Luna

Our Moon, Luna, will be the focus of my columns for this coming school year. Data and information will be provided so that each month you and your students can follow the Moon and the Earth as the two orbit together around the Sun. Students can use this data, for example, to graph the Moon's changing apparent size and distance, watch for patterns or rhythms to develop, or combine this data with information from the internet to look for any correlations between Moon distance and tides, earthquakes, or volcanic activity.

With the exception of Pluto and Charon, our Moon is unlike other moons in the sense that it probably formed out of a collision that resulted in two objects of somewhat similar size orbiting the Sun together. In addition, our Moon does not orbit its planet equatorially as other moons do. The Moon's orbital path is tilted approximately 5 degrees from the Earth's orbit. From our perspective, the Moon has an orbit that takes it around the Earth. However, as will be seen in a future column, our Moon actually orbits the Sun with the Earth, pivoting around a common center of mass known as the *barycenter*. It does not actually go around the Earth.

Lunar basics

Immigrants brought many of the names we have for a full Moon to this country, and others are the names used by Native Americans. In Colonial America, the September full Moon was known as the *Fruit Moon*, the *Dying Grass Moon*, or the *Barley Moon*. Sometimes the full Moon of September is known as the *Harvest Moon*, but traditionally that name is given to the full Moon closest to the September equinox. By that rule, the October full Moon will be the Harvest Moon this year, and the following month, according to tradition, will be the *Hunter's Moon*.

The Moon, moving along its orbital path, will undergo a daily phase change as it progresses across the sky from west to east. The phase appearance of the Moon will increase from right to left as the Moon waxes through the first half of a lunar cycle toward full Moon. This part of the lunar cycle will be easily observed during the evening hours after sunset. By observing at the same time each evening, two patterns will become apparent: The waxing Moon will be seen further east, and it will rise about 50–60 minutes earlier each day. Following the full Moon phase, the Moon will continue moving eastward daily but it will be waning (decreasing) from right to left in phase appearance. Because waning phases occur late at night, they can be observed during the morning in the daytime sky.

From our perspective on Earth, we describe the Moon in terms of its orbit around the Earth, and say that the Moon's orbit takes about a month. Complicating this is that we use a calendar with months having lengths of 28, 30, or 31 days. So, exactly how long does it take for the Moon to orbit the Earth?

Using the phase cycle as a reference from which to determine the Moon's orbital period, it takes approximately 29.54 days to go from new Moon to new Moon. Called the *synodic* month, this is not the time it actually takes for the Moon to orbit the Earth, but rather the time it takes to return to the same phase. The *sidereal* month is a measure of the actual time and it is determined by using a star other than the Sun as a reference point from which

Bob Riddle (bob-riddle@currentsky.com) *is a science educator living is Lee's Summit, Missouri. Visit his astronomy website at* www.currentsky.com.

Questions for students

1. Does the Moon rise and set every day?
   (Yes. Even though we may not be able to see the Moon, it still rises and sets every day. The new Moon, for example, rises and sets with the Sun.)
2. What is the difference between this month's apogee and perigee?
   (406,500 km – 357,175 km = 49,325 km)
3. How is a waxing Moon different from a waning Moon?
   (The Moon increases in phase appearance while it is waxing, and during the waning phases the phase appearance decreases.)
4. Use the celestial coordinates to plot the Moon's position at each quarter phase on the SFA star charts.
5. Start analyzing the data for patterns that may develop during the next several months.

to find the Moon's orbital period. The sidereal month is approximately 27.33 days, the time it takes the Moon to orbit the Earth, or return to the reference star. If the sidereal month is rounded off to 28 days then it serves as the basis for dividing the lunar cycle into quarters of seven days and emphasizing quarter phases. This is probably the source for the commonly used practice of teaching that there are seven days between quarter phases and that we have a lunar cycle of 28 days.

The difference between the Moon's sidereal month and its synodic month is based on our understanding that the Earth is moving along its orbital path around the Sun while the Moon is following its own orbital path relative to the Earth's orbit. If the Earth were not revolving, and we started the observation with a new Moon phase, the Moon would take 27.33 days, a sidereal month, to return to the same phase. However, because the Earth is revolving at the same time, the Moon would not be at the same phase as when the observation was started. Because the Earth is also revolving, it will take an additional two days or so for the Moon to line up with the Earth and Sun and return to the same phase.

