Exploring Lunar and Solar Eclipses via a 3-D Modeling Design Task

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Understanding events involving the Earth–Sun–Moon system is a significant part of our study of the universe. However, students often have difficulty understanding the processes that cause lunar and solar eclipses. A common initial idea students have is that a total lunar eclipse is the same as a new Moon lunar phase (Barnett and Morran 2002). (For more information on Moon phases, see "Using Multiple Representations to Teach Science" in this issue.) Many students also initially believe that a solar eclipse is a global event viewable from everywhere on Earth (Kavanagh, Agan, and Sneider 2005). Based on our experience teaching this topic, we believe it is essential for educators to develop and refine students' initial ideas and understanding of eclipses and to have students explore eclipses not only because they are spectacular natural, observable phenomena, but also because they play an important role in scientists' development of a more complete understanding of the laws governing the universe. It is also important for students to know that scientists today still make observations of the Sun's corona and continue to take accurate measurements of the Sun's diameter, the shape of the Moon, and the distance of the Earth to the Moon during solar eclipses.

In this article, we demonstrate our approach for developing, enlarging, and refining students' initial ideas about lunar and solar eclipses by using a 7E (Engage, Elicit, Explore, Explain, Elaborate, Evaluate, Extend) learning-cycle model (Eisenkraft 2003) to help illustrate how science teachers can immerse students in a range of inquiry-based science experiences. We also use the Know-Learn-Evidence-Wonder (KLEW) instructional teaching strategy (Hershberger, Zembal-Saul, and Starr 2006) to demonstrate evidence of student reflection on, learning about, and understanding of eclipses. Our approach further provides students with an opportunity to refine their thinking about eclipses, and to reflect on how their ideas have changed.

The instructional approach

We facilitated the following lesson with middle school science students who were beginning to learn about lunar and solar eclipses. We implemented

CONTENT AREA

Earth and space science

GRADE LEVEL

6–8

BIG IDEA/UNIT

Eclipses of the Sun and Moon

ESSENTIAL PRE-EXISTING KNOWLEDGE

Scale of the Earth–Sun–Moon system; complex motion of the Earth–Sun–Moon System; shadows; phases of the Moon

TIME REQUIRED

180 minutes

COST

Less than $20

this lesson after students completed inquiry-based lessons on the size and distance scale of the Earth–Sun–Moon system, the complex motion of the Earth–Sun–Moon system, shadows, and the phases of the Moon. Prior to this lesson, students learned that the orbits of the 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. Students also understood cyclic patterns of lunar phases and that the seasons are a result of the Earth's tilt and are caused by the differential intensity of sunlight on different areas of the Earth across the year. Students further discovered that the diameter of the Moon was approximately one-quarter of the size of the Earth's diameter and that the distance between the Earth and the Moon was approximately 30 Earth diameters. To provide an example of how this 7E lesson can be implemented in a middle school classroom, we specifically describe how the teacher, Mr. Lance (pseudonym), facilitates the inquiry-based lesson with his students and how the students respond to the tasks he asks them to perform.

Engage

Mr. Lance engages students in the topic by presenting a slideshow he created with copyright-free images of partial and total lunar eclipses as they typically appear from Earth. He instructs students to compile a list of observations individually on an Activity Worksheet (see Online Supplemental Materials. After a few minutes, Mr. Lance facilitates a whole-class discussion with students by asking them what observations they have about the images. Students mentioned that the Earth's shadow blocks the Sun's light, the Sun's light reflects off the Moon's surface, only part of the Moon's surface is visible, the Earth's shadow completely covers the Moon, and the color of the Moon is red-orange.

Elicit

To elicit students' initial ideas and their current understanding of eclipses, Mr. Lance formatively assesses students by asking them to list and describe anything they know about eclipses or have seen on television, in movies, the news, or real life that relates to eclipses. He instructs students to collaboratively work in pairs or groups of threes and to record their responses on the Activity Worksheet (see Online Supplemental Materials). Mr. Lance then conducts a whole-class discussion with students regarding their responses. As student groups share their responses with the rest of the class, he records their ideas under the "Know" section of a KLEW chart displayed in the classroom. Several student groups mention seeing horror or science fiction movies involving werewolves, zombies, crazy people, or omens of disasters about to happen. Some student groups explain that they have seen television shows in which certain types of eclipses gave ordinary people super-human abilities. Other student groups state that they have seen shows about eclipses on the Discovery Channel that show how the Earth, the Sun, and the Moon are specifically aligned, or they have watched news broadcasts that mention when an eclipse will specifically occur. A couple of student groups mention the car Mitsubishi Eclipse and the chewing gum brand Eclipse.

