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An Interactive Demonstration of Solar and Lunar Eclipses

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Abstract

This article describes a demonstration of solar and lunar eclipses using hoops and balls of different sizes to represent the orbits and bodies involved. The demonstration presents the students with a three-dimensional view of the arrangement of the Earth, its Moon, and their respective orbits, and illustrates why people on Earth do not experience eclipses every month.

1. EDUCATIONAL OBJECTIVES

In my years of teaching astronomy to first-year university/college non–science majors, I have found the diagrams of eclipses in textbooks and Internet resources to be somewhat confusing to the students. At their academic level, many of the students are unable to visualize in three dimensions the changing arrangement of the Earth and Moon, and their orbits in space. Furthermore, online animations do not illustrate why there is not an eclipse every month; they only show how an eclipse would appear to an observer outside the Solar System. They also do not actively engage the students.

The purpose of this demonstration is to assist the students in visualizing the orientation of the orbits involved, in observing how the Moon orbits the Earth, in gaining an appreciation for the term "line of nodes," and in understanding why eclipses are not observed at every new moon and full moon phase. This demonstration is illuminating for students of all learning styles, but especially for visual and kinesthetic/tactile learners, because it engages them even if they are not actively assisting with the demonstration.

2. MATERIALS AND ASSEMBLY

The following is a materials list. I often omit the light bulb because the students are viewing the demonstration directly, and most light bulbs are too bright. If this demonstration is performed in a large classroom or lecture theater, brightly colored hoops and balls are more visible to students at the back of the room. This demonstration is very inexpensive to construct: all the materials may be purchased for under $30. Note that no attempt was made to ensure that the orbits and bodies were to scale.

2.1 Materials

- Dim light bulb for the Sun, preferably red or orange to help prevent glare (optional)
- Hula hoop representing the Earth's orbit around the Sun
- Smaller hoop representing the Moon's orbit around the Earth
- Medium-sized solid ball representing the Earth
- Small solid ball representing the Moon

2.2 Assembly

Holes were drilled through the center of both balls, the hula hoop was separated at its seam, and the Earth ball was threaded onto the hula hoop. Because the Moon's orbit hoop was a solid ring, the Moon ball was sliced halfway through to the drilled hole, the ball was slipped over the hoop, and the cut faces were glued back together. One of the ends of the hula hoop was passed through the Moon's orbit hoop, and then the hula hoop was rejoined, yielding interlaced hoops as shown in Figure 1.