This difference is easily observable and typically each month there will be an opportunity to find a bright reference star to use. Find

FIGURE 1 **September 1, 9:00 p.m. The waxing gibbous Moon east of Antares.**

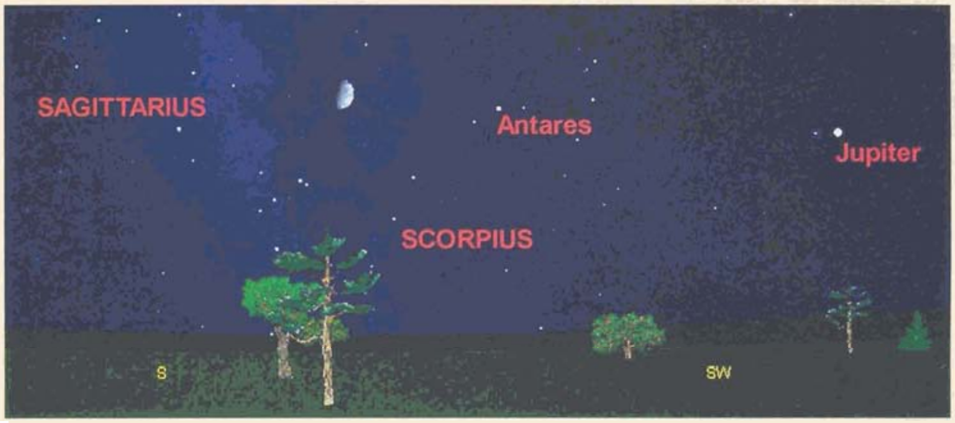


FIGURE 2 **September 28, 9:00 p.m. The waxing crescent Moon near Antares.**

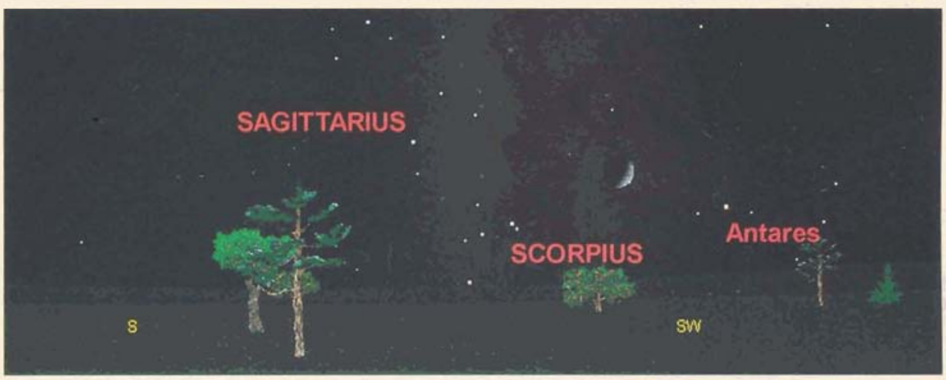


FIGURE 3 **September 30, 9:00 p.m. Waxing gibbous Moon.**

Moon data and events for September

Date	Moon event
9/1	Waxing gibbous Moon east of Antares
9/7	Full Moon Right ascension: $23^h29'$; Declination: –4°39′ Partial lunar eclipse
9/8	Ascending node Illuminated fraction: 1.0% Perigee distance: 357,175 km Apparent size: 0.5576°
9/14	Last quarter Right ascension: $6^h5'$; Declination: 27°57′
9/22	New Moon Right ascension: $12^h\ 23'$; Declination: –4°26′
9/21	Descending node Illuminated fraction: 0.0%
9/22	Annular eclipse Apogee distance: 406,500 km Apparent size: 0.4899°
9/28	Waxing crescent Moon east of Antares
9/29	First quarter Right ascension: $18^h12'$; Declination: –29°19′

an evening when the Moon is close to a bright star and note the phase and age in days of the Moon. The age of the Moon would be the number of days since new Moon. Next, count the days until the Moon returns to that same spot relative to the star. Will the Moon be at the same phase and be the same age in days?

Figures 1–3 show a view toward the southern horizon after sunset on three days during September. On the evening of September 1 at 9:00 p.m. local time, the 8.5-day-old waxing gibbous Moon will be east (to the left), of the reddish star Antares in Scorpius, the Scorpion. Further to the right will be the bright planet Jupiter. After approximately 27 days, on September 28, the Moon will return to approximately the same location east of Antares. However, it will be only a 6-day-old waxing crescent Moon. That was the sidereal month. To complete the synodic month, it will take an additional two days of Earth revolution for the Moon to return to an 8-day-old waxing gibbous phase. The Moon will also be further east of Antares.

Use the link to "Your Sky" (see Resources) for an online star map that may be set to any day and time for any latitude and longitude location. This can be used to model the difference between a synodic and sidereal month. Use the Earth-Moon Viewer link at the bottom of the "Your Sky" web page to generate data and an image of the Moon for any day and time.

A pair of eclipses

Lunar and solar eclipses occur as eclipse pairs separated by approximately 14 days. During the calendar year there can be as many as three pairs of eclipses, and, depending on the dates, there can be as many as seven eclipses. An eclipse happens only when the alignment between the Earth, Moon, and the Sun are such that the Moon either blocks the Sun from view, or alternately passes through some or all of the Earth's shadow.

