Astronomy with a Stick

Introduction

This unit details observations to be made on a sunny area of the school playground. The outdoor investigations stimulate questions about shadows and moving bodies and motivate the search for causes.

Objective

To make indirect observations of the Earth's rotation

Materials

- A portable perpendicular gnomon (This can be constructed with or without the class present. See item 1 of the procedure.)
- Sidewalk chalk
- Whistle
- Seasonally/topically appropriate word finds, crossword puzzles and other paper and pencil activities
- A meter stick
- A string compass made from a piece of string 50 cm long with an anchor at one end and a piece of chalk at the other
- A wooden chalkboard compass (if unavailable, angles can be bisected with the string compass)
- A protractor
- Student created journal
- Graph paper

Activity 1 - Tracking a Moving Shadow

Learning Outcomes

- Accurately record the movement of a shadow over a period of time.
- Accurately record the changing length and position of a shadow over a given period of time.
- Describe the movement of the Earth as it relates to the sun.
- Formulate a hypothesis for the movement and the changing length of the shadow.
- Accurately express the relationship between the sun and the Earth that causes the shadow of an object to move and change length.

Misconceptions

The following concepts may be difficult for students to grasp initially (misconceptions are italicized):

- *The sun moves across the sky.*
- *The earth rotates in a clockwise manner.*
- *The earth is closer to the sun during summer and farther away during winter.*
- The rotation of the earth on its axis every 24 hours produces the night and day cycle.
- The turning of the planet makes it seem as though the sun, moon, and star are orbiting around the earth once a day.
- The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.
- The motion of an object is always judged with respect to some other object or point and so the idea of absolute motion or rest is misleading.

Time Allotment

- 45 Minutes prior to observation day (informal observations, creating the gnomon).
- 60 minutes on a sunny day for the observation. This will need to occur over solar noon, 11:30AM–12:30PM. If under daylight savings time the observation should happen between 12:30PM and 1:30PM.
- 60 post observation for discussion, recording, and graphing.

Safety Precaution

Emphasize that you will be making an indirect observation of the Sun. Caution the students that they must never look directly at the Sun's disk because even brief viewing can damage the retinas of their eyes.

Procedure

Prior to the day of the observation:

- Prepare a perpendicular gnomon. This can be constructed by inserting a 60-cm (24-in.) dowel, as near to vertical as possible, into a #10 can filled with wet plaster of Paris that has thickened. A good use of materials is to use the bucket that the plaster of Paris came in. Allow the plaster to harden before using. To make sure the gnomon is vertical a plum bob or bullet level work well. Be sure to make the gnomon at least a day ahead.
- Point out to the class that a perpendicular gnomon differs from a sundial because the gnomon of a sundial is set parallel to the Earth's axis of rotation. If an unattached sundial is available, bring it in for the class to examine.
- NOTE: This is a good opportunity to work in some physical science as well. When plaster of Paris hardens a chemical reaction is taking place. This reaction is an exothermic reaction; heat is released as the plaster dries.
- Tell the students that you will be observing how the relationship between the Sun and the Earth changes by marking shadows. Make a journal for recording these and later observations.
- Brainstorm possible variables that could affect the shadow thrown by the gnomon. These should include: moving the gnomon, clouds, wind, who and how the length and position of the shadow

is marked, etc. With this list in mind, the students will decide how to control the independent variables listed.

- Writing Connection: Brainstorm a list of possible locations for your gnomon. Task the students to write a short persuasive essay with the goal of convincing you (the teacher) of the best location for the gnomon. A desirable location for the gnomon is paved, in a sunny location, level, away from busy areas of the school grounds, with adequate space for a class to spread out.

Day of the observation:

- Assemble the class outside at the observation site at least 20 minutes before your first scheduled observation. The students will set up the gnomon being mindful of controlling the independent variables from the brainstorming list. Once the gnomon is set up the observations can begin.
- At five-minute intervals mark the length and direction of the shadow on the pavement. Use the whistle to bring the students attention back to the observations.

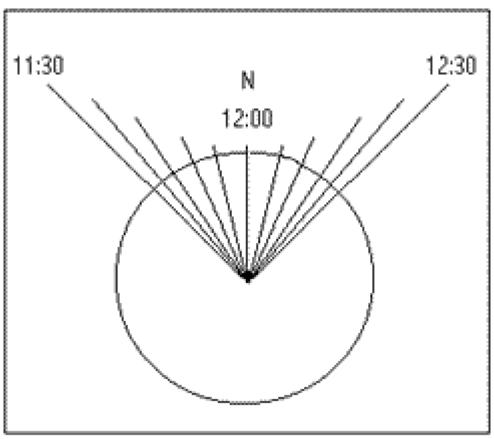

Figure 1. Marking the shadows for direction and length.