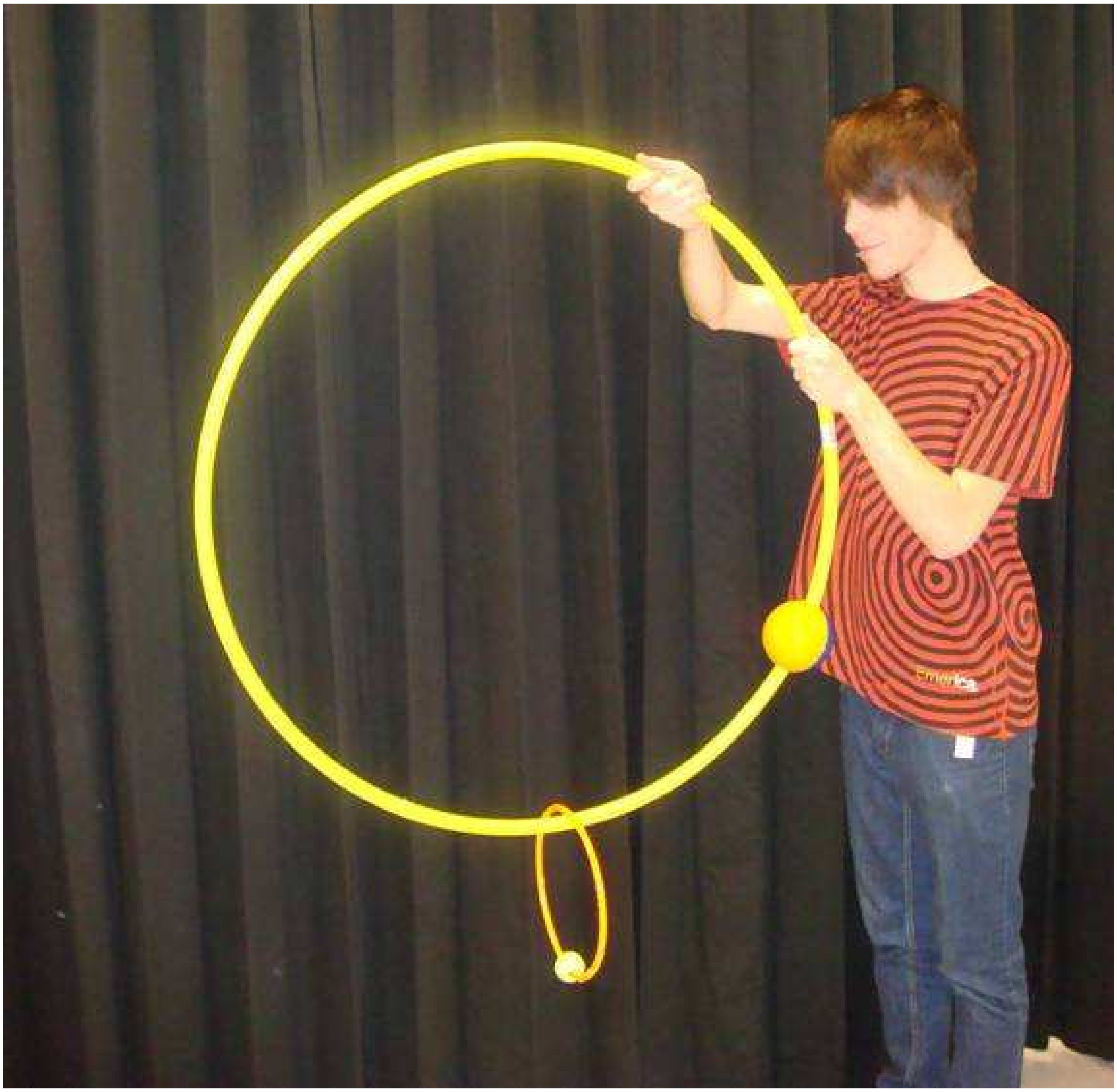

Figure 1. A student displays the interlaced "orbits."

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3. METHODS

This demonstration assumes that the students already have learned about orbits and lunar phases. Before beginning the demonstration, I explain the term "line of nodes," then enlist one student to hold the hula hoop horizontally over the light bulb Sun (if using), ensuring that the Sun is in the center of the hoop, and in the same plane. I orient the Moon’s orbit hoop with an exaggerated inclination with respect to the Earth’s orbit plane but reiterate to the students that the angle is not actually that large! With my explanation of the line of nodes still fresh in the students’ minds, I show them where the line of nodes would be by placing my fingers at the intersection of the orbits and then ask them to visualize a line connecting the two points (Figure 2).

