National Aeronautics and Space Administration

www.calendarinthesky.org

Solar Alignments at El Castillo

What You'll Need

- Clear plastic 12" hemisphere, 40 gauge

  You can purchase a set of two at: www.themedecor.com Click on "Sphere Vacuum Formed" in the left hand column

- Model of El Castillo

  You can create your own model using the instructions in "Make Your Own El Castillo"

- Strong, small LED flashlight. The one we use has nine 5mm LED lights and uses 3 AAA batteries

  You can purchase one here at: www.acehardware.com

- Printouts of the following pages: Base, Cutout Strips, optional Background Info and Supplemental Concepts sheet

- Scotch Tape

- Masking Tape

About this Activity

In this activity, a clear plastic hemisphere and a model of El Castillo are used to illustrate the different solar alignments present at different times of the year. It is a demonstration best done with a small group of no more than seven participants so everyone can see the "snake of light" effect on the west side of the northern staircase. Also, this must be done in a room that can be darkened or the "snake of light" effect will be difficult to see.

The activity with the model of El Castillo, Hemisphere, and Base ready for the solar alignments demonstration.

Preparation

Purchase a clear plastic hemisphere and follow instructions in "Make Your Own Model of El Castillo" and have the model ready.

1) Prepare the Base. Either print on a large-format printer, or follow these instructions using a regular printer. *Optional: You can have the printed base laminated or mounted on foamcore to be more durable for multiple presentations of this activity.*

   1. Open the print dialogue box in Acrobat.
   2. Under "Page Sizing & Handling" or "Page Handling" (it depends on your version of Acrobat), select "Poster" or "Tile all pages" under the "Page Scaling" pull-down menu. Check the box for "Cut marks". "Overlap" can be left at the default value (i.e. "0.005 inches").
   3. Carefully cut along the cut marks and tape the sheets together. *Tip: It is easier to cut the left hand sheets first, then tape over the right hand sheets (without cutting them). If you do a set of one left-hand page and one right-hand page, then trim the top of the set together before taping onto another set (without cutting it), it is easier to manage.*

2) Prepare the Hemisphere by placing it on the Base and aligning it to the circle.

   1. Mark the cardinal points (North, South, East, West) at the very base of the Hemisphere. *Tip: It is easier if you use a dry-erase marker to make all of the initial marks, then go over those marks with the appropriate permanent marker after all the initial marks have been drawn.*
   2. Using masking tape, carefully tape a straight line from North to South on the Hemisphere, making

- String (make sure it does not stretch at all). Dental floss is a good option
- Scissors
- Permanent markers, preferably in black, blue, red and green
- Dry-erase marker (optional)

sure that the tape is offset so the edge represents the true line. Draw the line with a marker, using the edge of the masking tape as a ruler. This is the meridian. *Tip: This line could be drawn using a black permanent marker.*

3. Cut a length of string to match the North-South meridian line. This will act as your ruler as it is hard to measure lengths on the curved surface of the Hemisphere.
4. Fold the string in half to find the halfway point. Transfer that mark to the Hemisphere on the meridian line in black. This marks the zenith. Remove the meridian line masking tape.
5. Measure the following distances on the string, and then transfer the marks to the Hemisphere on the meridian line in the colors indicated (Fig. 1). It is crucial that you measure up from South, and not up from North.

    - Blue: 5.25” up from South
    - Green: 7.75” up from South
    - Red: 10.75” up from South

Fig. 1: Using the string as a ruler.

6. Using masking tape, carefully tape the following four straight diagonal lines, making sure that the tape is offset so the edge represents the true line (Fig. 2). Draw each line with its final color as indicated, using the edge of the masking tape as a ruler.

    - Line 1: In blue, from the blue marks on the Base through the blue mark on the meridian.
    - Line 2: In green, from the green marks on the Base through the green mark on the meridian.
    - Line 3: In red, from the red marks on the Base, through the red mark on the meridian.
    - Line 4: In black dashes, from the black dash marks on the Base, through the black zenith mark on the meridian.