This month, there will be the second eclipse pair for the year with a partial lunar eclipse on September 7, followed by an annular solar eclipse on September 22. Neither of these eclipses will be visible from the continental United States; however, we will see a total lunar eclipse in March.

Visible planets

- Venus will be visible very low over the eastern horizon before sunrise during the first week of the month.
- Jupiter will be visible over the southwest horizon to the right of the reddish giant star Antares in Scorpius, the Scorpion.
- Saturn will be visible over the eastern horizon before sunrise to the right of the much brighter Venus, and will continue to rise higher each morning, becoming more visible.

Resources

The Moon—*www.nineplanets.org/luna.html*

Moon names—*http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970314a.html*

Your Sky—*www.fourmilab.ch/yoursky*

Daily Moon rise and set—*http://aa.usno.navy.mil/data/docs/RS_OneDay.html*

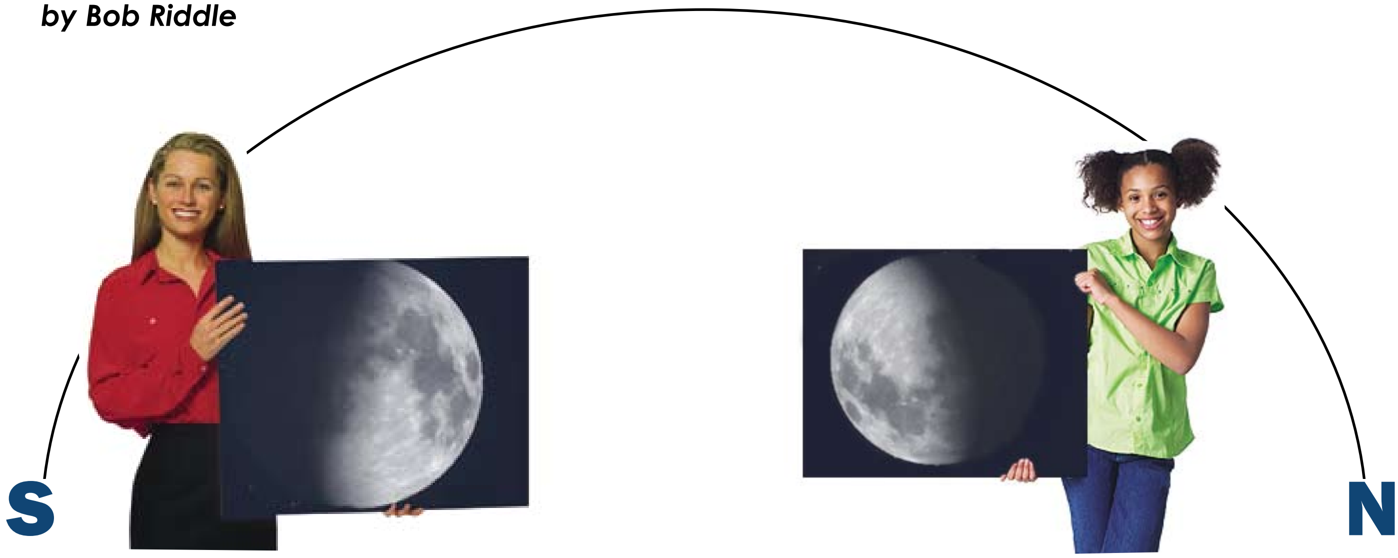
Monthly Sun and Moon rise and set—*www.sunrisesunset.com/custom_srss_calendar.asp*

Partial lunar eclipse map—*http://sunearth.gsfc.nasa.gov/eclipse/OH/image1/LE2006Sep07-Fig4.GIF*

Annular solar eclipse map—*http://sunearth.gsfc.nasa.gov/eclipse/OH/image1/SE2006Sep22-Fig5.GIF*

Lunar looks and latitude

by Bob Riddle



During December, the Sun gains a bit of notoriety as its celestial position this month marks a change of seasons, a solstice. The word *solstice* describes the day, or moment, when the Sun stops its north or south apparent motion. It comes from the Latin words *sol* for Sun, and *sistere* for stand still. This month, the Sun reaches the low point in its position relative to the Earth's latitude system for those who live north of the equator. On Sunday morning, December 21st, at 0704 EST, the Sun stands over the Tropic of Capricorn before heading north toward the equator and the March equinox. At that moment, the Sun will have the celestial coordinates of approximately 23.5 degrees south, and 18 hours of right ascension. From our perspective north of the equator at midday, the Sun will be low over our southern horizon. However, from the Southern Hemisphere, the Sun (with the same celestial coordinates) will be at its highest point above the northern horizon.