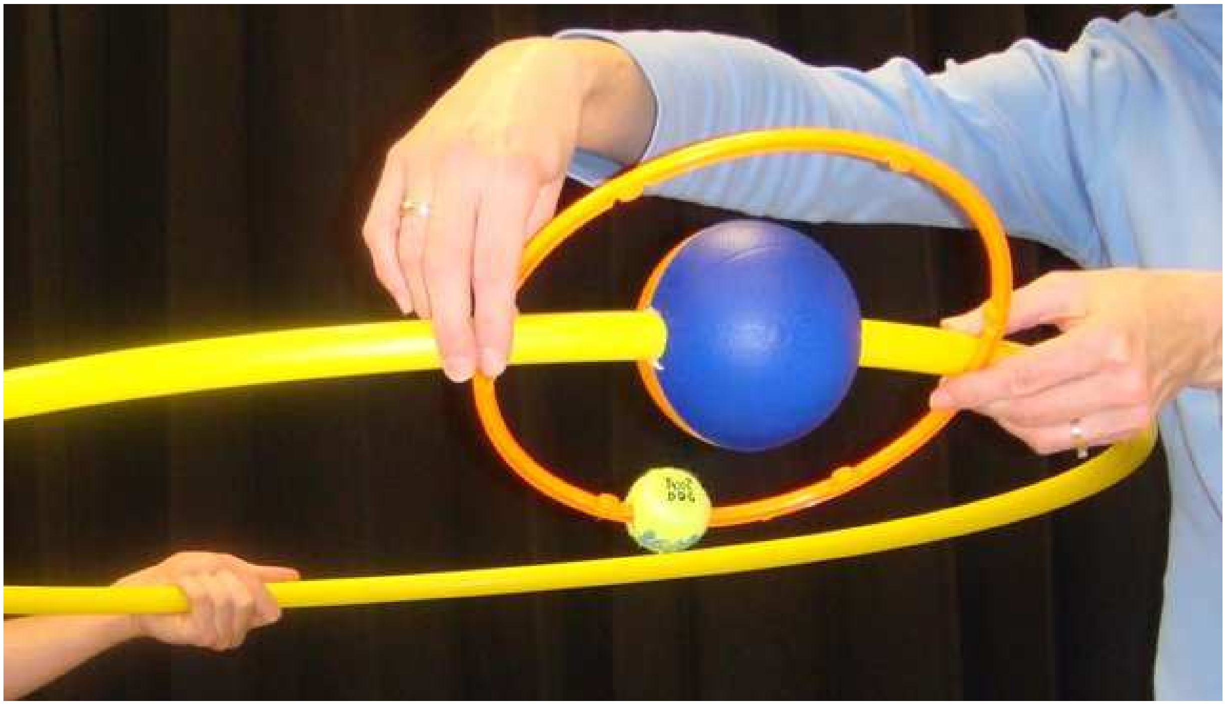

Figure 2. The location of the nodes and the line of nodes are demonstrated in this close-up image. The light bulb Sun has been omitted to reduce glare. The Moon's phase is new; a solar eclipse is not possible because the Moon is below the plane of the Earth's orbit around the Sun.

I begin the demonstration with the Earth on the side of the hoop closest to the students. The student holding the hoop stands to one side, usually to my right as I face the class. I orient the Moon's orbit hoop such that the Moon is in a new moon phase but below the plane of the Earth's orbit (Figure 2). While maintaining the orientation and inclination of the Moon's orbit hoop, I rotate the Moon's hoop until the Moon is in a full moon phase; the Moon now is above the plane of the Earth's orbit (Figure 3). As I perform this part of the demonstration, I explain that for both phases, eclipses will not be possible because the Moon is either above or below the Earth. Therefore, the Moon's shadow will not fall on the Earth, in the case of a solar eclipse, nor will the Moon pass into the Earth's shadow, in the case of a lunar eclipse.

