Measuring the Earth's Tilt

Elementary Grades

Lesson Summary

A shadow stick is used to measure shadows at midday on the equinoxes or solstices enabling students to measure and calculate the Earth's tilt.

Prior Knowledge & Skills

Ability to:

- Measure length
- Measure angle
- Make and record observations

AAAS Science Benchmarks

The Nature of Science
The Scientific World view
Scientific Inquiry ★
The Nature of Mathematics★
Patterns and Relationships
Mathematical Inquiry
The Nature of Technology★
Technology and Science
The Physical Setting★
The Universe
The Earth
Motion

NSES Science Standards

Science as Inquiry
Abilities to do Scientific Inquiry ★
Understanding about Scientific Inquiry
Physical Science★
Position and Motion of Objects
Light, Heat, Electricity, and Magnetism
Earth and Space Science★
Objects in the Sky
Changes in the Earth and Sky
Science and Technology★
Understanding about Science and Technology

NCTM Mathematics Standards

See Appendix

Teaching Time: Long-term project

Materials

- Wooden dowel or pole, at least 50 cm long (one for entire class)
- Meter stick
- Large sheet of paper
- Colored markers
- Protractor

Advanced Planning

Preparation Time: *15 minutes*

1. *Review instructions*
2. *Gather necessary supplies*
3. *Choose location for shadow stick*

Editor's Recommendation

Fun in the Sun, Introduction to ch. 2, Harvard-Smithsonian Center for Astrophysics
http://hea-www.harvard.edu/scied/SUN/SunActivities.html#seasons
Eyes on the Sky Feet on the Ground, ch. 2, Harvard-Smithsonian Center for Astrophysics
http://hea-www.harvard.edu/ECT/the_book/Chap2/Chapter2.html

The Sun and the Seasons

If you ask students what a particular season means to them, they'll probably mention the weather usually associated with it. Summer is hot. Winter is cold. Spring and Fall are in between. (For those of us living close enough to the poles, winter means snow, too!) A common misconception (even among a disturbingly large number of college graduates) is that the Earth is closer to the Sun during the summer, causing summer's warmer temperatures. This model, of course, is inconsistent with the fact that while the Northern Hemisphere has summer, the Southern Hemisphere has winter. Furthermore, while it is summer for the Northern Hemisphere, the Earth is actually slightly farther away from the Sun than during the Northern Hemisphere winter.

During the Northern Hemisphere's summer, the North Pole is tilted towards the Sun. During the winter, it is tilted away. This tilt causes the Sun to appear higher in the sky during the summer than during the winter. The higher Sun causes more hours of daylight and more intense, direct sunlight, or hotter conditions on the surface of the Earth. Questions to ask the class include: How is summer different from winter? What changes as winter gives way to spring? What changes are there as summer becomes fall? What about when winter approaches?

It is important to note that even without the tilt of the Earth, there would still be variations in temperature from one location to another, caused mainly by the curvature of the earth. Locations closer to the equator would still, on the average, be warmer than locations closer to the poles. Light and heat (radiation) from the Sun would still strike polar regions at more of an angle than nearer the Equator. This angle tends to "spread out" the same amount of energy over a larger area, thereby decreasing its intensity and the amount of heat it brings to the Earth. The activities addressing this topic demonstrate and test this assertion.

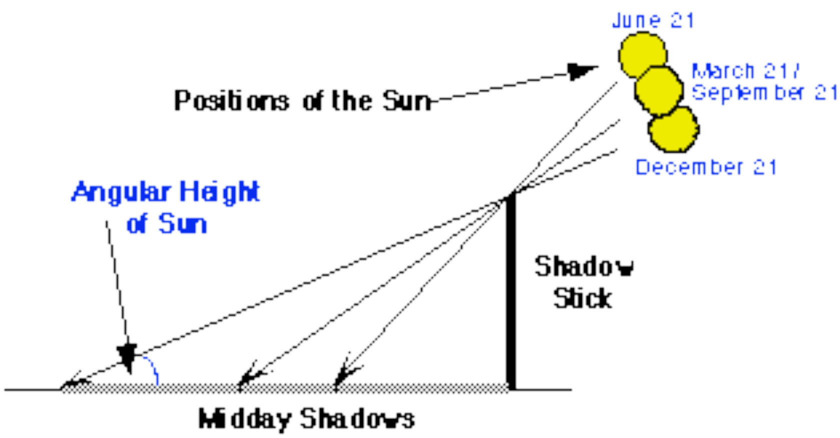
Measuring the Earth's Tilt

This activity is suitable for grades 3 through 6.

While the effects of the tilted Earth model are consistent with observation, might it not be possible to measure the Earth's tilt directly? Using observations with a simple shadow stick, we can measure the Sun's angular height in the sky over the course of weeks and months. It is the tilt of the Earth's axis which causes the height of the Sun's path to change. In this activity, we will measure this change to infer the amount of the Earth's tilt. This activity shows that as the height of the Sun changes, it casts different length shadows at midday. By recording these midday shadow lengths and the height of the shadow stick, we can "reconstruct" the situations from these days and measure the angular height directly. The difference of the angular heights of the Sun between an equinox (September 21 or March 21) and a solstice (December 21 or June 21) is equal to the tilt of the Earth's axis, 23.5^0.

Materials: Shadow stick from Chapter 1; observations of the midday shadow lengths; large sheet of paper; colored markers; protractor.

1. Obtain midday shadow lengths for convenient equinoxes or solstices (September 21, December 21, March 21, June 21) as described in the activity "Sun Shadows" of the previous chapter. Also make sure to keep a record of the height of the shadow stick.



2. On a large sheet of paper, draw a line the same length as the shadow stick. To reconstruct the angle of the Sun's height for each equinox and solstice in your data, start at the bottom of the shadow stick and draw a line perpendicular to the shadow stick the same length as the midday shadow for each solstice and equinox in your data. Try using different color markers for each day. Your drawing should resemble the figure above.

3. Have the class measure the angular height of the Sun on the paper with a protractor for each equinox and solstice. The difference of the angular height between subsequent equinoxes and solstices should be about 23.°5. The difference in angular height between the two equinoxes or the two solstices should be twice that, or 47°.

Analysis Option

Mathematically, since the shadow stick and its shadows form right triangles, the shadow stick height and the shadow lengths are all that is needed to compute the Sun's angular height; it is simply the arctangent of the ratio between the shadow stick height and the shadow length. While such trigonometric functions are certainly beyond the scope of the elementary school classroom, this fact can be used to verify the students' results.

Discussion

- When are the midday shadows the longest? Why?
- When are they the shortest? Why?
- What causes the shadow lengths to change?
- Can you relate your measurements to our model of the seasons?