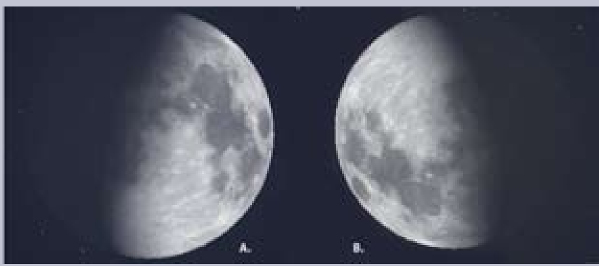
The height that the Sun reaches in the sky depends entirely on the viewer's latitude. However, regardless of the latitude, the viewer will nearly always have to look toward the equator to view the Sun. This is because of the apparent path the Sun and other celestial objects follow during the day and night. From the Northern Hemisphere we look east, south, and west to follow the apparent paths of most celestial objects, while from the southern hemisphere we look east, north, and west to follow the same celestial objects. Both hemispheres do share one common apparent sky motion, that of *circumpolar motion,* or the apparent circular path objects near either celestial pole follow around their respective celestial pole.

So, what else is different or not different about the sky as seen from north or south of the equator? Figure 1 shows two images of the nearly first quarter Moon at sunset. The longitude is the same for both images, however the latitude for one is 40 degrees north, and the other is 40 degrees south. Can you tell which is which and, if so, how? One way would be to know the general appearance of the Moon using the patterns of the dark areas, or *maria*. However, how many of us know the Moon well enough to differentiate that way? A much easier way, and one that lends itself nicely to teaching Moon phases, is to explore the relationship between the Moon and the Sun. During all lunar phases, the rounded side of the Moon is toward the Sun. And, most noticeably during crescent phases, the points or *cusps* of the Moon always point away from the Sun.

With this in mind, look at both Moon images. Based on the rounded side of the Moon, the Sun must be to the right in image A, and to the left in image B of Figure 1. Because the Moon is waxing during first quarter phase, it will be following the Sun toward the west as the Earth rotates. So this means that image A is the first quarter Moon as seen in the northern hemisphere over the south horizon and image B is the first quarter Moon as viewed from the Southern Hemisphere over the north horizon—both at approximately sunset.

To follow up on the computer modeling, you can have students dynamically or kinesthetically model the differing appearances of the Moon caused by latitude. Draw and cut out a circle on a sheet of paper. Color one

FIGURE 1 First quarter Moon from different latitudes



Southern view Northern view

half of the circle darker to represent the unlit portion of the Moon. Hold the cutout with the dark side on the left at arm's length at an upward angle. This is a view of the first quarter Moon as seen facing south from the Northern Hemisphere, north of the equator. The visible (white) rounded side is to the right or west, meaning that the Sun is to the right as well.

Explain that this will be a model that shows how traveling south toward the equator and beyond affects the position and appearance of the Moon. Ask students to predict what would happen to the angle between the Moon and the horizon if you were to travel south. How would the Moon change in appearance? When traveling south, latitude decreases and all celestial objects over the south horizon, including the Moon, will get higher in the sky until reaching the zenith (straight up). Then, as one continues traveling south, those objects near the zenith will start lowering but over the north horizon. Students should imagine that the Moon is following a curved line that goes from due south up to the zenith then down to due north. (In astronomy, this curved line is known as a *meridian*.)

To model the effects of traveling south to the equator, students should increase the angle of their arm, so that the Moon images are directly above their heads. If they were to keep moving south, they would need to lower their arms behind their backs. Rather than snapping their arms off at the shoulder, students can simply turn around and face the opposite direction—toward the north. Be sure that they *do not rotate* the Moon model as they turn around. In other words, at the beginning all students should face the same direction in the room (call this south) and always keep the lighted side of the model toward the wall on their right (west). As they continue to lower their arms facing north, they should observe that the rounded side of the Moon is now to their left, but still toward the west and the Sun.

The conclusion should be, as one student said, "The Moon is the Moon in the sky. It doesn't change, but I do." That student saw that the Moon, when viewed facing south, looks different when you face north and look at the same Moon.

Visible planets over the eastern or western horizon are also viewed differently from other latitudes. The descriptions I use for the visible-planets information based on a mid-northern latitude, of 40 degrees. The further south one is from that latitude, the higher and better-placed these rising and setting objects will be over the horizon. This month, Mars is described as low over the eastern horizon, so if you live in Florida, for example, Mars will be higher and more easily seen then it will be from further north at 40 degrees.

Visible planets

Mercury will be visible over the western horizon for most of the month and will move east to catch up with Jupiter by month's end.

Venus will be visible over the southwestern horizon at sunset, setting several hours after the Sun.

Mars is still low over the eastern horizon but will start becoming more visible over the eastern horizon before sunrise during this month as it rises earlier each day.

Jupiter will be visible over the western horizon at sunset and will pair off with Mercury on New Year's Eve.

Saturn will be visible over the southeastern horizon before sunset.