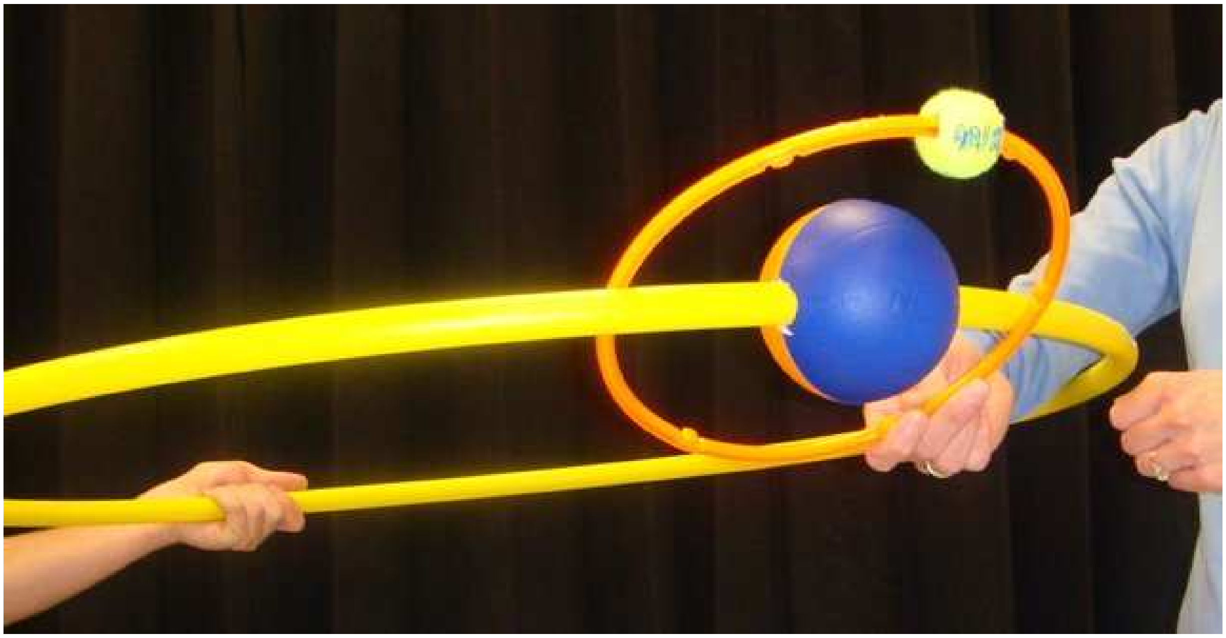

Figure 3. A close-up of the full moon phase is shown. A lunar eclipse is not possible because the Moon is above the plane of the Earth's orbit, and the line of nodes is not pointing at the Sun.

Next, the student rotates the hula hoop counterclockwise (as seen from above) a quarter turn; now the Earth is on the right side of the hoop, as viewed by the class. During this rotation, I have walked my Moon orbit around a quarter turn as well, ensuring that the orbit orientation is not changed during the rotation. This time, when the new moon and full moon phases are demonstrated, the students are able to see that eclipses are possible for *this* arrangement. Figure 4a shows the Moon at its new phase, and Figure 4b is a close-up view of the Moon when full.

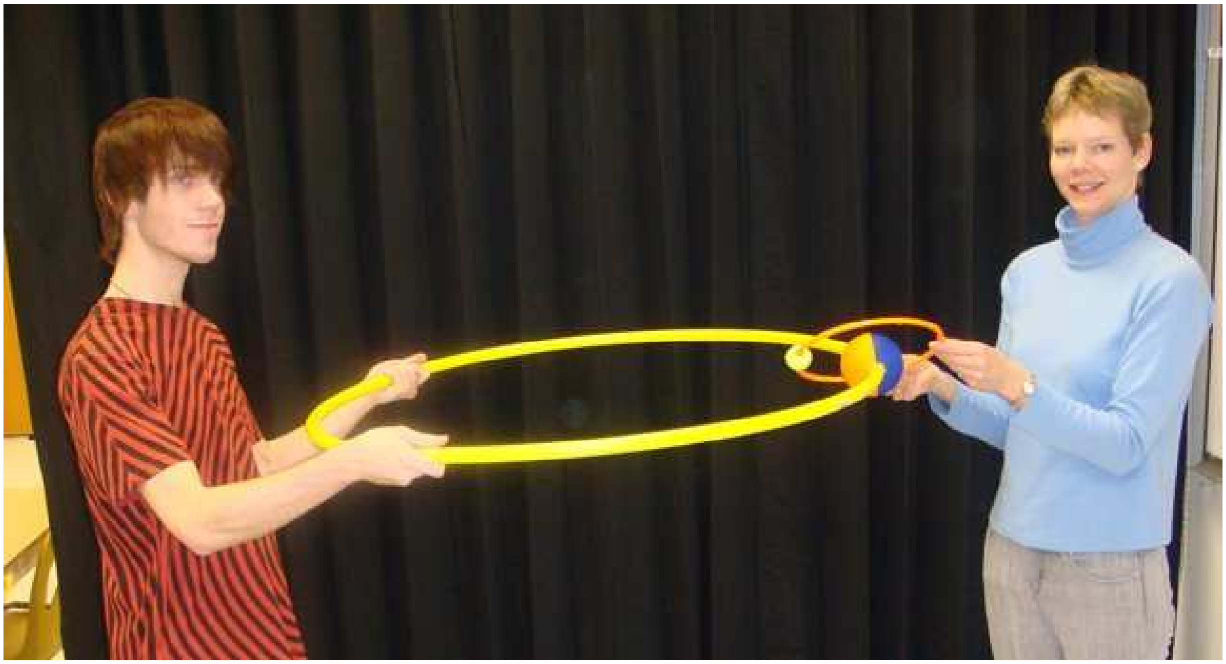

Figure 4a. At new moon, the Sun (not shown but assumed to be in the center of the hula hoop), Moon, and Earth are in the same plane. The Moon is at a node, and the line of nodes is pointing toward the Sun. A solar eclipse is possible in this case.

