EXPLORATION 2: INCREDIBLE SHRINKING MOON!

Is the Moon really larger near the horizon?

The purpose of this exploration is to design an experiment, using the telescope, to investigate the apparent size of the Moon when it is near the horizon, compared to when it is higher in the sky.

- To the eye, the Moon appears much larger when it is near horizon.
- Yet when the Moon is near the horizon, it is actually slightly *further* from Earth than when viewed higher in the sky. If anything, we would expect the horizon Moon to look *smaller*.
- Measurement is important because our senses and our intuition are often a poor guide to reality.

The Moon when it is near the horizon is one of nature's stunning sights. It looks huge, and so close that you could practically touch it. Can it really be that large? What's going on?

This investigation offers students important opportunities to learn about how and why we do science—from question-posing, to forming a hypothesis, to designing an experiment, gathering evidence and coming to a conclusion.

Students first discuss why the Moon might look so much larger when it is near the horizon. They must draw on their understandings of how the world works: What factors might influence the perceived size of an object?

Second, as they reason from a simple Earth-Moon model, they are confronted with contradictory evidence: Though the Moon *looks* larger near the horizon, it *ought to* look smaller, because it is farthest

GRADE LEVEL:
7-12

TIME OF YEAR:
Anytime, but *best* when Moon is nearly full (see text).

SCIENCE STANDARDS:
Earth-Moon system
Science as inquiry

MATERIALS NEEDED:
✔Online telescopes (or use archived images.)
✔ MOImage, software provided
✔ Earth globe
✔ Printer (optional)

TIME NEEDED:
2 class periods

away there. Students then confront the fact that their own perception does not seem to support the Earth-Moon model.

Third, students develop a reasonable plan for settling the matter through investigation. And finally, students interpret their results and show how their conclusions are supported by the evidence. They are forced to confront the theme of this investigation: “Which do you believe, your own eyes or the evidence?”

As a math extension to this activity, students can use the data they collected to estimate the distance to the Moon.

Materials Needed

	For each team of students
	Rulers for measuring printed images in millimeters
	For the class
	Internet access to the MicroObservatory online telescopes
	Image-processing software (MOImage) on your local computer
	Printer (black-and-white)
	For the teacher
	Globe of the Earth
	Post-It or other sticker
	Ball to simulate the Moon
	Optional: Balls of different sizes to simulate perceived Moon sizes

Background

Through the centuries, the Moon has cast its spell on lovers, poets, and myth-makers. It is the closest celestial object, and the furthest that any human has set foot.

The Moon is thought to have been formed from the Earth itself, blasted into orbit when the Earth was young, by the impact of some enormous object. Though the Moon has a composition somewhat similar to Earth’s, it is now a vastly different world. Because of its small size relative to Earth, its gravity is only one-sixth that of Earth. As result, it is too small to hold an atmosphere, which long ago evaporated into space. (That's why the Moon's boundary appears so sharp against the background of space: it has no atmosphere to blur its silhouette.) It is also too small to have retained its interior heat, so its land masses do not move, as they do on Earth.

Without an atmosphere, rain, erosion, or the slow movements of continents, the Moon's surface appears much as it did billions of years ago. The craters that mark its surface are a record of the deep past.

About the Moon illusion

That the Moon appears much larger when viewed near the horizon was described thousands of years ago in early Greek and Chinese writings, and appears in Aristotle's writings around 350 B.C.E. The illusion applies to the Sun, Moon, constellations and any celestial phenomenon that can be viewed low in the sky.

Although many people assume that the phenomenon has something to do with the Earth's atmosphere, in reality the refraction of light by the atmosphere acts to make the Moon appear slightly *smaller* and *flatter* near the horizon—not larger. Various activities provide evidence that the illusion has to do with the way in which our brain processes visual information. For example, if you bend over and look between your legs at the Moon — or if you lie on your side, or if you close one eye — you can reduce or eliminate the illusion.