December

1 Launch of Herschel-Planck satellite
5 Mars in conjunction with Sun
12 Moon at perigee: 356, 568 km
13 Geminids meteor shower peak
17 50th anniversary of Project Mercury
21 December Solstice (0704 EST)
Cassini spacecraft *Titan* flyby
26 Moon at apogee: 406,602 km
28 Thin waxing crescent Moon near Mercury

Questions for students

1. What effect, if any, does longitude have on one's local view of celestial objects above the horizon?
The local longitude will determine the time for when a celestial object is visible above the horizon. In terms of rising or setting times objects, to your east rise and set earlier, and objects to your west earlier.

2. What effect does latitude have on viewing celestial objects?
The altitude of an object is related to the latitude of the observer. Objects appear higher above the horizon for viewers at lesser latitudes, or conversely, lower for viewers at greater latitudes.

3. Toward which direction do the phases of the Moon change? Is there a difference when viewed from either Northern or Southern Hemisphere?

Throughout a lunar cycle the changes in the Moon's phase appearance are always on the side opposite from the Sun—remember the curved side is toward the Sun. In the Northern Hemisphere we see this as increasing from right to left until full Moon, then decreasing from right to left until new Moon. It is the opposite as seen from the Southern Hemisphere.

4. How can you tell which Moon is which in figure from looking at the patterns of the maria, or lunar seas?

Look at Image A in Figure 1. Notice the rounded lunar sea on the right side? That is Mare Crisium, to the left are two larger rounded maria, and below them is sort of a V-shaped pattern. These are what we first see as the Moon waxes. In the Southern Hemisphere they see the same pattern of lunar seas emerging as the Moon waxes.

Resources

Solar Dynamics Observatory—*http://sdo.gsfc.nasa.gov*

Cassini—*http://saturn.jpl.nasa.gov*

SFA star charts—*http://midnightkite.com/starcharts.html*

Northern and Southern Hemisphere Star Maps—*http://skymaps.com*

Virtual reality lunar phases—*http://tycho.usno.navy.mil/vphase.html*

Complete Sun and Moon data—*http://aa.usno.navy.mil/data/docs/RS_OneDay.php*

Home Planet—*http://fourmilab.ch/homeplanet*

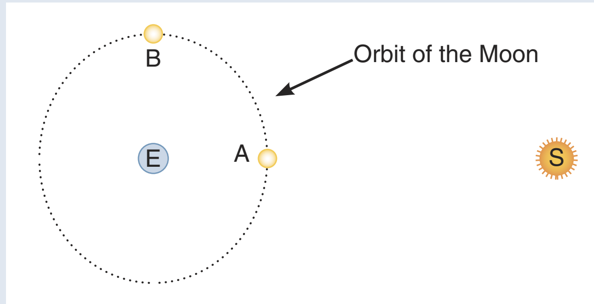
Bob Riddle (*briddle@kcmsd.net*) is the planetarium director for the Kansas City, Missouri, school district. Visit his astronomy website at *www.currentsky.com.*

Phasing in lunar observations

This interdisciplinary Moon unit was recently taught in seventh-grade science, mathematics, and English classrooms with three experienced teachers and 186 energetic students. Within the unit we incorporate aspects of the National Science Education Standards (NRC 1996), the National Council of Teachers of Mathematics Principles and Standards (NCTM 2000), and the National Council of Teachers of English Standards (NCTE 1996). This interdisciplinary unit lasts six to seven weeks where students explore the phases of the Moon through science, mathematics, and language arts. In order to gauge students' prior knowledge regarding the Moon and its phases, we administer the Lunar Phases Concept Inventory or LPCI (Lindell 2002). Questions on the inventory include the time of a lunar cycle, the direction of the Moon's orbit, and the cause of the Moon's phases. Figure 1 illustrates an example question from the LPCI. (For a complete copy of the inventory, contact Rebecca Lindell at *rlindel@siue.edu*.) We also use this inventory at the end of the unit to assess student learning.

FIGURE 1 **Lunar Phases Concept Inventory sample question**

19. If you could look down on the Earth/Moon/Sun system from a point in space located above the Earth's North Pole, you would observe that the Moon orbits around the Earth. At one Point in time it is in position A, as shown below. At some later time, the Moon is in position B.



How much time passed between these two observations?

a. 1 hour
b. 3 hours
c. 6 hours
d. 1/2 day
e. 1 day
f. 1 week
g. 2 weeks
h. 3 weeks
i. 1 month
j. More than 1 month

Phase one

We begin this unit by having students observe the Moon over a five-week time period. They are asked to make sense of their Moon observations and are required to keep a daily Moon journal. In this journal, students are given an invitation to write "whatever they wish and think is relevant," with at least two sentences per entry. Students can conduct their viewing sessions on their own, or invite family and even pets to accompany them. Students are encouraged to use descriptive language when making their observations, and to supplement their entries with poetry, sketches, and other artistic endeavors inspired by their daily viewings. This approach generates a mix of creative and scientific entries. On the same page you are apt to find the Moon described both as a "watermelon in the sky" and a "waxing gibbous." Meteorological conditions will often be layered below prose, as evidenced in this student verse.