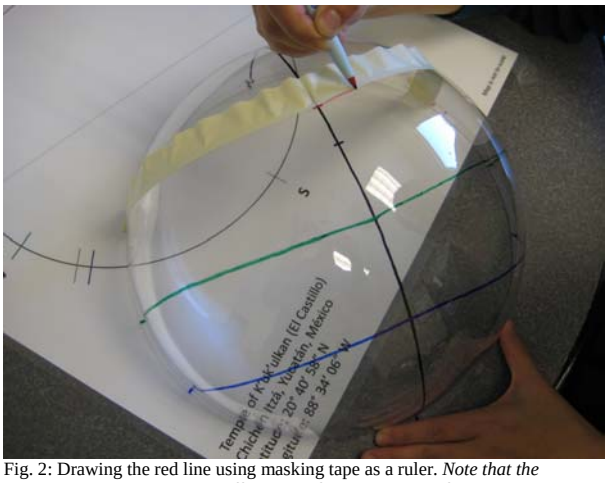


Fig. 2: Drawing the red line using masking tape as a ruler. *Note that the Hemisphere has been moved off the Base for the purpose of this photo, but that the colored marks from the Base have been transferred to the very base of the Hemisphere before taping and drawing these lines.*

3) Prepare the Cutout Strips by printing the sheet and cutting the strips. *Optional: You can have the individual strips laminated to make them more durable as well.*

To Do and Notice

1) Setup the pyramid on the Base with the East-West staircases centered on the grey line transecting the circle.

2) Set the Hemisphere over the pyramid, aligning the cardinal points and colored lines with the colored lines on the Base.

3) Introduce the activity by saying, “This activity is a model of the solar alignments at El Castillo. There are some things that are accurate and some things that are not accurate about this model (i.e. scale size).” *Tip: Start building up your participants’ vocabulary with glossary terms from the Background Information Sheet.*

4) Start by providing context on the El Castillo pyramid itself to your participants, using whatever information from the Background Information Sheet that is appropriate for your participants.

5) Introduce the demonstration by saying, “This plastic hemisphere represents the dome of the sky. The circle on the base represents the horizon. The flashlight represents the Sun. The Sun always rises on the eastern horizon and sets on the western horizon, but where it rises and sets on the horizon changes throughout the year.” *Optional: Ask your participants to think of their house or school and if they recall noticing the Sun rising and setting at different points in relation to a window, or tree on the horizon.*