Explore

Mr. Lance asks students to individually illustrate and predict the configuration of the Earth–Sun–Moon system that would result in the partial and total lunar eclipse images they observed on their Activity Worksheet. He instructs students to work in pairs or in groups of threes to share predictions and to decide which prediction best represents their observations. Mr. Lance then conducts a whole-class discussion with students regarding their predictions. All student groups share with the class their prediction and accurate spatial drawing of an Earth–Sun–Moon configuration that would result in the lunar eclipse images. However, Mr. Lance notices that their drawings are not to scale.

Accordingly, through a guided-inquiry activity, Mr. Lance allows students in pairs or threes to explore lunar eclipses via a 3-D modeling design task that centers on the development of a physical scale model of the Earth–Sun–Moon system to refine their initial ideas and understanding of lunar eclipses. He provides the guiding question, "Can you construct a 3-D physical *scale* model of the Earth–Sun–Moon system to recreate your observations of the partial and total lunar eclipse images?" However, he allows students to develop procedures to explore the question and to make observations and conclusions themselves. Mr. Lance reviews safety procedures (e.g., use safety goggles, do not throw objects at other students, do not put objects in your mouth, do not stare at the point-source flashlight bulb for an extended period of time, do not shine your flashlight in someone else's face) and informs students about clean-up procedures.

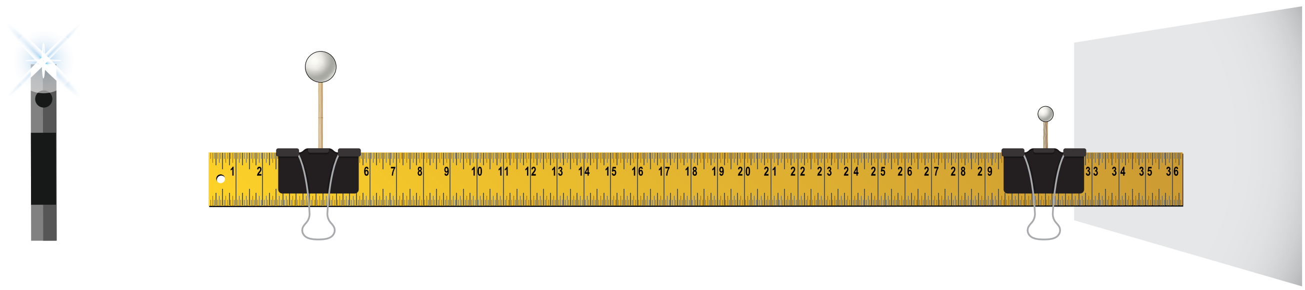
He instructs one student from each group to obtain materials from the supply table in the front of the room and bring them back to their table. The materials include:

- one meter stick
- 1″ polystyrene ball
- ¼″ round plastic necklace bead
- two pointed toothpicks
- two medium-sized binder clips
- one point-source flashlight (or a lamp without a shade).
- one bottle of all-purpose/school glue
- one 4″ × 6″ index card

Mr. Lance challenges student groups to use any of the materials to construct their own 3-D model of the Earth–Sun–Moon system to scale for the Earth and Moon, and to use their point-source flashlight and 3-D model to recreate their observations of the partial and total lunar eclipse images. He instructs students to clearly draw and label their 3-D model of the Earth–Sun–Moon system and to specifically describe procedures for constructing their 3-D model on their Activity Sheet. Students further record observations using their 3-D model, generate conclusions, and clean up when they are finished with the activity. Mr. Lance closes all classroom blinds and turns off the classroom lights when student groups are ready to use their point-source flashlight and constructed 3-D model. As he moves from group to group during the Explore stage, Mr. Lance reminds student groups that appeared to have difficulty coming up with their own model to reflect on a prior lesson in which they discovered that the diameter of the Moon is about one-quarter of the Earth's diameter, and the Earth–Moon distance is about 30 Earth diameters. To further help student groups that had difficulty perfectly aligning their 3-D model with their point source flashlight, Mr. Lance encouraged them to project shadows onto a 4″ × 6″ index card.

