LIVING MAYA TIME
SUN, CORN, AND THE CALENDAR

Observing and Tracking Shadows

Summary of Activity

Students will learn about the apparent motion of the Sun in the sky and the rotation of the Earth on its axis. The students will be able to find the cardinal directions by observing and tracking shadows created by the Sun. Students will work in pairs to draw and track the shadow of a fellow classmate. This activity requires a sunny day and enough time to see changes in their shadow lengths and direction, typically one class period or preferably 2-3 hours during one school day.

As an extension group project, students can track shadows during equinoxes[1] and solstices, and throughout the school year. Using a vertical stick or flagpole, the students can track the shadows cast and see how the cast shadows change throughout the school year. The shadows change with the changing seasons. Students will observe and discuss the cause of the shadows' changes over time.

Living Maya Time Website Connections

This activity provides an example of how the ancient Maya observed the movements of the Sun and tracked shadows. These observations allowed Maya astronomers to predict seasonal change to plan their agricultural and ceremonial cycles. Today, Maya farmers still observe the movements of the Sun to plan the planting of corn and their ceremonies.

Students should watch the following resources from the *Living Maya Time* website ahead of time:

- The entire *Maya Sun* section
- *Corn and Calendar Traditions* in the *Corn and Maya Time* section

Objectives

Students will learn that:

- Most objects in the Solar System, including the Earth, are in regular and predictable motion; these motions explain such phenomena as the day and the year
- The position of the Sun in the sky changes throughout the day
- The Sun has patterns of movement that can be observed and recorded; one way is by observing and recording shadows cast by the Sun
- The Sun's apparent movement reflects the Earth's daily spin on its axis

[1] Definitions for the words in red-colored font can be found in the Glossary page in the Resources section of the *Living Maya Time* website.

Smithsonian
National Museum of the American Indian
AmericanIndian.si.edu/maya

- Earth's nearly circular yearly orbit around the Sun causes us to see different shadows at different times of year:
  - Outdoor shadows are longest during the morning and evening and shortest during the middle of the day
  - Changes in the length and direction of an object's shadow indicate the changing position of the Sun during the day

Students will be able to:

- Observe, measure, and mark the position of their shadows including length, direction, and motion of their shadows as time progresses:
  - Observe that the length of their shadows is shortest at about noon, and infer that this is because the Sun is highest in the sky (but not directly overhead) at about that time
  - Explain how shadows could be used to tell the time of day
  - Develop an understanding of the Earth's rotational motion and identify the cause of the Sun's apparent motion in the sky
  - Identify the cardinal directions by tracking shadows during a few hours bracketing mid-day
  - Make connections between tracking shadows, the time of day, and the time of year
  - Understand the connections between shadow patterns, seasonal cycles, and the passage of time
  - Identify connections between the movements of the Sun, cyclical time, and calendars

Grade Level

Grades 5-8 (Group Project best suited for grades 7 and 8)

National Science Education Standards Addressed

- Observing, Measuring, and Identifying Properties
- Seeking Evidence
- Recognizing Patterns and Cycles
- Identifying Cause and Effect and Extending the Senses
- Designing and Conducting Controlled Experiments

<u>Physical Science</u>

  - Position and motion of objects

<u>Earth and Space Science</u>

  - Objects in the sky
  - Changes in Earth and sky

Duration of Activity

- 50 minutes (1 period option)
- 1 day (extension option)
- Throughout the year (group project option)

Student Prerequisites

Students should:

- have the ability to notice patterns of change
- have a basic knowledge of cardinal directions
- explore the Living Maya Time website in advance of doing the activity

Materials

- Chalk

Teacher Preparation

- Locate a sunny playground or other similar surface for students to draw shadow outlines with chalk
- Read **Teacher's Notes** section below
- Explore the *Living Maya Time* website in advance

Procedure

<u>In the classroom</u>

Safety Note: Please impress on the students that it is dangerous to look directly at the Sun with or without a visual aid, such as a lens, binocular, sun glasses, or the unaided eye. We NEVER look directly at the Sun! It can cause irreparable damage to the eye.

