of the Earth-Moon-Sun system (lightbulb, Styrofoam balls, and their heads) to describe the relationship between the three objects in space and to help them develop an understanding of what causes lunar phases and eclipses. 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. **HS-ESS1.B: Earth and the Solar System** • Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun (extension).	Students determine the order of the lunar phases and understand the cause of the phases. Students use their knowledge of lunar phases and what causes them to determine what causes solar and lunar eclipses.
Crosscutting Concepts	**Patterns** • Empirical evidence is needed to identify patterns. Science assumes that objects and events in natural systems are understandable through measurement and observation. (MS-ESS1-1) **System and System Models** • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions.	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. Students understand the value of their model of the Earth-Moon-Sun system as a way to test ideas and make predictions.