- Mark the end point of the shadow of the gnomon with a dot of one color and the direction with a line of a separate color.
- Continue marking the intersection and the end of the shadow over a period at least 60 minutes. Students can take turns marking the shadow once they understand what is involved. Continue the observation until at least 12:30PM local standard time (see figure 1).
- Using their journals, students will record their observations including environmental observations such as the weather.
- Discuss with them whether it is the Sun or the Earth that is moving in the observations you are making, will the length or position of the shadow tell us anything, will the shadow continue to get longer, etc.
- At the conclusion of the observation time period use the string compass to draw a circle that intersects all of the shadow lines. This circle can be used for creating a compass rose on your playground as detailed later in this unit.

In the topmost tier of states in the US, if the students can stand the cold, this is very interesting to do in December. Because of the tilt of the Earth at this time of year there will be a great deal of movement in the shadow length and position.

Discussion/Conclusions

Upon returning to the classroom discuss the students' observations and list them. Using the observations bring the class to consensus regarding the following conclusions:

- The Sun's clockwise motion is an apparent motion caused by the rotation of the Earth.
- The counterclockwise rotation of the Earth in the Sun's light causes the shadow of the gnomon to move clockwise.
- As the Sun appears to move higher above the horizon before solar noon, the shadow grows shorter and shorter. After solar noon, the shadow grows longer and longer. The Sun is at its highest altitude above the horizon when the shadow is shortest. You can tell the students that at this instant, the Sun is on the meridian and is due south of the observer. NOTE: Depending on your location and the time of year, the length of the gnomon's shadow will vary. Therefore, your students may have to experiment to find a workable gnomon height and circle circumference in order to find the true North at Solar Noon.

Outcome/Assessment

- Create a line graph showing the relationship between time and the length of a shadow over solar noon.
- Write a persuasive essay (scored using district writing rubric/standards) regarding where to place the gnomon.
- Successfully predict what a shadow will look like in a variety of situations.

Web-based and Computer Resources

- Science NetLinks: Measuring Shadows
- MS Excel or other graphing application
- Word processor

Activity 2

Objective

To construct a permanent compass rose and use it to find directions

Time Allotment

About 60 minutes, including the time between 11:30 A.M. and 12:30 P.M. standard time (add 1 hour for daylight savings time).

Procedure

1. Move the class outdoors to a sunny spot. If possible construct this compass rose on a hard surface where it can be marked in place permanently. As in the previous exercise, lay out a 60-cm circle and place the gnomon in the exact center. Every 5 minutes between 11:30 A.M. and 12:30 P.M. standard time mark the points at which the moving shadow of the gnomon intersects the circle and mark the end of the shadow.

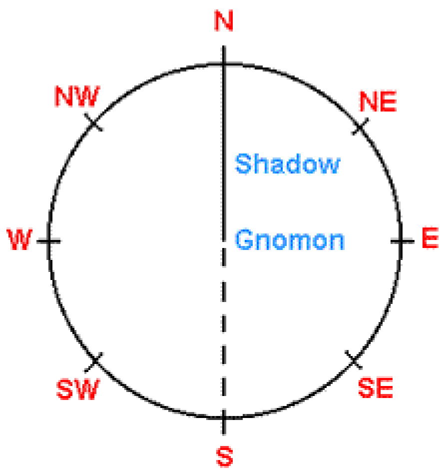

Figure 2. Creating a compass rose.

2. Label the point at which the shortest shadow intersects the circle "N" for north. This point may not be reached at exactly 12:00 noon standard time. For one thing, solar time is exactly standard time at only one meridian in each time zone, and other factors cause solar time to deviate from clock time.
3. Remove the gnomon from the circle. With a meterstick, draw a straight line connecting the "N" point, the center point of the circle, and the point opposite the "N" point on the circle. Label this opposite point "S" for south.
4. If available, use a wooden compass with chalk (the kind used to draw geometric constructions on the chalkboard) to bisect the right-hand arc between N and S to locate east. Label the point "E." Bisect the opposite arc to locate west and label that "W." Continue bisecting arcs until at least eight points of the compass have been marked (see figure 2).

Discussion

Back in the classroom, discuss the fact that the students have found the compass points on their playground by using the Sun's shadow. Be sure that they understand that when they stand facing north as they have marked it, they are actually looking north. How do they know this? When the Sun's shadow is shortest it is solar noon, the Sun is directly south, and its shadow will point north. Have the students record in their journals information about this activity.

Refer the students to maps to study compass rose designs. Why is the compass rose on a map important? (It tells us which way is north on that map.) If they want to, students can decorate their permanent compass rose to match one of the examples they find.

Activity 3

Objective

To mark degrees on the compass rose and use it to measure and record the azimuth of the Sun over a period of time. Azimuth is the direction along the horizon measured in degrees clockwise from north. In our activities, we measure the Sun's azimuth by extending the shadow line through the center of the rose and out to the marked circle on the opposite side.