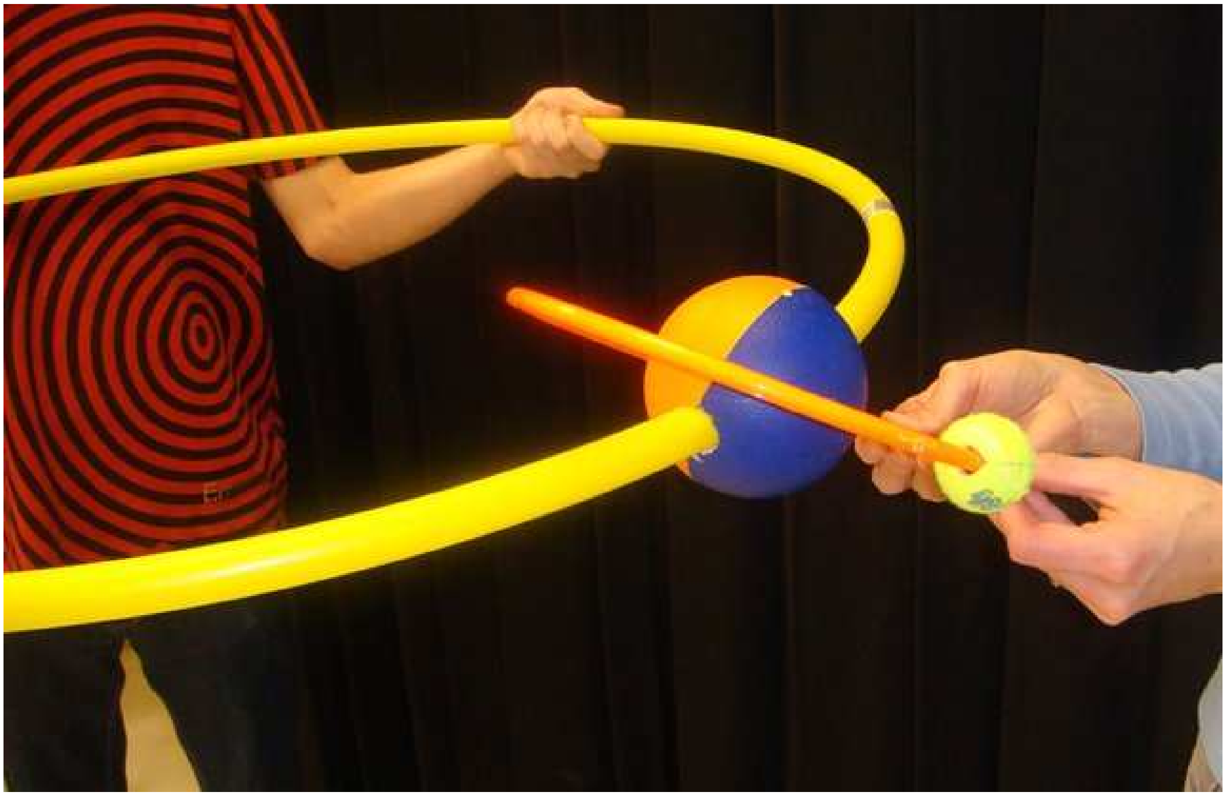

Figure 4b. A close-up shows the Moon at its full phase. A lunar eclipse is possible in this case.

Another student is invited to show the class where the line of nodes is in this case. This reinforces the idea that the line of nodes must be pointing toward the Sun, with the Moon at a node, for an eclipse to occur. Note that I begin the demonstration with the Earth in a position closest to the students because it is easier for them to see that the Sun, Earth, and Moon are in the same plane during the new and full moon phases once the Earth has moved through a quarter of its orbit.

At this point, I conduct an oral survey as to whether the students would see eclipses "six months later" (i.e., after a further half orbit of the Earth). After asking the student helper to move the Earth around to that spot, I repeat the new moon/full moon portion of the demonstration one final time to confirm that the potential exists for another solar and lunar eclipse at *this* location as well. Note that when the Earth is moved to this location in its orbit, the Moon's orbit hoop will have to be flipped left to right so that it remains oriented properly as it moves with the Earth.