Visit Donald Simanek's site at

http://www.satellitescience.org/moon.html

to explore these ideas further, and to read about competing theories of the what causes the Moon illusion.

Students' thoughts about the Moon.

It is important for students to experience the phenomenon they are investigating. If possible, have students go outdoors to observe the Moon when it is near the horizon and then again a few hours later when it is higher—in advance of this exploration Most students already will have noticed that the horizon Moon seems particularly large, and they may have vivid recollections of particularly beautiful, “large” Moons they have seen.

Survey of past observations

Have students *estimate* how much larger the horizon Moon looks compared to a Moon higher in the sky, by circling one of the four horizon Moon drawings in the illustration in their journals. Have students report their perceptions by a show of hands. Many students will have circled the largest or next largest horizon Moon in the illustration. The consensus will be that the horizon Moon looks considerably larger.

Alternatively, have a bucket of balls of different sizes so that students can physically choose two balls that model the relative sizes they perceive. (For example, if a tennis ball represents the Moon high in the sky, a hardball or softball might look more like the horizon Moon. Similarly, a soccer ball, basketball and beach ball might be used.)

Thoughts on why

Before they carry out the investigation, have students write down their ideas about why the horizon Moon looks so large.

Discuss with students, “What are the factors that might affect how large the Moon looks?” Among the factors students may cite: How big it actually is. How far away it is. Effect of the atmosphere? Illusions or some effect of the mind? Lighting? By collecting students’ ideas, you help students personalize the investigation.

Students will be quick to point out that the Moon itself doesn’t actually expand or shrink like a balloon, so something else must be going on. Many students will say that it is an illusion; others will say the Earth’s atmosphere is involved. (In reality, the atmosphere makes objects near the horizon appear slightly *flattened* rather than larger, but the effect of the atmosphere is minor and is *not* a factor in this investigation.)

Some students may cite distance as a factor. Could the Moon actually be closer when it is near the horizon? Accept all answers as ideas that students may re-examine as they carry out their exploration.

Planning the investigation

Explain to students that in this exploration, their challenge is to use the telescope as a measuring device, to determine whether the Moon's image really *is* larger when viewed near the horizon, compared to when the Moon is viewed higher in the sky—and if so, how much larger

ALERT: STUDENTS' PRIOR IDEAS. Some students will be confused about whether the telescope is an “objective” measuring device (like a ruler) or is capable of being fooled (like the eye). “Shouldn’t the telescope see the same illusion or scene as our eye?” some students ask. Explain to students that the telescope records images. It does not “see” the way we do—it would need a brain to do that. Make certain they understand that the crux of the investigation is to determine the relative size of the images that the telescope records, and to compare those “objective” sizes with the “subjective” sizes that our eye and brain perceive.

Students' predictions

Ask students what they expect to find when they compare a telescope image of the horizon Moon with an image of the Moon taken when it is higher in the sky. Will the horizon Moon appear larger in the telescope image as well? Some students think the images will be the same size. Many students think the horizon Moon image will be larger, just as it appears to the naked eye.

Have students record their predictions in the journal. By committing to a prediction, they will have a stake in the outcome of their investigation. At the end of their investigation, students will be able to return to and confront their initial beliefs.

Reasoning from a model of the Earth-Moon system: Students' predictions revisited

After students have recorded their initial predictions, examine with students the following physical model of the Earth-Moon system. Explain that it is often useful to make predictions on the basis of a *physical model*, which helps you visualize the phenomenon you are exploring.