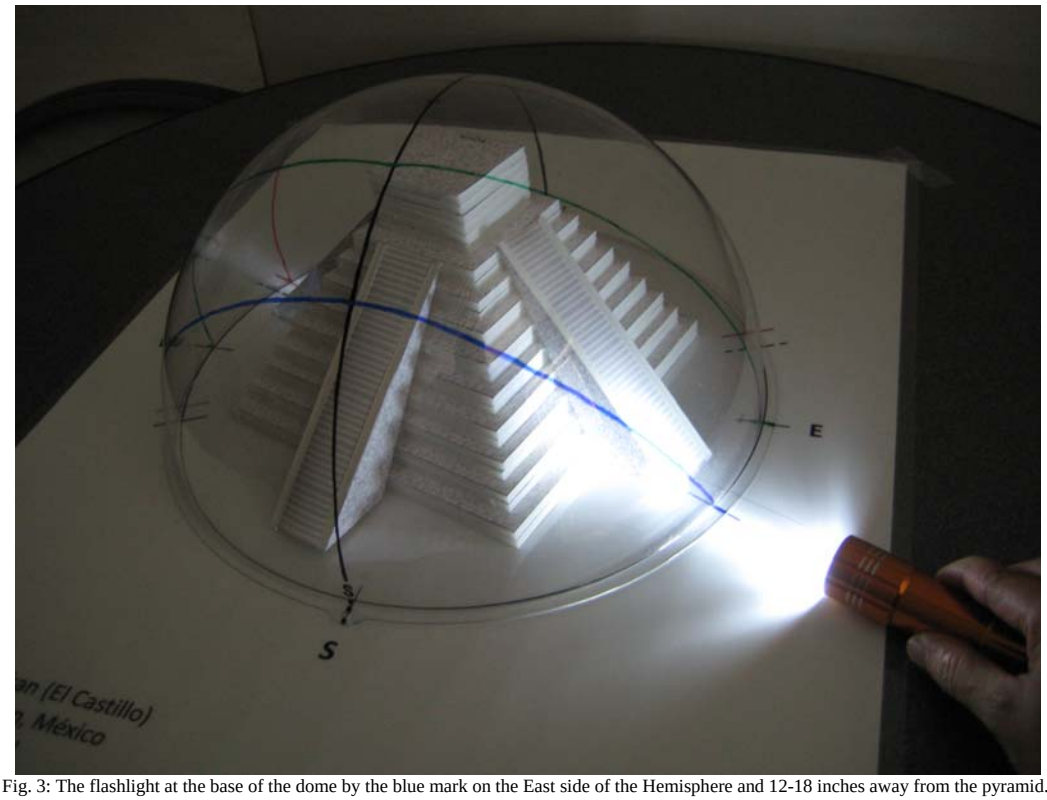


Fig. 3: The flashlight at the base of the dome by the blue mark on the East side of the Hemisphere and 12-18 inches away from the pyramid.

6) Turn the flashlight on, and start with the flashlight down on the Base by the blue mark on the east side of the Hemisphere about 12-18 inches away from the pyramid (Fig. 3). Slowly and carefully move the flashlight so that it always points at the pyramid (i.e. straight down at the top, at a diagonal from the sides) and follow the arc of the blue line on the Hemisphere, but keeping 12-18 inches away from the pyramid the entire time. *Tip: You may need to practice this movement a bit until it feels natural.* This indicates the path of the Sun in the sky on winter solstice. Note to the participants how the Sun rises toward the southeast and sets toward the southwest. Tape down the appropriate Cutout Strips labeling “Winter Solstice Sunrise” and “Winter Solstice Sunset” at the appropriate points on the base. *Optional: You can also say, “This time of the year is when the Sun is at the lowest point in the meridian (i.e. at the lowest point in the sky) or at a 45° altitude. The day of winter solstice is the shortest day of the year (i.e. the longest night).”*

7) Repeat with the flashlight following the arc of the red line on the Hemisphere to indicate the path of the Sun in the sky on summer solstice, always keeping the flashlight about 12-18 inches away and always angled towards the pyramid. Note to the participants how the Sun rises toward the northeast and sets toward the northwest. Tape down the appropriate Cutout Strips labeling “Summer Solstice sunrise” and “Summer Solstice sunset” at the appropriate points on the base. *Tip: You can either tell your participants the time of year steps 6 & 7 take place, or have the participants guess the times of year if it is appropriate to your audience. Optional: You can also say, “The day of summer solstice is the longest day of the year (i.e. the shortest night) and the Sun is at an 87° altitude.”*

8) Ask your participants what they think the green line on the Hemisphere represents. Point out that when the Sun rises due East (that is, exactly East) and sets due West, the hours of the day are equal to the hours of the night. If the participants do not guess that the green line represents the equinoxes, tell them. Tape down the appropriate Cutout Strips labeling “Equinox sunrise” and “Equinox sunset” at the appropriate points on the base.

Fig. 4: The Sun Serpent effect on the western side of the northern staircase.

9) MODEL THE SHADOW: Now it is time to model the Sun Serpent shadow effect that takes place on the equinoxes. Gather your participants on the west side of the base so they can see the western side of the northern staircase and darken the room. Starting with the flashlight down on the base due East, move the flashlight slowly following the arc of the green line on the hemisphere (Fig. 4). The Sun Serpent shadow effect happens in the afternoon, not at sunset! *Tip: It helps to practice the angle you hold your flashlight beforehand to get the right effect. It also helps to practice the speed at which you can see the Serpent shadow effect best. Optional: Have the participants try to "be the Sun" after you have modeled the shadow effect. Let them play with the flashlight.*

10) After repeating the Sun Serpent shadow effect several times, ask your participants if they think the same effect happens at the winter and summer solstices. *Answer: No, it does not!*

11) Play the time-lapse video (see link below). Discuss the meaning of the shadow, using information from the Background Information Sheet.