1. Begin the discussion of shadows by asking students what they know about them. For example, students may share that…
    - Light from the Sun or other sources creates shadows
    - Objects do not cast shadows when it is cloudy
    - If the Sun is shining behind us, we will see our shadows in front of us
    - The length of shadows varies throughout the day, and shadows are shortest closest to midday
    - Shadows can be used to tell time and find the cardinal directions (most students may not be familiar with this)
2. Alternatively, students may work in small groups and discuss what they know and what questions they have about shadows and cardinal directions, and then share their thoughts with the entire class.
3. Ask the students to pair up and explain that the class will work outside for one period (and optionally repeat the activity several times during a 2-3 hour block) and will draw an outline of a friend's shadow using chalk.
4. Ask for a student volunteer to help you demonstrate how to trace a shadow.
5. Tell the students that the goal is to draw their partner's shadow and discuss the location of the shadow, length, motion, etc. as a function of time.
6. Remind students NEVER to look directly at the Sun.

Outdoors

1. Ask students to work in pairs and to spread out over the yard where they can draw their shadow outlines.
2. Ask students to position themselves to make shadows.
3. Direct students to begin tracing by outlining their partner's shoes or feet; this is especially important to be able to return to the same spot to draw the outline at a later time.
4. Have the pair of students mark each shadow with the students' names and note the time of tracing.
5. Ask students to notice shadows of other objects in the yard, and to discuss similarities, or patterns that they see; for example, that all shadows point in the same direction, opposite where the Sun is; or that shadows are longer when the Sun is low in the sky near the horizon, etc.
6. Ask students to predict whether and how their second and subsequent tracings of their shadows might change over time.
7. After 10 minutes have gone by, have the pairs return to their outline spots, stand on the outlined "shoes" and draw another shadow outline and note the time again.
8. Repeat this 3 or 4 times over the available time (1 period or 2-3 hour block).

Discussion

1. The following questions can guide a discussion of what students observed:
   - Did anything change in your tracings? What looks different?
   - How did your shadow move? What do you think made the shadows move? How can you explain that?
   - Did the Sun move? Did we, or the Earth, move? (Explain to students that shadows move as a result of the Earth's rotational motion.)
   - How will shadows move during a whole day? What can be predicted? Why will the shadows change and how?
2. If activity was done over a 2-3 hour period, ask these additional questions to continue the discussion:
   - When was the shadow shortest? Where was the Sun?
   - How did the Sun move over the span of several hours?
   - On what cardinal direction does the Sun rise? Set?
   - If the Sun moves east to west, how is the Earth spinning?
   - How can we use the shadows we traced to find the north-south direction? East-west?

Assessment

Ask students to write about their observations, predictions, and outcomes. Have students draw what they observed outdoors in a worksheet.

Teacher's Notes

Why did the shadows change? Astronomers talk about the apparent motion of the Sun across the sky. Why is the word "apparent" used, when the Sun indeed seems to be moving? From an Earth-based or geocentric perspective, the Sun is observed to be moving across the sky while we on Earth feel that we are stationary. From a space-based or heliocentric perspective, if we could go up in space on a space ship and see the solar system from high above, we would see that the Earth and the other planets move around, or revolve, about the Sun in a counterclockwise direction. We would also notice the planets themselves, including Earth, rotate on their own axes. This rotation creates day and night. During the day, the light of the Sun creates shadows on objects on the surface of the Earth. Thus, the changing shadows are caused by the fact that the Earth is rotating, or spinning, on its axis from west to east on a daily basis, making the Sun appear to move across the sky in the opposite direction, from east to west.

The shadows are always opposite the direction we observe the Sun. Shadows are longer at sunrise and sunset, and get shorter as mid-day approaches, getting shortest at solar noon. The shortest shadow may not be seen exactly at 12 o'clock noon according to our clocks, due to conventions shared by geographical regions with the same time zones, and daylight savings time. Solar noon is defined as the time when the Sun is highest in the sky and crosses the local meridian, thus making the shortest shadow. The meridian is an imaginary line connecting the north and south poles on Earth and passing directly overhead. Local noon is the moment when shadows will be shortest and, at that moment, the shadow of a vertical stick will be pointing in the north-south direction.