1. Use a globe of the Earth to represent Earth.

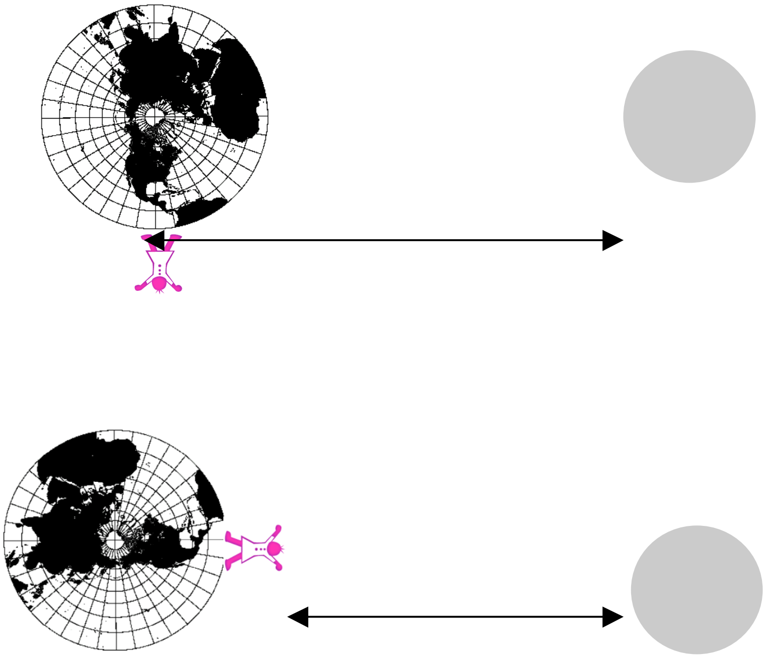
2. Have students locate the position of your town on the globe, and place a Post-It or other sticker at that location, to represent the observer — you or the telescope.

3. Crease the Post-It so that a portion of it is "standing up" off the surface of the globe.

4. Have a student hold a smaller sphere (such as a ball or orange) about ten feet away to represent the Moon. (IMPORTANT NOTE: This model of the Earth-Moon system is not to scale! For this activity, you do not need to know the distance to the Moon. In fact, students' results will enable them to estimate the Moon's distance. See Math Connection below.)

5. Have a student rotate the globe so that the observer (Post-It) "sees" the Moon directly overhead. Now rotate the globe so that the observer "sees" the Moon near the Earth's horizon.

6. Ask students, "When is the Moon farther away—when it is viewed near the horizon, or when it is viewed overhead? It should be clear to students from examining the globe that the Moon is a little *further away* from the observer when viewed near the horizon. The Moon is a little *closer* to us when we see it overhead.



When viewed near the horizon (**top image)** the Moon *farther away* than when it is overhead **(bottom image)** several hours later. As the Earth turns on its axis, the Moon appears to rise and becomes higher in the sky. The drawing is not to scale.

You and your students have now uncovered a strange contradiction: When the Moon is on the horizon, it is farther away, according to our model of the Earth-Moon system. So the horizon Moon should look smaller. Yet the horizon Moon *looks* larger to the naked eye. What could possibly be going on?

Have your students recommit to a position. Do any of them want to switch their initial prediction? When they image the horizon Moon, will it be larger, the same size, or smaller than a Moon higher in the sky? If you can believe your eyes, then the horizon Moon should be *larger*. If you are confident in your reasoning from the Earth-Moon model, then the horizon Moon should be *smaller*, regardless of what our eyes tell us. But only *evidence* can settle the question.

Students' experimental methods

Ask students to design an experiment with the telescope to find out whether the horizon Moon really is larger than the Moon when it is higher in the sky—or whether that is just an illusion. Have them record their preliminary ideas, including:

How many images will they need to take? When should they be taken? How will students measure and compare the Moon's size in the images?

Many students will see how to proceed: Take an image when the Moon is near the horizon, and then take an image when the Moon is higher in the sky, a few hours later. Then compare the size of the Moon in the two images.

The Art of Science

Many students believe that science is a method for proving what you think OUGHT to be true — for garnering just the evidence that supports your belief. Here is an opportunity for students to discover an important ethic of science: Science is a way of finding out how nature behaves — not how you'd like it to behave.