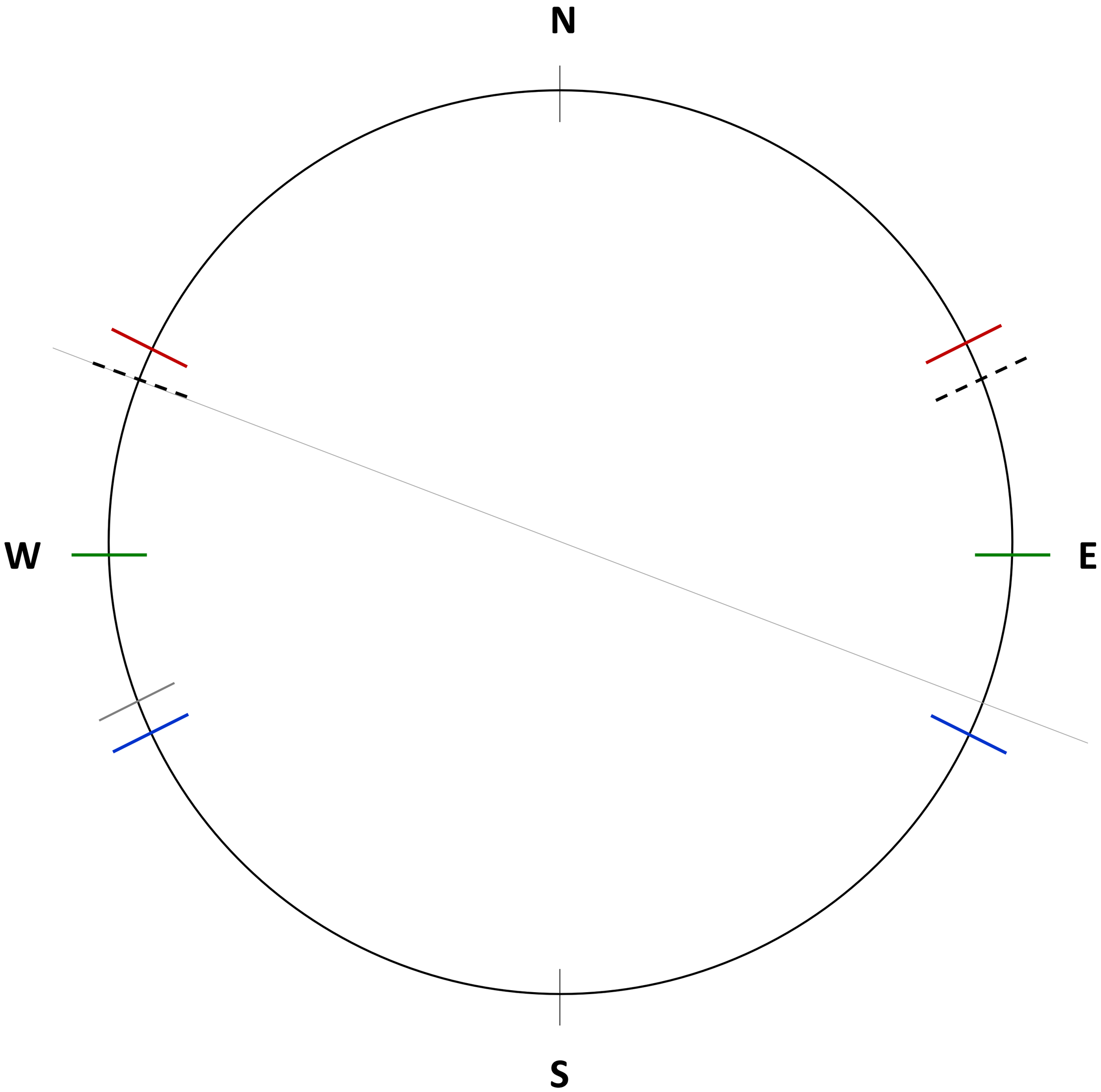
12) Talk about the zenith passage of the Sun (i.e. the dotted line on the Hemisphere). Point out how the Sun passes straight though the zenith point. Address the misconception that the Sun passes through the zenith every noon of every day. Emphasize how this only happens in the Tropics (in areas between 23.5° North and 23.5° South latitude of the Equator) and only twice a year (once a year if you are located right at 23.5° North/South latitudes). Model zenith passage with the flashlight, following the dotted line on the Hemisphere. Point out that the West staircase of the pyramid is aligned to the zenith sunset. Tape the Cutout Strips labeling "Zenith sunrise" and "Zenith sunset" at the appropriate points on the base.