The full Moon glows with its soothing light.
Not a single star glimmers on this cold Thursday night.
As I breathe, a cloud forms in front of my face,
And I hear the wind blow, at a quick, steady pace.

Students create the correct geometric configurations for various Moon phases using styrofoam balls (representing the Earth and the Moon), and an overhead projector (representing the Sun).

Phase two

In English class, students read multicultural, mythological tales surrounding the Moon and natural phenomena. Stu-

Jennifer Wilhelm (jennifer.wilhelm@ttu.edu) *is an assistant professor of mathematics and science education,* **Sally McMillan** (sally.tyler@ttu.edu) *is an assistant professor of language arts, and* **Kendra Walters** (kendra.l.walters@ttu.edu) *is a doctoral student in mathematics and science education in the College of Education, all at Texas Tech University in Lubbock Texas.* ***Emma Lovering*** (ehintze@lubbockisd.org) *is a seventh-grade science teacher at Ed Irons Junior High School in Lubbock, Texas.*

FIGURE 2 **Examples of artwork used in *The Moon Phases Poetry and Legends Scrapbook* and poems inspired by observations**

Blue Moon

Seems like on some nights when you are scared of the world and alone
You cover up with a blue blanket
to block out the crime and evil events
Just like a little girl does when she hears thunder
Some nights I feel like climbing stairs up to you and doing the same.

The Moon and I

Between you and me Moon
I like you the best
As your light enhances the evenings
I enjoy a peaceful rest.
Without your bold appearance
The night sky would be so dark
Of all the other twinklings
You seem to make the mark.
So please keep shining upon me Moon
As I go through the night
And I will gaze forever
Upon your wondrous light.

FIGURE 3

Student's geometric configuration needed for a waxing cresent Moon to be seen from Earth (configuration shown is looking down on the Moon-Earth-Sun system above the Earth's North Pole).

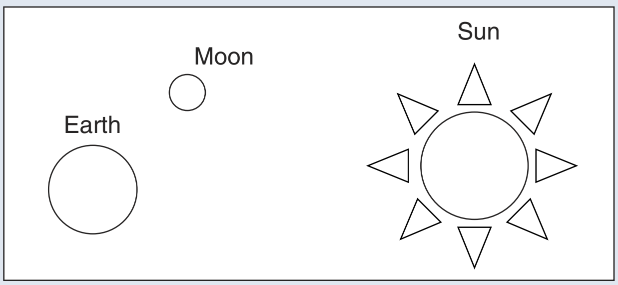
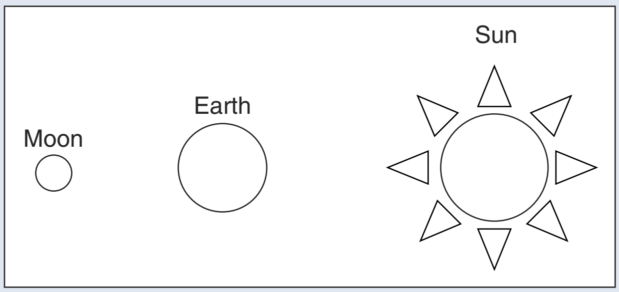


FIGURE 4

Student's geometric configuration needed for a shadow of the Earth to be cast upon the Moon (configuration shown is looking down on the Moon-Earth-Sun system above the Earth's North Pole).



dents also take turns each day reading a tale to their class from *Thirteen Moons on Turtles Back: A Native American Year of Moons* (Bruchac and London 1997). In addition, students compile lists of nature-oriented figurative language. These lists contain entries from their Moon journals, such as "the peaceful Moon calms the inner soul," and a portrayal of the Moon as a "lantern in the sky." This language broadens students' descriptive powers, and is put to practical use in their next assignment, The Moon Phases Poetry and Legends Scrapbook.

Over a period of approximately two weeks, students create their scrapbooks (using materials such as construction paper, yarn, markers, and glitter). Within the scrapbooks, students assemble their own images and depictions of the Moon. They can be original illustrations and prose; and/or imagery and descriptions taken from magazines, websites, and books. The language arts teacher provides additional instruction on painting, drawing, and collage techniques to help students express and organize their collections. Prior to these art lessons, we present students with an assortment of art prints of lunar images for the purpose of inspiration and to show the many different ways that people have visualized the Moon. A sample scrapbook cover and examples of student's prose are shown in Figure 2.