Deciding on a protocol

Discuss with students the details of the investigation. Make sure that students understand how to take the images (using information provided). How many images should be taken, and at what times? Between which two points should they measure? It is important to take more than one image at each time, because otherwise there is no way to know how reproducible are the size of the telescope images. For example, are students looking for an effect that is smaller than the normal variation in images? As it turns out, the size of the telescope images is highly reproducible. Students can increase the precision of their measurements by averaging the results of measurements on several Moon images taken at (nearly) the same time. In either case, each pair of students must decide on a protocol for measuring the diameter of the Moon in their images. That is, they must agree on which two points in the image to measure between.

Student teams: Double-blind investigation

If you are expecting a particular result, could that affect the way you make measurements -- even if only inadvertently? To improve the credibility of their results, scientists carry out "double blind" experiments, in which the people who measure or analyze the data do not know the source of the data -- at least until AFTER they have made their measurements.

In order to model a credible investigation, and also to have more fun, try dividing the students into teams: One team takes the images and carefully records which images are the "horizon" Moons. The other team measures the images and tries to predict which of the images are the horizon Moons. (Alternatively, each team could take their own images and measure the other team's images.) The important point is that the person making the measurements should not know whether they are measuring a horizon Moon or not, until their partner reveals it.

Carrying out the investigation.

NOTE: This exploration can be done at any phase of the Moon's cycle, but it is *best* when the Moon is full or nearly full, because:

The full Moon rises at sunset, when students can easily view the effect by eye, and can compare their naked-eye observations with their telescope observations; and

The size of the Moon is easiest to measure when it is nearly full.

1. Students work in pairs. One student is responsible for imaging the Moon near the horizon; the other is responsible for imaging the Moon about four hours later, when it is higher in the sky.

2. Determine which telescope is available for use by checking the telescope Website.

3. Help students find out when the the Moon rises *at the telescope site*.

    - You can find the time of moonrise for any city or town in the United States, for any date, at the U.S. Naval Observatory website:

      http://tycho.usno.navy.mil/

      Or you can go directly to the moonrise page at:

      http://aa.usno.navy.mil/data/docs/RS_OneDay.html

    - At this Website, obtain the time for moonrise at the telescope's location (not your own hometown).

4. Have students schedule their first Moon image for about one hour after moonrise: The telescope will not take images of objects that are too close to the horizon, since buildings may obscure the view.

5. To take images of the Moon, students use the settings recommended in the 'Scope it Out! section.

6. Have students download and save images in the GIF format (this is the format that your picture appears on the Web page). Remind students to label their image files clearly, so they know which image is which.

IMPORTANT: Make certain that students also download or print the **Image Info** file for each image. This file contains a record of how many degrees above the horizon the Moon was, when the image was taken.

Measuring the images

Students measure the size of the Moon in one of two ways, either ONSCREEN or from a PRINTED IMAGE (see below).

To measure the images onscreen:

- Launch the MOImage program on your computer.
- From the program, open the Moon image to be measured.
- Move the cursor between the two points to be measured, while holding the mouse button down. The distance in pixels between the two points will appear in the display box.

Alternatively, to measure the printed images:

- Print the image of the Moon. (To save your printer's toner, you may want to first invert the image in a program such as MOImage before printing, so there is less black to print.)
- Students measure the diameter of the Moon using a ruler that measures in millimeters or other fine gradations.

Make certain that students record their results on the DATA PAGE for the activity.

The Moon need not be full for this activity. Students can measure the distance between any two prominent features on the Moon, instead of the actual diameter, provided the features are almost as far apart as the diameter of the Moon. For a crescent Moon, it is easiest to measure the distance between the points of the crescent.

IMPORTANT: Students should be advised to measure carefully. The differences among the images will be small but significant.

Students should keep accurate records of the names of each image and where in the sky (horizon or higher) the Moon was. The “Image Info File” that comes with each image will help, but this information may be lost if the image is processed or converted to a different file format.

