Activities in Archaeoastronomy For the Classroom, Grades 4-8

developed by

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Table of Contents

Ancient Eyes Looked to the Skies
Sunwatchers of the Southwest

Overview

Historical

Long before telescopes, mechanical clocks, and modern scientific investigation, ancient cultures carefully watched the changes in the world around them, and came to recognize repeating patterns. In many cases, they learned to use these repeating patterns to establish accurate calendars and time-telling techniques, making astronomy—the observation of celestial objects and events—one of the oldest sciences.

Right: Casa Rinconada, Chaco Canyon. This enormous kiva was built in almost exact alignment with the cardinal horizon directions, and is debated to possibly possess architectural features that produce alignments of beams of sunlight on certain days of the year. *Photo credit IDEUM*.

Many of these sky-watching cultures left little or no written records of their observations, techniques, and ideas about the cosmos. They may have left behind only their tools—stone "observatories" and other enduring objects of celestial observation—petroglyphs and pictographs of witnessed astronomical events, and verbal accounts passed down through generations. But from these archeological and sociological clues, we can attempt to piece together what these ancient astronomers did, and why.

This Activity Guide

The activities in this package were developed to provide hands-on projects in building "instruments" and models for use in actual observation of the patterns of motion of the Sun—a celestial object that many cultures used to measure time and establish direction. The archaeoastronomy focus for these activities is on North America, in particular the Chaco Canyon culture that existed in what is now the northwest corner of New Mexico.

Some of the activities are short-term and can be conducted over several hours of a day, or even during a class period. Others are longer-term projects, requiring participation by students periodically, for brief intervals, over a month, a semester, or a school year.

A basic understanding of the sky, directions, and the daily and seasonal motion of the Sun is helpful, but this guide was designed so that students may explore and learn about these topics in the course of conducting the activities.

Each lesson begins with a summary describing the activity, the objective, the required materials, suggestions for grouping the students, and the approximate time each part of the activity will require. A brief discussion of the activity's connection to its archaeoastronomical inspiration is also given.

The bulk of each section consists of step-by-step instructions for conducting the activity. Most activities contain two or more parts, usually to be performed in sequence. Each activity part starts on its own page so that they may be photocopied as student handouts. All pages with instructions for students are printed in large font for easier reading and identification as student handouts.

Most of the activities require, explicitly or otherwise, that students maintain a notebook of the observations they make. Careful descriptions of observations, surroundings, experiments conducted, results obtained, and answers to discussion questions are to be included in the notebook. In some cases, carefully drawn and detailed sketches or diagrams are required.

Each activity includes a section titled *Do the Math*. These are optional mathematics activities that teachers may choose to assign or students may elect to conduct, if it fits the needs and grade level of the class.

What is Archaeoastronomy?

A Brief Introduction to Archaeoastronomy
by Dr. John Carlson
The Center for Archaeoastronomy

The study of the astronomical practices, celestial lore, mythologies, religions and world-views of all ancient cultures we call ***archaeoastronomy****. We like to describe archaeoastronomy, in essence, as the "anthropology of astronomy," to distinguish it from the "history of astronomy".*

You may already know that many of the great monuments and ceremonial constructions of early civilizations were astronomically aligned. The accurate cardinal orientation of the Great Pyramid at Giza in Egypt or the Venus alignment of the magnificent Maya Palace of the Governor at Uxmal in Yucatan are outstanding examples. We learn much about the development of science and cosmological thought from the study of both the ancient astronomies and surviving indigenous traditions around the world.

With its roots in the Stonehenge discoveries of the 1960s, archaeoastronomy and ethnoastronomy (the study of contemporary native astronomies) have blossomed into active interdisciplinary fields that are providing new perspectives for the history of our species' interaction with the cosmos.

One hallmark of the new research is active cooperation between professionals and amateurs from many backgrounds and cultures. The benefit of this cooperation has been that archaeoastronomy has expanded to include the interrelated interests in ancient and native calendar systems, concepts of time and space, mathematics, counting systems and geometry, surveying and navigational techniques as well as geomancy and the origins of urban planning. We feel the excitement of the synergy that results when the new syntheses are more than the sum of their parts.