13) Optional: Talk about the nadir passage of the Sun, referring to the information on the Background Information Sheet.

Related Websites

Calendar In The Sky: Time-lapse video
http://calendarinthesky.org/MultimediaResources/Video.aspx?moid=183

Article: The Descent of K'uk'ulkan
http://calendarinthesky.org/Articles/MayaScience/MayaScienceArticleView/tabid/139/ArticleId/8/The-Descent-of-Kukulkan.aspx



Temple of K’uk’ulkan (El Castillo)
Chichén Itzá, Yucatán, México
Latitude: 20° 40’ 58” N
Longitude: 88° 34’ 06” W

Map is not to scale

Summer Solstice sunrise

Summer Solstice sunset

Winter Solstice sunrise

Winter Solstice sunset

Equinox sunrise

Equinox sunset

Zenith sunrise

Zenith sunset

Nadir sunrise

Nadir sunset

	Background Information and Supplemental Concepts
Big Idea	The ancient Maya built the Temple of K'uk'ulkan (El Castillo) to align with astronomically and culturally significant days, such as the zenith passage of the Sun and the equinoxes.
Location Info	The Temple of K´uk´ulkán is located in the ancient Maya city of Chichen Itza in the Yucatan peninsula of Mexico. The Temple of K´uk´ulkán is also known in Spanish as El Castillo, meaning "The Castle". Latitude: 20° 40' 58" N; Longitude: 88° 34' 06" W
About the Pyramid	- The temple is built on top of a four-sided pyramid. The pyramid has nine platforms that may represent the nine underworlds. - Each side of the pyramid has a staircase with 91 steps. There were serpent heads at the base of each staircase.  Image Credit: Bryan Mendez, UC Berkeley This photo is also available at: http://calendarinthesky.org/MultimediaResources/Images/Photos.aspx?moid=1086 - When the steps on all four staircases are counted along with the common top step, there are a total of 365 steps. This may symbolize the haab calendar (solar year). - Inside the temple, there are 18 panels that may represent the 18 months of the t'zolkin calendar. - The orientation of the pyramid is offset 21° from cardinal points. This means that the pyramid's central axis is aligned along the solar zenith passage sunset and the nadir passage sunrise.
About K'uk'ulkan	- K'uk'ulkan is one of the Maya creator gods who is usually pictured as part snake and part bird.