Reflecting on the results.

Have each pair of students report their results to the class. You may ask for a *qualitative* result ("Is the horizon Moon larger?") or for a *quantitative* result ("Which Moon is larger, and what is the percentage difference between the two Moons?") If you record students' quantitative results on the board, you will be able to go on to the math extension, "Estimating the distance to the Moon."

Qualitative results: Wrapping up

Students will have found that the Moon is slightly *smaller* when imaged near the horizon than when it is higher in the sky. This result surprises most students, teachers, and even professional astronomers—because the horizon Moon appears so much larger to the eye!

1. Ask students what they make of their results. Somehow, there must be an illusion that fools the eye—but not the telescope—into seeing the horizon Moon as larger. Students who want to pursue this question should be encouraged to try the illusions in the Briefing Room section, and to explore the Moon illusion further using the interactive demonstrations on the Web site listed.

2. Discuss with students the take-home message of this exploration: Our senses are not always a reliable guide to how the world works. That's why we do careful experiments in science; nature has plenty of surprises in store for us. Constructing a physical model—such as the Earth-Moon system—can help us to visualize and to reason about situations where our intuition or our senses might not be reliable.

Quantitative results

1. Keep a running tally on the board of students' quantitative results, so that students can compare their results.

2. Ask students what might account for the variation among their results, i.e., why isn't everyone's result the same? Examples of explanations include: The images were not all taken at the same time, so some Moons are higher than others. Students may have measured between slightly different points on the Moon's image. It's hard to measure the size of the Moon precisely.

3. If you are NOT going on to the Math Extension, "How Far is the Moon?" then ask students *whether their results seem reasonable*, given the Earth-Moon model you discussed and the known distance to the Moon (about 230,000 miles). Since the horizon Moon is a few thousand miles farther from the observer—that is, a few *percent* farther—we would expect the horizon Moon to appear a few percent smaller than the higher Moon images. That is just what students will have found.

Which is the horizon Moon?

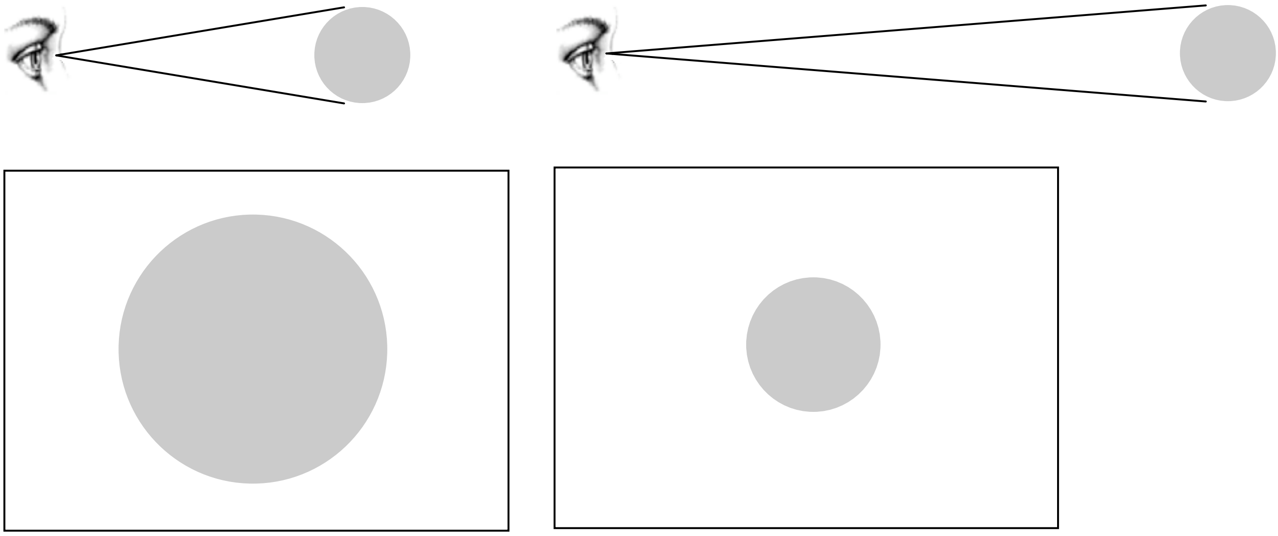
The Moon on the right was 11 degrees above the horizon. The Moon on the left was taken about five hours later and was 53 degrees above the horizon. The horizon Moon is a few pixels smaller than the Moon at left—about 1 percent smaller. (Images reduced in size here.) ***Images by Jim Kernohan's students at Milton High School*****, MA.**