After asking the students if they have any questions, I administer a short, informal quiz (five minutes or less, often oral because of time constraints) about the concepts illustrated in the demonstration: the line of nodes, conditions required for eclipses to occur, how many times per year solar and lunar eclipses are expected, and how much time elapses between a solar and a lunar eclipse in the same lunar cycle. If there is no time for a quiz immediately following the demonstration, I ask those questions (or more involved ones) on a quiz or longer exam later in the term. A short list of possible exam questions is given in section 6 of this article.

4. LOGISTICS AND PITFALLS

This demonstration is best performed in a tiered lecture room, although it is more difficult to maintain interaction in a large group. Only a small amount of space in front of the classroom is required. The set-up time is minimal; we keep the balls permanently attached to their respective hoops and hang the hoops together on a hook in our equipment room until needed.

There are a few things to be aware of in this demonstration. First, it is very easy to accidentally vary the orientation of the Moon's orbit as it is moved around with the Earth, which may result in no eclipses at all, or eclipses all the time! It is best to practice the demonstration a few times before presenting it to the students. In addition, because the hoops are interlaced, it is important to begin the demonstration with the Moon's orbit oriented such that the right side of the Moon's orbit hoop is on the outside of the hula hoop (as seen by the class), and the left side is inside the hula hoop (Figure 3). This prevents the Moon's orbit from becoming forced into an incorrect orientation as the Earth is moved in its orbit counterclockwise.

5. VARIATIONS AND RELATED EXERCISES

For smaller groups, the students are able to gather around the apparatus. If the room can be darkened, the light bulb Sun may be used to project the shadows of the Moon and Earth onto pieces of paper held by other students. As the Moon is moved around in its orbit, the students are able to see directly how its shadow may or may not be projected onto the Earth at new moon phase and how the Moon may or may not fall into the Earth's shadow at full moon phase. Note that the success of this depends on the relative sizes of the orbits and the balls, and the brightness of the light bulb.

Another option in a smaller class would be to break the class into a few groups, provide them with models and background information, and have them try to work through the demonstration independently (with assistance from the instructor). Afterward, the demonstration, as described above, could be performed for the whole group. This exercise would be useful in that it would illustrate the misconceptions that students may have about eclipses and reinforce the concepts given in the background information.

In addition to the orbital inclination of the Moon, other factors conspire to make eclipses a rarity in the Solar System. If time permits, ask students what they think these additional factors are (the relative sizes of the Earth and the Moon, and the separation between the two) and use their responses to initiate a discussion of what happens to the eclipse scenario if the two bodies are the same size. The instructor should incorporate into the discussion (thus reinforcing the lecture material) the following points. The ratio of the diameters is 3.67:1, whereas the average separation is 384,000 km. The Sun is a distant 150 million km from the Earth-Moon system. As a result, the umbral shadows of the Earth and Moon are long and narrow, which, when combined with the orbital inclination of the Moon and the distance between the Earth and Moon, results in infrequent eclipses. Indeed, when solar eclipses do occur, the Moon's umbral shadow on the Earth is only about 270 km in diameter, a small spot compared with the diameter of the Earth itself. The instructor may also ask the students what might cause the spot's size to vary from eclipse to eclipse.

At this point, if the instructor wishes to do an in-class exercise rather than present a discussion or give a quiz to test understanding, the class could be split into pairs or groups (depending on the classroom/lecture theater layout), presented with the following scenario and questions, and given 5–10 minutes to discuss and formulate answers to be shared with the rest of the class. Note that if preferred, a separate model may be constructed and a new demonstration performed instead.

The scenario: Assume that both the Earth and Moon are the diameter of the Earth (12,756 km). Ask the students if a total solar eclipse would appear the same as we actually see it, and if not, what the separation between the two bodies would have to be for the same size shadow to be projected onto the Earth's surface (the students need to remember that the Sun and Moon must have the same angular diameter for total solar eclipses to occur). Have each group sketch the new configuration, placing the Moon at approximately the correct distance. Repeat the exercise for a lunar eclipse situation. In the latter case, the students should realize that no configuration will produce the same lunar eclipses that we actually see. A follow-up question could be asked on an assignment or exam, in which both bodies are the size of the Moon (3476 km) rather than the Earth.

