March measurements

by Bob Riddle

Sometimes I tell folks that I am a reading teacher—not to confuse them, but to reinforce the importance of reading and developing language skills, even in a science classroom. I drive my students crazy at times because I check their written work for grammar, punctuation, and spelling. While science is certainly language based, it is also bilingual in the sense that mathematics is also "spoken" in science classes. There are many opportunities throughout the school year to integrate the language of mathematics with science lessons and activities.

One such example is an activity that occurs during the spring and autumn on or about the day of the equinox. The activity can also be done any day during the year. This is a popular activity for students in either hemisphere to get involved with measuring the circumference of the Earth based on the method used by Eratosthenes many centuries ago. Eratosthenes was a librarian and mathematician who lived in North Africa, in what we now know as Libya. With information about the position of the Sun and the length of a shadow at two cities with different latitudes, Eratosthenes was able to determine the circumference of the Earth. In a similar manner, students often use one of the online projects to find a school lying either north or south of their location to partner with. Students could also use the equator as the other "school" location. Either way, the latitude angle difference and the distance between the two will be used to calculate the Earth's circumference.

For these projects, the equator is often used as the companion location because the angle of the Sun (its position above the horizon) is always known on the day of the equinox. On that day, the Sun is directly overhead, at the zenith, with an altitude angle of 90°. At any other latitude location on the Earth, the Sun would not be directly overhead, but at an altitude angle determined by the local latitude (see Noon Day Project website in Resources for more information).

In effect, when students conduct this activity they will actually be calculating the circumference of the Earth based on the distance around the Earth from pole to pole, the polar circumference, rather than the equatorial circumference. While there will always be a margin of error, students' calculations generally come out close to the given value for the polar circumference of the Earth. There is a small difference between polar and equatorial circumferences because the Earth is not a perfect sphere, but is somewhat flattened at the poles. The equatorial circumference is given as 24,901.55 miles (40,075.16 km), and the polar circumference is given as 24,859.82 miles (40,008 km). While a globe is shaped as a perfect sphere and the Earth is not, it is still helpful, as students think about a flattened sphere, to show them a globe to help them visualize the shape of the Earth. From their observations of the globe, students can see how much greater the circumference is at the equator compared with other locations north or south from the equator. If a ball is available (e.g., volleyball), it can be slightly squeezed from top to bottom to show what a flattened sphere looks like.

Using the above information plus the time of the Earth's rotation, 24 hours, students can take this activity a step further and calculate the speed at which the Earth is rotating at the equator and at their home latitude. To start, students use the equatorial circumference plus the formula for calculating speed (distance divided by time) to determine the rotation speed of the Earth at the equator. With a rotation time of about 24 hours and an approximate circumference of 25,000 (40,233 km) miles, the Earth is rotating at approximately 1,042 miles per hour (1,676 km/hr.) at the equator. We do not feel the speed of the Earth's rotation because the rate is constant; the Earth is neither speeding up nor slowing down, so there is no sense of motion.

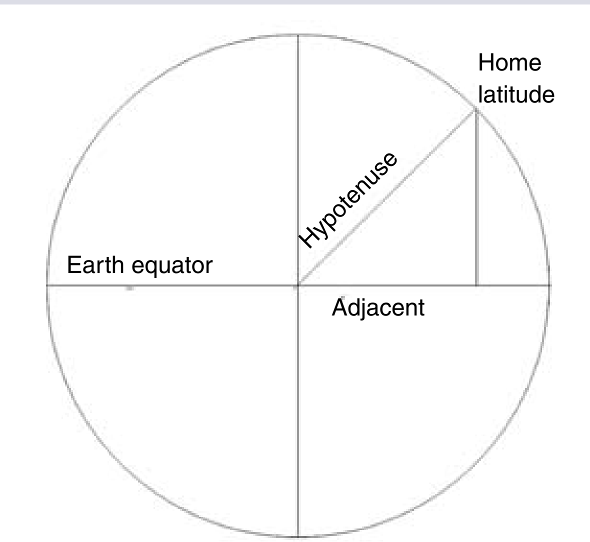
Students may wonder how fast the Earth is moving at their latitude. Could it be the same as at the equator? The simple answer is no, because the circumference of the Earth at other latitudes is not the same distance as at the equator. Students should notice that as latitude increases the circumference decreases. In mathematical language, the circumference will decrease in direct proportion to the cosine of the latitude. The cosine is one of several math functions dealing with angles and is used in this case to generate a value needed for the calculations students will do. Measuring the circumference of the Earth is based on the use of a right triangle, and the cosine value is the ratio of two of the angles, the adjacent over the hypotenuse (see Figure 1).