Math extension:
Distance to the Moon

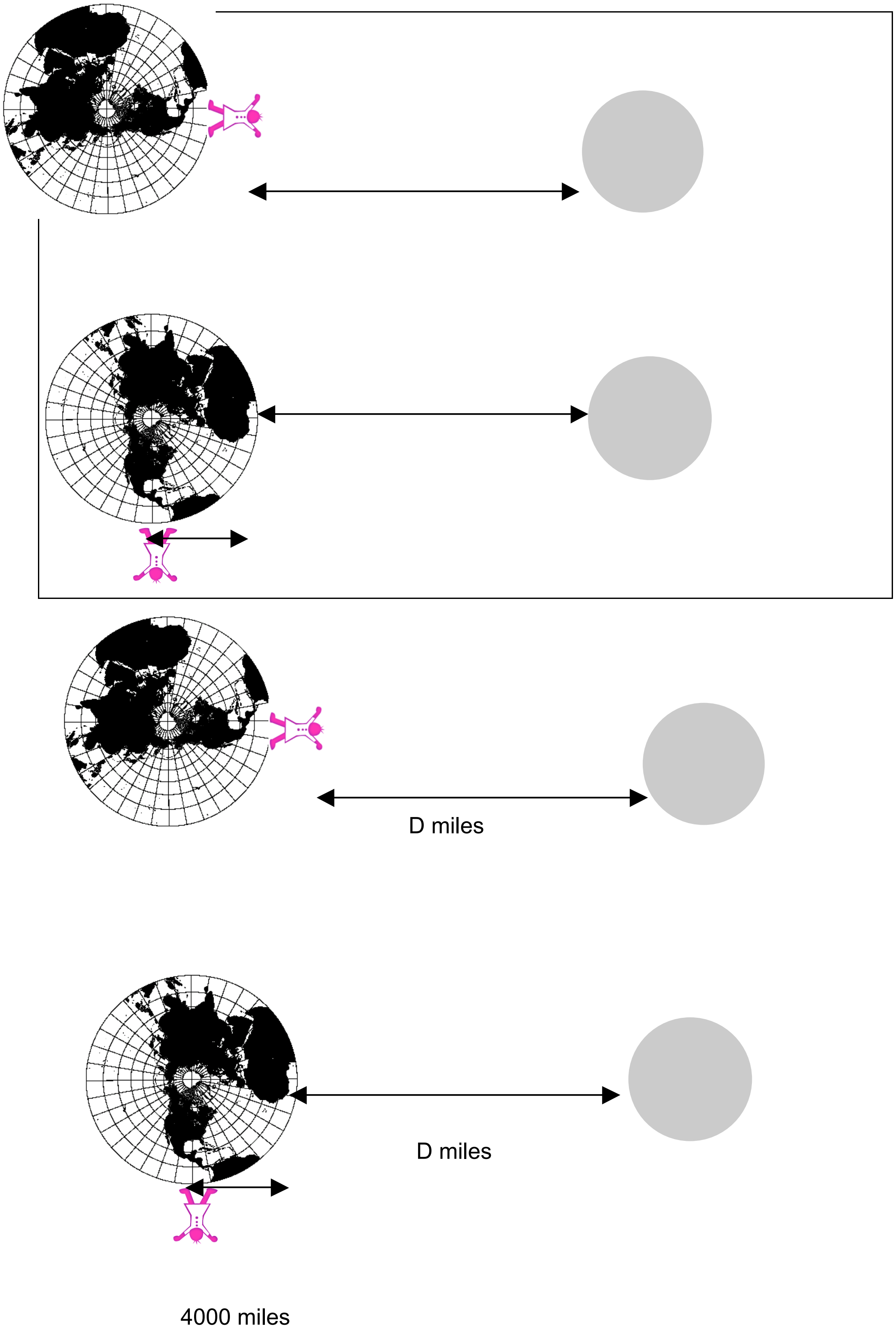
Students can *estimate* the distance to the Moon, using the results of their measurements.