Throughout the Explore stage, Mr. Lance takes anecdotal student notes in a personal notebook regarding what he observed student groups doing. Mr. Lance observes all student groups as they use the polystyrene ball to represent Earth and the ¼″ round bead to represent the Moon. He also notices that all

FIGURE 1: Lunar eclipse 3-D model



student groups attach toothpicks to these items with glue so that they can hold them easily. He sees that some student groups hold the Moon stationary and move both the point-source flashlight and the Earth until they are able to create an Earth shadow on the Moon similar to the lunar eclipse images. Other student groups attach both the Earth and Moon directly to the meter stick with binder clips approximately 76 cm (30″) apart from each other, and move the point-source flashlight toward their 3-D Earth and Moon scale model until they are able to recreate the lunar eclipse images (Figure 1). Mr. Lance further notes that all student groups project shadows of the Earth on an index card to align their 3-D model.

Explain

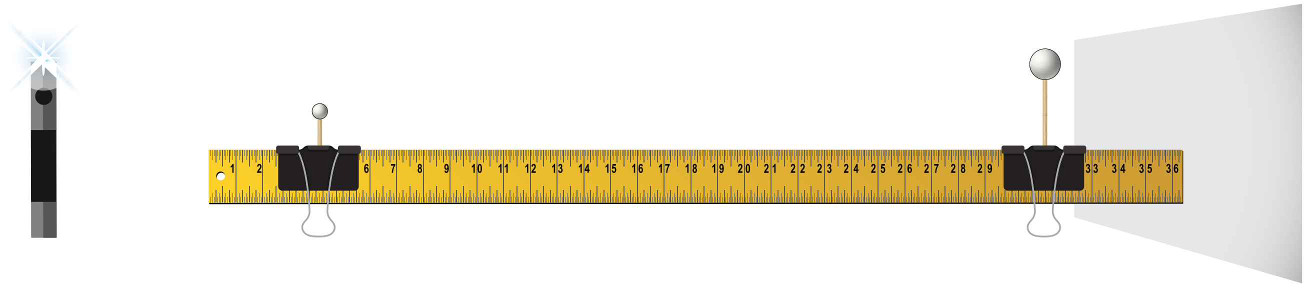
Mr. Lance prompts student groups to articulate what they have learned about lunar eclipses based on observations and evidence they collected using their 3-D model of the Earth, the Moon, and the Sun via a whole-class discussion. Each student group displays this information on their group dry-erase boards and explains their findings to the rest of the class. Mr. Lance records students' responses under "Learn"

> *A couple of student groups articulate that a limitation of their model was that the point-source flashlight, which represented the Sun, was not to scale.*

and "Evidence" on the class KLEW chart. All of the student groups mention that their Earth–Sun–Moon configuration was accurate in recreating the lunar eclipse images. A few student groups explain how they made the distance between the Earth and the Moon to scale in their model to recreate the images. A couple of student groups articulate that a limitation of their model was that the point-source flashlight, which represented the Sun, was not to scale. These groups further describe how they had to move their point-source flashlight close to their Earth and Moon scale model to recreate the lunar eclipse images, and that the Sun is not really that close to the Earth. One group mentions the actual distance between the Sun and the Earth and states that in order for their model to truly be to scale, the Sun would have to be about the length of a football field away from their model of the Earth.

After groups present their findings to the class, Mr. Lance introduces new vocabulary terms (*lunar eclipse*, *ecliptic*, *tilt*, *shadow*, *umbra*, *penumbra*, *partial lunar eclipse*, *total lunar eclipse*, *super-Moon*, and *elliptical orbit of the Moon*) to explain what students are describing related to lunar eclipses. He then has

FIGURE 2: Solar eclipse 3-D model



students create picture glossaries in their notebook to record these terms. Mr. Lance also creates a picture word wall on a bulletin board in the front of the classroom. Throughout the discussion, he further ensures that students articulate and understand that a lunar eclipse occurs when the Moon passes into the shadow of the Earth and is partly or wholly obscured.