So how do you determine the circumference at your latitude or any other latitude? We know that the formula for circumference is pi times the diameter ($C = \pi d$), so the equatorial circumference of the Earth using that formula and the following values is 3.14 × 7,926.41 miles (12,756.32 km) = 24,889 miles (40,055 km). The Earth's diameter is a given value, but could be determined by dividing the circumference by pi.

To determine the circumference at other latitudes, the formula is modified to include the cosine of the latitude as follows: Circumference at my latitude (CL) equals Earth equatorial circumference (C) times the cosine of my latitude (L). That is, $CL = C \times \cos(L)$. An easy way to determine the value for your latitude or any other latitude is to type the word "cosine" followed by the latitude number into the search box on your web browser. After substituting numbers and using our latitude of 40º, my students used the following to determine how fast we are rotating in Kansas City, Missouri.

Circumference at our latitude =
24,889 miles (40,055 km) × 0.767 (cosine of 40º) =
19,089 miles (30,722 km)

FIGURE 1 The cosine angle



To determine the rotation speed at Kansas City, we divided the circumference at Kansas City (19,089 miles) (30,722 km) by 24 hours (19,089/24 hours) (30,722 km/24 hours). We determined that we are moving more slowly at our latitude than at the equator, with an approximate speed of 795.36 miles per hour (1,280 km per hour).

Students summarize the calculations from their home latitude and other latitudes and what they have learned from the math used in the activity. For example, students may notice that the circumference divided by its diameter is the value of pi, 3.14. When given the diameter or radius (half the diameter), students are able to determine the circumference. Or, when given the circumference of a circle, students are able to determine its diameter or radius. ■

March

1	Moon near Saturn
2	*Cassini* flyby of Saturn's moon Rhea
3	Moon near Spica
	Cassini flyby of Saturn's moon Helene
7	Last quarter
11	Mars ends retrograde motion
12	Moon at apogee: 406,011 km
14	Spring forward—begin Daylight Saving Time
	Mercury at superior conjunction
15	New Moon
17	Uranus in conjunction with the Sun
	Asteroid Vesta at opposition
20	Spring equinox (1:33 pm EST)
22	Saturn at opposition
23	First quarter Moon
25	Moon near Mars
28	Moon at perigee: 361,877 km
29	Moon near Saturn
30	Full Moon
	Mars at aphelion

Visible planets

Mercury will move from superior conjunction, behind the Sun, into the evening skies toward the end of the month.

Venus will start to become visible over the western horizon at sunset.

Mars will be high over the southwest horizon near the Gemini Twins at sunset.

Jupiter will rise just ahead of the Sun this month and will be too close to the Sun to be visible.

Saturn will rise at sunset and will be visible all night, setting at around sunrise.

Resources

Cassini Mission— *http://saturn.jpl.nasa.gov*
Daylight Saving Time— *http://geography.about.com/cs/daylightsavings/a/dst.htm*
Eratosthenes biography—*www-history.mcs.st-andrews.ac.uk/Biographies/Eratosthenes.html*
Noon Day project—*www.ciese.org/curriculum/noonday*
Riddle, B. 2006. Location, location, location. *Science Scope* 30 (5): 60–62.
Space Weather Media Viewer— *http://sunearth.gsfc.nasa.gov/spaceweather*
Sun-Earth Day 2010—*http://sunearthday.nasa.gov/2010*
Sun Shadow Investigation Project— *http://sunship.currentsky.com*

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Questions for students

1. Why are the calculations for the Earth's circumference and diameter not the same as values shown in textbooks or online resources? (*The calculations students make are based on the Earth as a perfect sphere, while the given or standard values for the Earth are not.*)
2. Explain why the speed is slower at Kansas City than at the equator. (*The Earth is a solid, so the rotation rate of 24 hours is constant—the same everywhere on the Earth's surface. The circumference decreases the father one gets from the equator, but the time period stays the same at 24 hours. We are traveling at the same rate, 24 hours, but traveling a shorter distance at that same rate.*)
3. Using the information in this article, plus the following values, calculate how fast we are traveling around the Sun, as well as around the center of the Milky Way galaxy. (*Earth's orbital radius is approximately 93,000,000 miles; the diameter of the Milky Way galaxy is approximately 100,000 light years, and we are about 25,000 light years from the center*).