By finding the shortest shadow of their tracings, students will be able to find the north-south direction, which is the direction traced by a line running down the middle of the student's shortest shadow outline, from the middle of the head to the middle of the feet. They can then find east-west one of two ways. One way is to draw a line at a 90-degree angle from the north-south direction. The east-west direction can also be found by drawing a line joining the top points of any two shadows that have the same length (these will bracket, or be located at either side of, the shortest shadow).

Extension Group Project

Summary

This group project can engage students to observe the Sun throughout the changing seasons using a vertical stick, which astronomers call a gnomon. Students will notice and draw how the shadow of the gnomon changes with time during the span of a day, four times a year (during equinoxes and solstices). This method of observation and tracking will mimic observational techniques that ancient Maya and other Mesoamerican cultures used. Zenith tubes and vertical stelae were used at several ancient Mesoamerican sites, including Monte Albán in Oaxaca, Xochicalco, and Yaxchilán to measure the zenith passage of the Sun at the tropical latitudes of the Maya world. Students will also learn that the highest position of the Sun in the sky at latitudes outside of the tropics never reaches the zenith.

Living Maya Time Website Connections

This activity provides an example of how ancient Maya astronomers would have observed shadow patterns and the movements of the Sun throughout the year to mark key times of the year such as zenith passage, equinoxes, and solstices. Observations of the zenith passage allowed the Maya to accurately measure the length of the solar year.

Students should watch the following resources from the ***Living Maya Time*** website ahead of time:

- The entire *Maya Sun* section
- *The Sun Above, the Sun Below* video in the *Corn and Maya Time* section.

Materials

- Markers, string, stakes
- Broomstick and tools to dig a hole in the ground, and pound the stick in
- Plumb line (string with weight tied to it)
- Camera (photo or video)

Teacher Preparation

- Select a permanent location for planting the broomstick, or make arrangements to use the area around the flagpole to mark or draw shadows. Read **Teacher's Notes** section below.
- Begin the project on the September equinox; September 21 or 22 (Google the date of equinox for a given year).

Procedure

In the classroom

Safety Note: Please impress on the students that it is dangerous to look directly at the Sun with or without a visual aid, such as a lens, binoculars, sun glasses, or the unaided eye. We NEVER look directly at the Sun! It can cause irreparable damage to the eye.

1. Ask students to work in small groups to discuss anything they know about how shadows change throughout the year.
2. Facilitate a conversation about solstices and equinoxes, and what they are (definitions in Glossary in this website).
3. Ask students what they know about how the point of sunrise/sunset changes on the horizon throughout the year.
4. Ask students to make predictions about how a shadow of a vertical stick might look in the beginning of summer, compared to the beginning of the winter, or at the beginning of spring, or fall. Have them draw their predictions and keep them in a group log, or individual log.
5. Ask students to come up with ideas how they may set up an experiment outdoors to record shadows of a vertical stick throughout a year. For example, where they would set it up, what constraints they need to consider to account for cloudy or rainy days, wind, etc.
6. Suggest the use of technology (a photo camera, a video camera, etc. as well as sticks, string, chalk and other markers).

Outdoors

1. Have students plant a vertical stick securely, flagpole, or find a post they might use for the experiment.
2. Using a plumb line (attach weight to string), check that the stick is vertical. (Plumb line should hang touching the broom stick flush from top to bottom).
3. Establish the cardinal directions by marking the shadow of the vertical (see main lesson instructions above). Ask students to mark the directions on the ground.
4. Students need to "tend" the experiment, and take photos or record drawings of what they observe, shadow position and length measured at several times during a given day, four times a year during the equinoxes and solstices, drawing or recording the shadow as well as date and time.
5. Have students note the position of the Sun in the sky at noon during different times of the year (higher

in summer, lower in winter).