Time Allotment

At least 30 minutes will be needed to mark the degrees. Then short observations are made at scheduled intervals.

Procedure

1. To convert the compass rose constructed in activity 2 into a device to measure azimuth, move the class outside and mark the rose at 10° intervals. To do this, label the north point of the compass rose "0°". Using a protractor placed at the center of the rose and a meterstick to extend the measurements to the circle, move clockwise around the compass from north and mark the rose with tick marks at intervals of 10° around the whole 360° circle (see figure 3). Figure 4. Marking the the azimuth of the sun.
2. To find the azimuth of the Sun, mark the point on the circle where the shadow of the gnomon intersects it, remove the gnomon, and use a meterstick to draw a line connecting the point at which the shadow of the gnomon intersects the circle, the center of the circle, and the opposite point on the circle (see figure 4). This opposite point, recorded in degrees, is the azimuth reading for that time of day on that date of the year. Naturally this azimuth is only approximate because we are using rough instruments and a not-very-exact technique, but if we use the same procedure for all measurements, the changes in azimuth will be apparent.
3. Determine the azimuth of the Sun on the compass rose at set hours (perhaps every hour) during one school day, and have the students record it on a table in their notebooks.
4. Follow up these initial observations of azimuth by determining the azimuth of the Sun at a selected hour on a selected day every month (as nearly as weather conditions permit). It would be good to determine this on the day closest to the 22nd of each month in order to include the measurements at the time of the equinox.

Discussion

We are able to measure the azimuth, or horizontal position, of the Sun at different times during the day and at the same time on different days. Although the azimuth is always 180° from north at solar noon, it changes gradually throughout the year during the morning and afternoon hours. The azimuth readings for sunrise change from south of east in winter to north of east in summer; sunset readings for the same periods are south of west and north of west. Ask students who have a view that faces east at home to notice where the Sun comes up on a certain day of the month in relation to objects on the horizon that they can see. This is an informal way of observing the changing azimuths of sunrise. With a view facing west, the same observations can be made of the sunset.

As the students observe and record the changes in the Sun's azimuth during the same day, they are indirectly observing the rotation of the Earth. Changes in the Sun's azimuth at the same time on different days during the year are a part of the changes due to the revolution of the Earth around the Sun. Now that the students understand the concept of changing azimuth, they can progress to measuring the altitude of the Sun as it too changes with the seasons.

Activity 4

Objective

To show that the Sun reaches its highest altitude a solar noon and then to measure the altitude of the Sun at solar noon over a period of time and record it. The altitude of the Sun is the vertical coordinate of its position. It measures the number of degrees the Sun is above the horizon. In our activities, we will measure the length of the gnomon and the length of the shadow and compute the altitude from that. Measured from latitudes greater than 23 1/2° north or south of the equator, the angle is always less than 90°.

Time Allotment

For one day, the altitude and the azimuth of the Sun can be measured at 10:00 AM, at solar noon, and at 2:00 PM. The class will need to be on the playground briefly for the 10:00 AM and 2:00 PM measurements, and at least 40 minutes for the solar noon measurement. Allow time to repeat these measurements over a series of days, being sure to include the periods of the winter solstice and the spring equinox.

Procedure

Find the altitude of the Sun at 10:00 AM, at solar noon, and at 2:00 PM by measuring the height of the gnomon and the length of the shadow at each time. Have the students record the measurements in their notebooks for later conversion. Also, record the azimuth at each time.

In the classroom, show the students how to lay out the measurements on a piece of construction paper, 12" x 18". A horizontal line, labeled SG, should measure the length of the shadow. A vertical line, perpendicular to SG and labeled GH (use the protractor to measure a right angle), should measure the height of the gnomon. Connect lines SG and GH. This line, the hypotenuse of the right triangle, represents the light rays of the Sun (see figure 5). Find the altitude of the Sun by measuring the angle HSG with a protractor.

This activity should be repeated close to the solstice and equinoxes and at approximately 1- or 2-week intervals. Make a table with the class that includes the azimuths of the Sun, the altitudes of the Sun, and the time and azimuths of sunrise and sunset for each date (the data about sunrise and sunset can be obtained from an almanac, from the newspaper, or from an ephemeris).

Discussion

1. The discussion of these observations of altitude and azimuth should include the following conclusions:
2. The azimuth of the Sun is 180° from north at solar noon each day. This is due south.
3. The altitude of the Sun is highest each day at solar noon.
4. The altitude of the Sun at solar noon changes from day to day. It is lowest in winter and highest in summer. This makes the winter shadows longer than shadows at the same time in summer.
5. The daylight hours vary in relation to the daily changes in altitude and azimuth.
6. The length of daylight hours where we live varies as the Earth revolves in its yearly orbit around the Sun.

Source: http://www.nsta.org/publications/interactive/aws-din/aws-u1.aspx