	- One way of interpreting the god's name is "K'u" meaning god or sacred, "k'ul" meaning coccyx or vibration and "can" meaning serpent. - Since K'uk'ulkan is not named in inscriptions associated with the temple, not everyone agrees that this temple was dedicated to K'uk'ulkan.
About the Sun's Rising & Setting Points	- The Sun rises and sets at different points along the horizon throughout the year. - The Sun's position on the horizon is measured using azimuth. Azimuth is measured in a circle eastward starting from North (North=0°/360°; East=90°; South=180°; West=270°). - The meridian is an imaginary line that runs from north to south through the zenith (straight overhead or top of the sky). - The altitude of the Sun on the meridian changes throughout the year. The Sun's altitude on the meridian is measured upward from either the north or south point on the horizon, from 0° to 90° (the horizon equals 0° altitude and the zenith equals 90° altitude) - On the dome used in the activity, the colored lines indicate the path of the Sun across the sky at different days of the year. 1. Blue Line = The path of the Sun on the winter solstice (around Dec. 21); The Sun rises in the southeast at 115° azimuth, crosses the meridian at 45° altitude, and sets in the southwest at 245° azimuth 2. Green Line = The path of the Sun on the Equinoxes (around March 21 for Spring/Vernal; September 21 for Fall/Autumnal); The Sun rises due East at 90° azimuth, crosses the meridian at 69° altitude, and sets due West at 270° azimuth 3. Red Line = The path of the Sun on the summer solstice (around June 21); The Sun rises in the northeast at 65° azimuth, crosses the meridian at 87° altitude, and sets in the northwest at 295° azimuth 4. Black Line = The meridian 5. Dotted Line = The path of the Sun on zenith passage days (around May 21 and July 19 at Chichen Itza); The Sun rises in the northeast at 69° azimuth, crosses the meridian at 90° altitude, and sets in the northwest at 291° azimuth
About the Shadow	- As the Sun sets on the equinoxes, the northwestern corner of the pyramid platforms casts a shadow on the side of the northern staircase. - As the Sun gets lower in the sky, the shadow creeps closer to the stairs, creating a "serpent" of light that snakes its way down the side of the staircase. The carved serpent head at the base of the stairway is illuminated before the Sun's light disappears. - This shadow and light effect represents a hierophany; "A revelation of the sacred in an object or event of the otherwise profane world" (Mircea Eliade). - According to some Maya elders, the seven lighted and six dark triangles formed on the staircase on the equinox represent the seven days and nights of creation. The sum of these lighted and dark triangles represent the 13 levels of heaven in the Maya concept of the world. Similarly, the nine platforms of the temple represent the nine levels of the underworld.
Astronomical Connections to Agriculture	- For the Maya, the March equinox is an important marker of the transition time between the wet season and the dry season. - The March equinox indicates the time to observe a new beginning in the agricultural cycle. It is a signal to farmers to start clearing their fields in preparation for planting corn. Farmers will slash and burn the land to provide ash that nourishes the soil. When the rains come, these fires are extinguished. - The first zenith passage of the Sun (around May 21 at Chichen Itza) is a signal to start planting.

	- The end of the wet season is marked by the nadir passage of the Sun (the time when the Sun travels through the point directly opposite the zenith.)
Supplementary Concepts	*Solstices and equinoxes are points in the Earth's orbit around the Sun. These points are defined by the relative positions of the Earth's axis and the ecliptic, or the plane on which the Earth orbits the Sun.* *Equinoxes occur twice a year, at approximately March 21 and September 21. At the equinoxes, every place in the world receives roughly 12 hours of daylight and 12 hours of darkness.* *At the summer solstice (around June 21 in the northern hemisphere), the Sun rises in the northeast and sets in the northwest. It is the longest day of the year.* *At the winter solstice (around December 21 in the northern hemisphere), the Sun rises in the southeast and sets in the southwest. It is the shortest day of the year.* *It is a common misconception that the Sun is directly overhead everyday at noon. This is FALSE. The Sun only reaches the zenith at tropical locations (i.e. between 23.° North latitude and 23.5°South latitude). Even at these locations, the Sun only reaches the zenith twice a year (only once a year at 23.5° North and South latitude). The Sun never reaches the zenith at locations outside tropical latitudes.*
Glossary of Terms	***Azimuth*** *– The direction of a celestial object, measured in degrees clockwise around the observer's horizon from north; i.e., North = 0°, East = 90°, South = 180°, West = 270°* ***Altitude*** *– The angle of a celestial object, measured in degrees upwards from the observer's horizon; 0° = horizon, 90° = zenith; objects below the horizon are measured with negative degrees* ***Meridian*** *– An imaginary line that runs from the north point on the horizon through the zenith to the south point on the horizon; when a celestial object is on the meridian, it has reached its highest altitude for that day or night* ***Horizon*** *– the apparent intersection of the Earth and sky as seen by an observer* ***Zenith*** *– the point directly overhead the observer; i.e. 90° altitude* ***Nadir*** *– the point directly underfoot the observer (opposite the zenith); i.e. -90° altitude*