6. Repeat this during the four seasonal starts of the year. Note the shadow patterns for winter, spring, summer and fall. Students who are not on year-round school/home schooled will not be able to trace during the summer solstice, but can make predictions or continue the experiment at home.

Discussion

1. Ask students to compare their predictions and recorded observations of how the vertical stick's shadow changed over time.
2. The following questions can guide a discussion of what students observed:
   - Did anything change from season to season? What looks different?
   - How can you find your direction if lost in the desert, or in a forest, or in a city?
   - How can you use shadow patterns to predict what season we are in?
   - How might the ancient Maya use observations of shadows to tell time of year? To develop their calendar, or plan their agricultural and ceremonial cycles?
   - What is the zenith passage of the Sun?
   - Why does the zenith passage only take place within tropical latitudes (23.5 degrees N to 23.5 degrees S)?

Teacher's Notes

Schematics of the gnomon shadows for the equinoxes, summer solstice, and winter solstice are shown in Figure 1 at the end of this lesson plan.

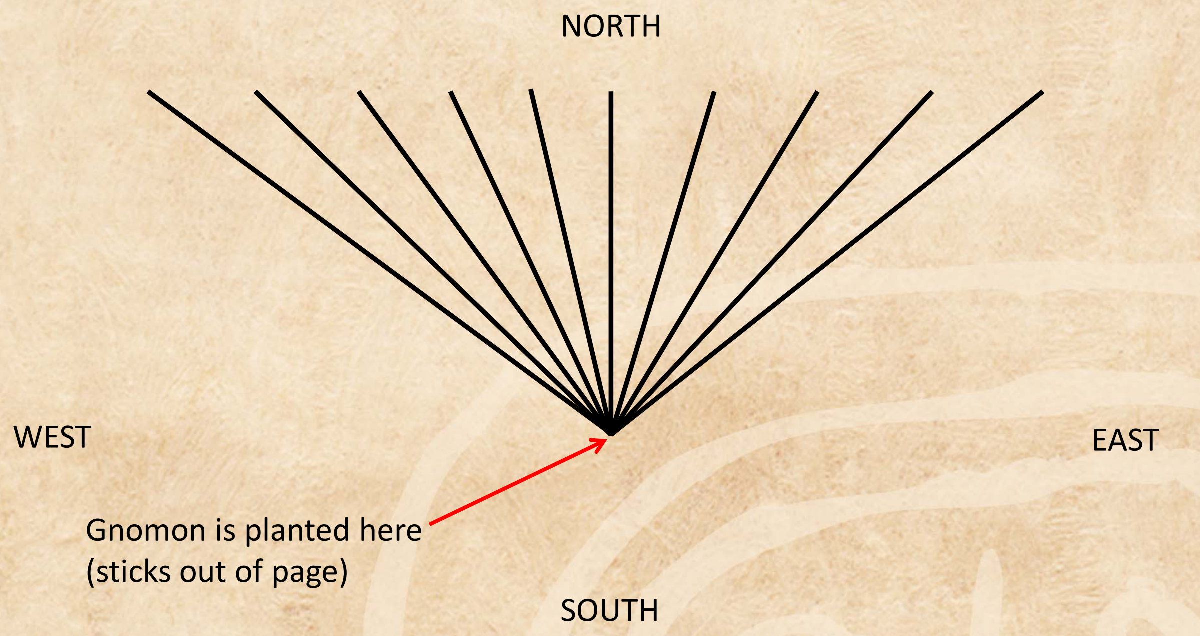
The Maya used their observations of the zenith passage of the Sun, when the Sun is directly overhead twice a year in the tropics, to accurately calculate the length of the tropical, or solar year defined as a complete cycle of the seasons (approx. 365.242 days). During the zenith, the shadow of vertical objects disappears. Zenith passage only occurs in the topics, within the latitudes of 23.5 degrees N to 23.5 degrees S.