Phase three

After completing the five weeks of lunar observations, students model the phases of the Moon using styrofoam balls to represent the Earth and Moon, and an overhead projector to represent the Sun. Students refer to their journal observations to help them correctly position the Moon, Sun, and Earth to create, for example, a waxing crescent Moon phase. The geometric configuration that students finally construct (Figure 3) demonstrates that the Earth's shadow plays no role in creating the observable crescent shape. The shadow misconception is a commonly held belief of middle school students.

As an extension, students try to determine the geometric configuration needed for the Earth to cast a shadow on the Moon (which would be a lunar eclipse), and they correctly arrive at the configuration shown in Figure 4. Through the styrofoam modeling of the Moon's phases, students also come to realize that this particular geometrical configuration can also result in the full Moon phase. They come to understand that the Moon appears full since most of the time it is either above or below the Earth/Sun plane.

Final phase

At the conclusion of the Moon unit, students complete a post LPCI. The LPCIs have indicated significant gains from pre- to post-unit every year the unit was implemented. The students showcased in this piece also displayed a significant increase in lunar understanding. The t-test for paired data at the α = .05 level showed a significant difference in the means, $t(104) = -7.18$, $p = 1.082 \times 10^{-10}$.

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The real shape of the Moon's orbit

In the typical Moon phase lesson, students learn that the rotation period for the Moon is approximately the same as its revolution period around the Earth. This is a situation known as synchronous rotation—where the rotation period is the same as the orbital period. A conclusion drawn from this similarity is that the Moon always has the same side toward the Earth. While that may be correct, it does give rise to the perception that the Moon revolves around the Earth, when in reality the Earth and Moon together revolve around the Sun. It is only from our position on the Earth's surface that it appears as if the Moon orbits around the Earth as the Earth orbits the Sun. From our perspective we can easily observe the Moon moving daily toward the east as it cycles through its phase changes, completing what appears to be a 360-degree circle. However, as your students complete the following activity, they will discover that the Moon's orbit is actually around the Sun, and not around the Earth.

As an introduction to this lesson and activity we review Moon phases. (See the September Scope on the Skies column.) Then, I have students draw a diagram of the Sun, Earth, and Moon such that it shows the Moon's orbital motion relative to the Earth for several months. The diagram does not have to be drawn to scale, as I want students to focus on what they think the Moon's orbital path looks like. Figure 1 is a copy of one student's diagram, and is typical of what many students will draw. Students show the Moon's orbit as a complete circle around the Earth and often will connect these circles with a curved line to the next circle/month. We usually have an interesting discussion about the diagram as students try to explain the curved line connecting each Moon loop.

In order to show the true path the Moon takes relative to the Earth, students can draw a diagram on a piece of paper of the Earth's orbital path and the Moon going through a couple of phase cycles. On the back of the paper, or on another sheet, have students draw a small circle in one corner to represent the Sun. Then draw a curved line the length of the paper from one corner to another to represent a part of the Earth's orbit. Draw a small circle near the bottom of the paper on this line to represent the Earth, and place a dot between the Earth and the Sun for the new Moon phase. Then draw another Earth about an inch further along the Earth's orbit line and place a dot on the Earth's orbit line below the Earth for first quarter phase. Draw another circle for the Earth another inch along the line and place a dot on the opposite side of the Earth for full Moon. Draw another circle for the Earth and place a dot on the Earth's orbit line ahead of the Earth for last quarter phase. Then to complete the lunar phase cycle, draw one more Earth circle another inch along the line and place a dot to show the Moon at new phase. Connect the phase dots as shown in Figure 2. This represents the Earth and Moon during one lunar cycle, or one month.

On a piece of paper, the shape of the Moon's orbit looks like a wavy line; however, by repeating the above steps several times, making the drawing much larger, or drawing to scale proportions, the orbit becomes noticeably smoother, a curved path nearly parallel with the Earth's orbit.

Conjunction function

As the planets and our Moon move about the Sun following their respective orbits, there will be times when some of the planets or the Moon will be in the same direction from the

Bob Riddle (bob-riddle@currentsky.com) *is a science educator living in Lee's Summit, Missouri. Visit his astronomy website at* www.currentsky.com.

Earth and will appear to be close to one another in the sky. These are known as *conjunctions* and they happen regularly throughout the year, especially with the relatively faster-moving Moon or inner planets catching up with the slower-moving planets.

This month, on the 10th, there will be a conjunction between Saturn and the Moon over the southwest horizon, and three planets, Mercury, Mars, and Jupiter, will arrange in a triple conjunction over the southeast horizon. On the 9th, Mercury will pass within 1 degree from Mars, and on the 10th, Mercury will be within 0.1 degree of Jupiter, with Mars close by. Together the three planets will be within a 1-degree field of view on that morning, as Figure 3 shows. Having nearby second magnitude stars (relatively bright stars) from the constellation Scorpius offers a convenient reference point from which to observe the different orbital speeds of the planets.