Here's the principle involved: As you get further from an object, it appears *proportionally* smaller. That is, if you move **x** times further away, an object will appear only **1/x** times as wide. (Note: This rule is only an approximation, but it is a good one for objects smaller than about one degree in your field of view.)

You can visualize this in the diagram below. The object at right is 2 times as distant from the observer as the same object at left. As a result, it appears to have only about 1/2 the angular width—and appears only 1/2 as wide—as the object at left.



The same principle applies to students' images of the Moon. Refer to the diagram below: When the Moon is overhead (or high in the sky), it is some distance **D** from the observer. But when the Moon is on the horizon, it is now further from the observer; the difference is *as much as* the radius of the Earth, about 4000 miles. (The actual difference will be less, depending on where the observer is located.)



The Earth-Moon system (not to scale), looking down on the North Pole. **Top:** An observer sees the Moon nearly overhead, when it is, say, D miles away. **Bottom:** When an observer sees the Moon near the horizon, the Moon is further away—by as much as the radius of the Earth, about 4000 miles. For an observer in North America, the change in distance will be *less than* 4000 miles.

Since the apparent width of an object is *inversely proportional* to its distance ("the greater the distance, the smaller the width"), we can set up the proportion:

$$\frac{\text{width (of horizon Moon)}}{\text{width (of high up Moon)}} = \frac{\text{distance (to high up Moon)}}{\text{distance (to horizon Moon)}}$$

$$\frac{\text{width (of horizon Moon)}}{\text{width (of high up Moon)}} = \frac{\mathbf{D}}{\mathbf{D + 4000}}$$

This equation can be solved for the distance, D, using simple algebra. The widths are what your students have measured from their images.

$$\mathbf{D} = \mathbf{4000\ mi.\ x} \ \frac{\textbf{width (high up)}}{\textbf{width (high up) - width(horizon)}}$$

As an example, say that the Moon is measured to be 371 pixels wide, when seen near the horizon, and 378 pixels wide when seen high up. Then an *estimated* distance to Moon would be

D = 4000 miles x (371 pixels) / (7 pixels)
D = 4000 miles x 53
D = 212,000 miles

So the estimated distance to the Moon is about 200,000 miles (to one significant figure). This is a *reasonable* estimate.

The *average* distance to the Moon is about 239,000 miles.

This varies by more than 10% as the Moon orbits Earth, because the orbit is an ellipse (see Student Projects).

Notes on the student projects

You can start students on their own open-ended, independent projects by introducing them to more optical illusions (provided). Students may wish to try to recreate the Moon illusion by drawing a horizon, a landscape, and Moons in several positions. However, it is remarkably difficult to recreate the illusion this way. An interesting 3-D approach to the problem has been published on the Web:

http://www.research.ibm.com/resources/news/20000103_moon_illusion.shtml

Students may wish to investigate this interactive 3-D tool and report on their findings.

Image at right by students at Lincoln-Sudbury Middle School, Sudbury, Massachusetts. Anita Honkonen, teacher.