Elaborate

Mr. Lance presents a slideshow he created with copyright-free images of partial, annular, and total solar eclipses as they typically appear from Earth. He instructs students to compile a list of observations individually on their Activity Worksheet. After a few minutes, Mr. Lance facilitates a whole-class discussion with students regarding their observations.

Mr. Lance asks students to individually illustrate and predict the configuration of the Earth–Sun–Moon system that would result in the partial, annular, and total solar eclipse images they observed on their Activity Worksheet. He instructs students to work in pairs or in groups of three, to share predictions with their group, and to decide which prediction best represents their observations. All student groups share with the class their prediction and accurate spatial drawing of an Earth–Sun–Moon configuration that would result in the solar eclipse images. Mr. Lance notices that all of the students' drawings now indicate the specific distance between the Earth and the Moon, to scale. However, the distance between the Sun and the Earth is still not drawn to scale in their illustrations. To address this, he facilitates a discussion with the class regarding what an astronomical unit is.

Mr. Lance provides groups with the following guiding questions: "How can you use your 3-D model of the Earth–Sun–Moon system to recreate your observations of the partial, annular, and total solar eclipse images you looked at?" and "From where on Earth would the solar eclipse be visible?" He reviews safety and clean-up procedures again and instructs student groups to use their point-source flashlight and 3-D model they developed in the Explore stage to recreate their observations of the partial, annular, and total solar eclipse images. Students record their observations, generate conclusions on their Activity Worksheet, and clean up when they are finished.

"How can you use your 3-D model of the Earth–Sun–Moon system to recreate your observations of the partial, annular, and total solar eclipse images you looked at?"

Throughout the Elaboration stage, Mr. Lance takes anecdotal student notes in a personal notebook regarding what he observed student groups doing. He observes some student groups holding the point-source flashlight stationary while moving just the Moon to recreate the solar eclipse images (students' heads now represented the Earth for these student groups). A few student groups hold their Moon far away from their heads, approximately 76 cm (30″), and have another student in the group move the point-source flashlight to recreate the solar eclipse images. Some student groups simply reverse their 3-D model from the Explore stage to recreate the solar eclipse images and to create the shadow of the Moon cast on the Earth (Figure 2).

Mr. Lance prompts student groups to articulate and explain what they have learned about solar eclipses based on the observations and evidence they collected using their 3-D model of the Earth, Moon, and Sun via a whole-class discussion. Student groups display this information on dry-erase boards or flip-chart paper and explain their findings to the rest of the class. He records students' responses under "Learn" and "Evidence" on the class KLEW chart. All student groups mention that their Earth–Sun–Moon configuration was accurate in recreating the solar eclipse images. Some student groups mention that it was easier to recreate the image using just the Moon ball and point-source flashlight, with a student's head representing the Earth. A few student groups mention that they maintained the distance of the Moon approximately 76 cm (30″) from their head (Earth) to keep the Earth and Moon to scale, and simply moved the point-source flashlight to recreate the images. Additionally, some student groups mention that not everyone on Earth can view a total solar eclipse and describe how the shadow of the Moon appeared on their scale model of the Earth. Throughout the discussion, all student groups describe in detail the limitations of their 3-D model.

After student groups present findings to the class, Mr. Lance introduces new vocabulary terms (*solar eclipse*, *partial solar eclipse*, *total solar eclipse*, and *annular solar eclipse*) to explain what students are describing related to the topic of solar eclipses. He then has students create picture glossaries in their science notebook to record these terms. Mr. Lance also adds pictures to the word wall. He also facilitates a discussion with students about how solar eclipses only occur during the new Moon phase. Throughout the discussion, he further ensures that students articulate and understand that a solar eclipse occurs when the Moon passes between the Earth and the Sun and the Moon casts a shadow on the Earth, partly or wholly obscuring the Sun.

Evaluate

To evaluate students' understanding of eclipses and their modeling, Mr. Lance selects and provides students with a specific image of a lunar eclipse (partial and total) or a solar eclipse (partial, annular, and total) and instructs them to work in pairs or groups of three. Students use their point-source flashlight and 3-D model to collect data to identify the type of eclipse in the image. To further challenge students, Mr. Lance selects an unrealistic image of an eclipse where a correct Earth–Sun–Moon model is unable to account for the phenomenon shown. This challenge allows students to view astronomical images critically, because many images on the internet are often produced, enhanced, manipulated, or inaccurate. He discusses the challenge with students and allows student groups to use their 3-D model to collect data as evidence to support whether the phenomenon in the image is either realistic or unrealistic.