Visible planets

- Mercury will be at its best morning apparition this year as it will start the month above the eastern horizon at sunrise, and will remain visible for about the first three weeks of the month. It will be in close conjunction with Jupiter and Mars on the 10th.

FIGURE 1 **Part of a student drawing showing the Earth and Moon orbiting the Sun**

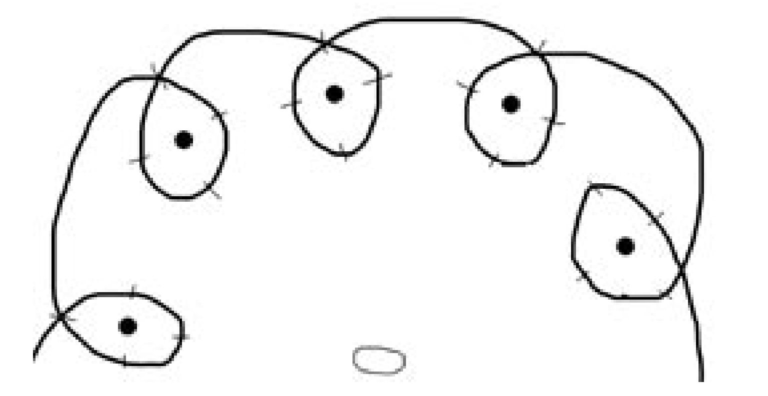

FIGURE 2 **Earth and Moon orbits for one month, as drawn by a student**

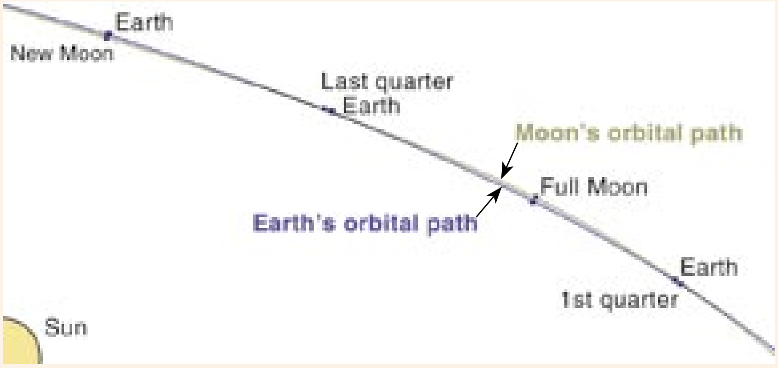

FIGURE 3 **Triple conjunction as seen through 7 x 50 binoculars**

Questions for students

1. With regard to the Earth-Moon system, what is the barycenter and where is it located?
(The barycenter is the center of mass, the balance point between the Earth and Moon, and is the point about which the two pivot as they orbit the Sun together. The barycenter is located approximately 1,700 km (1,056 miles) below the surface of the Earth.)

2. Look up Kepler's laws of planetary motion and answer the following question: At which point in an orbit—apogee or perigee—is the Moon moving the fastest? Which of Kepler's three laws explains this?
(According to Kepler's second law, the Moon will move faster near perigee and then more slowly at apogee.)

The December Long Nights Moon

Date	Moon event
12/1	Perigee Distance: 365,926 km Apparent size: 0.5443°
12/5	Full Moon Right ascension: 5^h 7'; Declination: 27°33'
12/12	Last quarter Right ascension: 11^h 4'; Declination: 6°6' Descending node Illuminated fraction: 0.52%
12/13	Apogee Distance: 404,410 km Apparent size: 0.4925°
12/20	New Moon Right ascension: 17^h 24'; Declination: –28°29'
12/26	Ascending node Illuminated fraction: 0.34%
12/27	First quarter Right ascension: 23^h 54'; Declination: –0°3' Perigee Distance: 370,347 km Apparent size: 0.5378°

- Venus will return to the evening skies, but will be low over the southwest horizon at sunset for the duration of this month.
- Mars will rise one to two hours before the Sun this month, and will slowly move higher over the eastern horizon with each passing day. Watch for Mars to be in conjunction with Mercury on the 9th, and Jupiter on the 12th.
- Jupiter will come back into view as a morning planet this month, and will be visible low over the eastern horizon at sunrise.
- Saturn will rise with the bright stars of Regulus several hours after sunset and will be visible high over the southern horizon at sunrise. Saturn will begin retrograde motion this month near the constellation Leo, and will form a distinctive small triangle with Regulus and Algieba.

Resources

SFA star charts—*observe.phy.sfasu.edu*

Daily Moon rise and set—*aa.usno.navy.mil/data/docs/RS_OneDay.html*

Monthly Sun and Moon rise and set—*www.sunrisesunset.com/custom_srss_calendar.asp*

Gravity simulator software—*www.orbitsimulator.com/gravity/articles/barycenter.html*