In general, because it is often difficult to conduct group activities in a large class, and it is even more difficult to allow every group to present their findings, students can be split into groups at the beginning of term with the understanding that even though each group will have to participate in the exercises, they will only be called on once or twice during the term (on class dates given to them in advance) to present their findings. The number of times that each group will be in the "hot seat" depends on the size of the class, the number of groups, and the frequency of the in-class exercises. To ensure that students attend the classes for which they will be in the hot seat, a portion of their grade may be allotted to their participation. This technique is used effectively by L. Baldwin, one of our biology professors (private communication, 2008).

6. EVALUATION

Demonstrations are performed to illustrate a concept or method, and educators are becoming more aware of the need to assess how effective the demonstrations are in enhancing student learning. I first performed this demonstration a few years ago, and since then, I've been fine-tuning the presentation and subsequent questions; therefore, there are no concrete data yet on the effectiveness of the demonstration. I now am satisfied with the demonstration and will begin to collect quiz data this fall to assess the demonstration's effectiveness. Potential quiz questions include simple sketching questions illustrating the configuration of the Sun, Earth, and Moon during eclipses and more thought-provoking questions that expect the students to understand and incorporate concepts such as synchronous rotation of the Moon. The following is a short list of sample questions. In the past, I have asked Questions 1–3 orally in class, on quizzes given later in the term after the demonstration was performed, or on more major exams. Question 4 follows from one of the related exercises that I have not yet presented to the students.

1. Given a schematic diagram of the Sun, Earth, and Moon (in a location suitable for either a solar or a lunar eclipse), state the type of eclipse illustrated, draw in the shadows of the Earth and Moon, and state the phase of the Moon for that type of eclipse.
2. Describe what is meant by the "line of nodes" and explain why we do not see solar and lunar eclipses every month.
3. Suppose that people on the Earth were experiencing a total solar eclipse. Describe what you would see if you lived on the edge of the Moon's crater Copernicus. (Alternate version: Ask what you would see if people on Earth were experiencing a lunar eclipse.) You may draw a diagram if it helps you to answer the question, but a diagram alone is not sufficient for full marks. (Question adapted from Fraknoi, Morrison, & Wolff 2004).
4. Suppose that the Earth were the same size as the Moon (3476 km). Would solar and lunar eclipses be the same as they are in reality? Explain. Draw a diagram as part of your answer, but note that a

diagram alone is not sufficient for full marks.

My notes regarding the students' understanding of eclipses indicate that the demonstration is helpful to their understanding. Although several students continue to err on Question 1, I believe this is because they forget which body "disappears" during the eclipse in question. This fall, I will ask them to come up with mnemonic devices and share them with the class. Incorrect answers to Question 2 are due to a lack of remembering basic facts. I am pleased to see that most students are able to answer Question 3, which indicates that they have understood the demonstration and that it helps their spatial visualization of the situation as viewed from a different vantage point. I have not asked Question 4 yet; I probably will ask it on an assignment first because that will enable me to assist the students with their answers if necessary, and I can assess whether the question is a fair one for an exam.

I plan to evaluate formally the demonstration's effectiveness by administering pre- and postdemonstration quizzes and then comparing the results. I will also administer a survey with one or two questions that ask the students what they thought the demonstration contributed to *their* understanding and whether they think that anything should be added to the demonstration to increase their comprehension of the concepts. After the results of the quizzes and surveys have been analyzed, the demonstration will be modified if necessary.

7. SUMMARY

A three-dimensional demonstration of eclipses may be constructed inexpensively and easily using balls and hoops of different sizes to represent the Earth and Moon, and their orbits. This demonstration illustrates the conditions necessary for eclipses to occur. Pitfalls and related exercises have been described, and sample test questions have been given. Over the past few years, while the demonstration was being refined, assessments of the effectiveness of the demonstration were qualitative; now that the demonstration has been fine-tuned, concrete assessment data will be obtained and evaluated beginning this fall.

Acknowledgments

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References

Fraknoi, A., Morrison, D., & Wolff, S. 2004, *Voyages to the Planets*, 3rd edition, Brooks/Cole.