The highest position of the Sun in the sky, when it crosses meridian, depends on the latitude. For example, in the northern hemisphere, at latitudes greater than 23.5 degrees N, the highest point of the Sun in the sky, when it crosses the meridian, is always south of the observer. In the southern hemisphere, at latitudes greater than 23.5 degrees S, the highest point of the Sun in the sky is always north of the observer. Within the tropics, between latitudes 23.5 degrees N and 23.5 degrees S, the Sun crosses the zenith or point directly overhead twice a year, the same number of days before and after the summer solstice in that hemisphere. The exact dates of the zenith passage for a given location depend on the latitude. At the Equator, zenith passage happens on the dates of the two equinoxes. At the latitudes of the Tropic of Cancer and the Tropic of Capricorn, the zenith passage happens once, at the summer solstice either June 21 in the northern hemisphere, or December 21 in the southern hemisphere. Zenith passage cannot be observed at latitudes north of the Tropic of Cancer or south of the Tropic of Capricorn.

Assessment

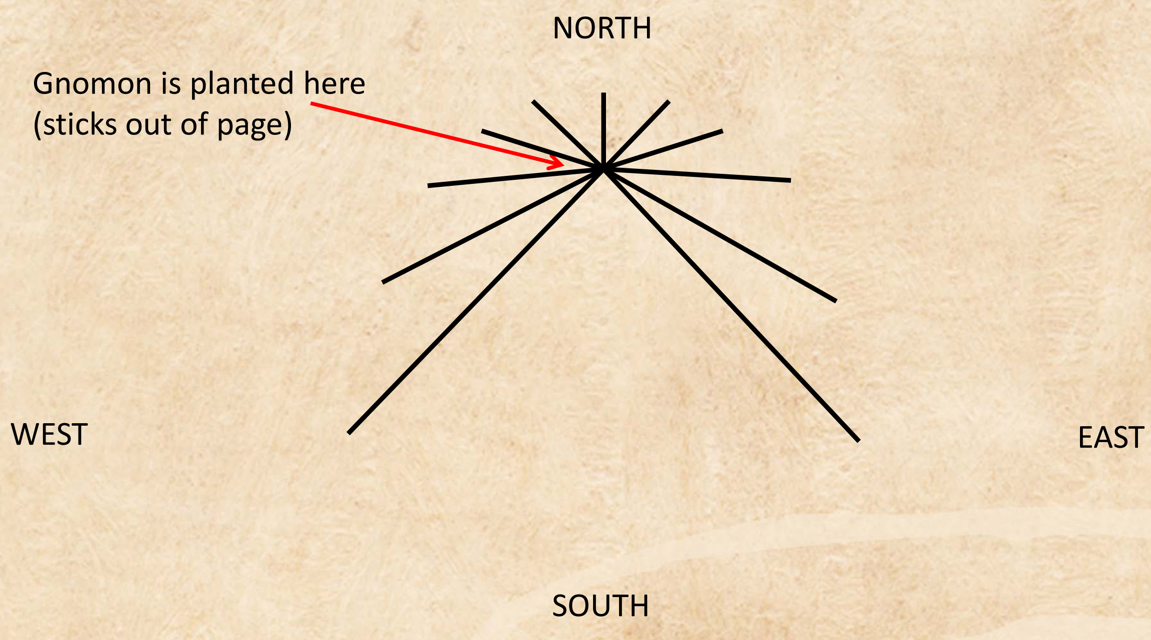
Students' logs and discussions can serve as an assessment of their progress. Student teams can create a poster or oral presentation with their drawings and explain their findings.