Extend

Our approach for integrating the "Wonder" from the KLEW teaching strategy with the Extend phase of the 7E learning cycle model can be effectively used to implement open inquiry by providing an ideal opportunity for students to apply their knowledge to new domains, which includes raising new questions and hypotheses to explore.

Thus, Mr. Lance facilitates open inquiry by showing students images of lunar and solar eclipses from another planet such as Mars or Venus. He also shows students images of the transit of Venus and mentions that there cannot be a transit of Mars for viewers on

Earth and suggests that students consider why. Mr. Lance then asks students to write down observations and any new questions they have regarding the images. After a few minutes, students share their questions and record their responses under the "W" in the KLEW chart in the classroom. Using an open-inquiry template (Hermann and Miranda 2010), Mr. Lance helps student groups formulate their own question to explore (see Online Supplemental Materials for the template). Some questions that Mr. Lance hears from student groups are "Which planets can we see transit across our Sun from Earth?" "Which planets can we not see move across our Sun from Earth?" "What stars might be blocked by planets in our solar system?" "Why is there not a lunar and solar eclipse every month?" and "What is an eclipse season?" Students develop their own 3-D physical scale model using various materials (e.g., different-size polystyrene balls, medium-size binder clips, different-size hula hoops, point-source flashlight, toothpicks, all-purpose glue, 4" x 6" index cards, etc.), develop their own procedures, record their observations, generate conclusions on their Activity Worksheet, and clean up when they finish the activity. Students then share with the rest of the class what they have learned based on their observations and evidence. Mr. Lance assesses student group presentations using a rubric (see Online Supplemental Materials).

Conclusion

Many students find eclipses to be a mysterious phenomenon that is difficult to explain. It is important for educators to provide students with opportunities to demystify the processes that cause lunar and solar eclipses and to demonstrate that they are predictable, natural phenomena that can be easily explained. Our approach integrates the 7E learning-cycle model and the KLEW instructional teaching strategy to facilitate scientific inquiry in the classroom (Miranda and Hermann 2012) on lunar and solar eclipses. The approach provides teachers with a mechanism to focus on both curricular and instructional practices and typically results in rich and rewarding experiences for both students and teachers. ●

ACKNOWLEDGMENT

The activity presented in this article is an adaptation of the activity, "Why do Eclipses Happen?" developed at the Astronomical Society of the Pacific for the Shadows and Silhouettes Outreach Toolkit for the NASA Night Sky Network. Funding for its development was provided by NASA's Kepler Mission education and public outreach program.

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RESOURCES

Shadows and silhouettes outreach toolkit manual—*http://go.nasa.gov/2afFhpj*

Unrealistic image of an eclipse—*http://bit.ly/2a33FHd*

Why do eclipses happen?—*http://go.nasa.gov/29TK0c8*

ONLINE SUPPLEMENTAL MATERIALS

Open-inquiry template—*www.nsta.org/scope1610*

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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.

Standard

MS-ESS1: Earth's Place in the Universe
www.nextgenscience.org/dci-arrangement/ms-ess1-earths-place-universe

Performance Expectation

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.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Developing and Using Models	Students construct a 3-D physical model of the Earth–Sun–Moon system to recreate their observations of lunar and solar eclipse images.
Disciplinary Core Idea	
ESS1-B: Earth and the Solar System • The solar system consists of the Sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them. (MS-ESS1-2, MS-ESS1-3) • This model of the solar system can explain eclipses of the Sun and the Moon.	Students use their constructed Earth-Sun-Moon model to explain eclipses of the Sun and Moon.
Crosscutting Concept	
Patterns, Scale Proportion, and Quantity	Students create spatial drawings of lunar and solar eclipses and construct a 3-D physical model of the Earth-Sun-Moon to scale.

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

ELA

RST.6-8.7 Students express new vocabulary terms by creating picture glossaries in their science notebook. The teacher creates a visual word wall on a bulletin board in the front of the classroom.

Mathematics

MP.4 Students create a 3-D physical scale model of the Earth–Sun–Moon system.