FIGURE 1a: Example of the equinox gnomon shadows as seen from northern latitudes above 23.5 degrees N



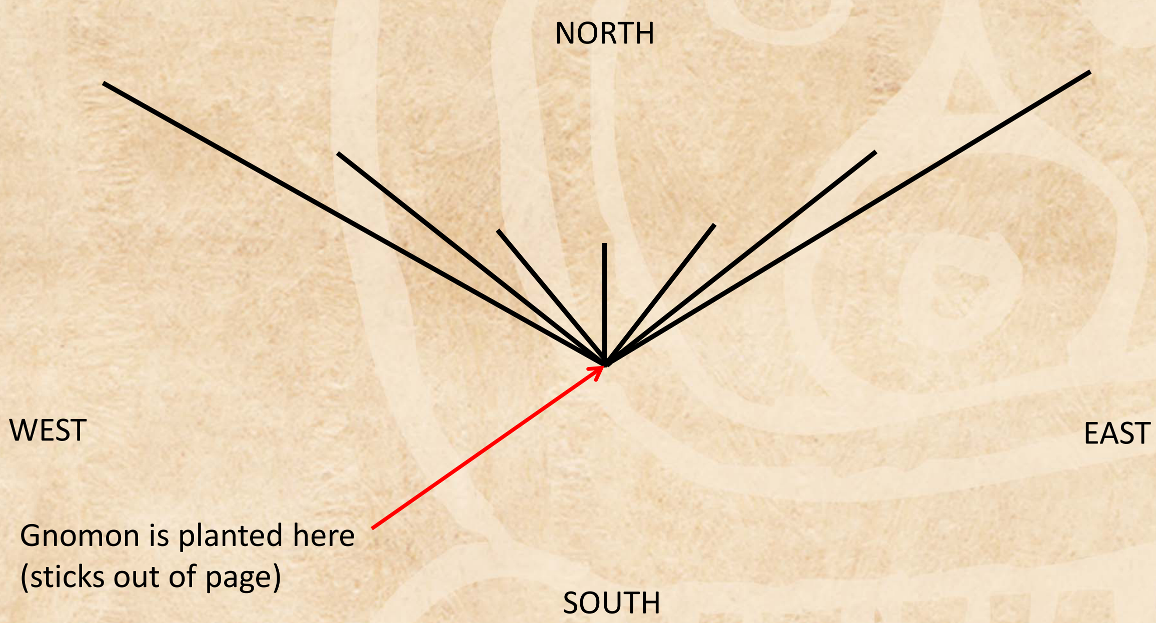
EQUINOXES: During the equinoxes in March and September, the Sun rises directly due east and sets directly due west everywhere on the Earth. Throughout the globe, day and night are of equal length, 12 hours of day and 12 hours of night. During the equinox, the gnomon shadows make this pattern over several hours at the northern latitudes above the Tropic of Cancer. The Sun's apparent motion in the sky traces an arch, starting exactly east at the eastern horizon, curving south, and finishing exactly west on the western horizon. When joined together, the ends of the gnomon shadows form a straight line that points east-west. The north-south direction is along the line of the shortest shadow.

FIGURE 1b: Example of the summer solstice gnomon shadows as seen from northern latitudes above 23.5 degrees N



SUMMER SOLSTICE: On June 21, during the summer solstice in the northern hemisphere, the Sun rises north of east and sets north of west. During the summer solstice, we experience the longest day and the shortest night of the year. The gnomon shadows make this pattern over several hours at the northern latitudes above the Tropic of Cancer. The Sun's apparent motion in the sky traces an arch, starting north of east in the eastern horizon, curving south, and ending north of west in the western horizon. A curve can be traced when the ends of the gnomon shadows are joined together. The north-south direction is along the shortest shadow. The east-west direction can be traced by any line joining two shadows of equal length.

FIGURE 1c: Example of the winter solstice gnomon shadows as seen from northern latitudes above 23.5 degrees N



WINTER SOLSTICE: On December 21, during the winter solstice in the northern hemisphere, the Sun rises south of east in the eastern horizon and sets south of west in the western horizon. During the winter solstice, we experience the shortest day and the longest night of the year. The gnomon shadows make this pattern over several hours at the northern latitudes above the Tropic of Cancer. The Sun's apparent motion in the sky traces an arch, starting south of the eastern horizon, curving south, and ending south of the western horizon. A curve can be traced when the ends of the gnomon shadows are joined. The north-south direction is along the shortest shadow. The east-west direction can be traced by any line joining two shadows of equal length.