Our subject is essentially a study of the Anthropology of Astronomy and world-views and the role of astronomy and astronomers in their cultures.

Why Chaco Canyon?

Chaco Canyon, in northwestern New Mexico, is believed to have been a major cultural and ceremonial center of ancestral Puebloan culture, particularly between 850 and 1250 C.E., when monumental public buildings, at a scale unlike anything seen before or afterward, were erected. This is both impressive and mysterious given the environmental harshness of this high desert region. It is an area of extreme temperature ranges and a limited growing season. Building on this scale, at this site, required a high level of organization for planning, gathering necessary resources, and construction. Of particular interest to archaeologists, astronomers, and archaeoastronomers is evidence that many of the buildings, landforms, and even the landscape itself may have been used as solar (and possibly lunar) calendars. Buildings, and the roads connecting them, show evidence of careful geometric positioning and celestial and geographic alignment. Some people believe solar and lunar cycles were marked by light and shadow patterns on stone carvings. Chaco Canyon remains a place of great importance to the native people of the southwest today.

Why Archaeoastronomy?

Astronomy was arguably the first "science." People throughout time and across cultures have carefully observed the sky and noticed the patterns of motion of the Sun, Moon, and stars. They have used this knowledge to survive, and as bases for literature, religion, government, and other elements of culture. Understanding the cycles of the Sun allowed people to know when to plant, harvest, or move to a different location. Through careful, on-going observation they were able to know that a "sunny day in February" was <u>not</u> truly the beginning of Spring. They were able to time their rituals, celebrations, and other important life events. If they were traveling from one place to another, this knowledge helped them find their way.

Today, most of us have lost this personal connection with the cosmos. Learning about ancient peoples (including their scientific understandings) and learning to carefully observe the sky as they did promote student learning. Students learn to appreciate people from different times and places, and they have the opportunities and invitations to make personal connections with the sky. They benefit from engaging in long-term, ongoing investigations. Collecting data first hand, finding patterns in that data, and reaching generalizations and conclusions is authentic science. Additionally, the subject of archaeoastronomy enables a rich blending of astronomy, anthropology/archaeology, mathematics, language arts, social science, and art. Further, there are almost as many interpretations of the data at Chaco Canyon (and other sites) as there are people examining and studying this information. These are real mysteries that students can ponder along with the experts. Students come to understand the nature of scientific thinking and reasoning from evidence. This kind of critical thinking will help them in all curricular areas.

Classroom Considerations

We invite classroom teachers to select the lessons they feel best fit their curriculum. For example, they can be used as extensions in a social studies unit on Native Americans or a science unit on astronomy. The lessons can be used to enhance the Open Court reading program's fifth grade astronomy unit.

We encourage teachers to have students keep science notebooks or logs. When students write about what they've done, they "think again." Notebook writing and drawing provide students the opportunity to clarify, extend, and communicate their understandings and questions. The notebook is more than a place where students can keep the data they collect; it also provides a record of student growth over time—in both scientific understandings and writing skills.

Langer and Applebee (1987) state: *"Writing encourages active engagement in learning and helps students activate their schema for the concepts to be explored. Expressive writing in notebooks and logs in children's own everyday language is their thinking written down, made permanent so that students can revisit their first impressions and revise their thinking as their understanding deepens. Writing helps students gain awareness of their developing knowledge and helps teachers to assess what students are learning and not learning, what they are interested in, and what difficulties they are experiencing. Further, research has shown that the more the scientific content is manipulated through analytic writing tasks, the better it is recalled."*

Some of the activities in this unit lend themselves better to a whole-class record or chart, some to individual student log entries, and some to both. The questions at the end of each activity can be used as writing prompts, as well as for partner, small group, or whole group discussion. Additionally, the outline for notebook writing in the *Build a Landscape* activity can be modified for other activities as well.

Many of the activities lend themselves well to year-long, ongoing observation and investigations (that allow students to see change over time and patterns) as well as inquiry and experimentation. While no formal written assessments are included, teachers are encouraged to observe students as they are working, and to look for evidence of understanding in students' written work, as well as qualitative and quantitative changes in the nature of their observations and questions as the year progresses.

A Final Note

For your convenience, we have included a section on National Standards alignment for both science and mathematics. Our museum-based summer workshop provides participants with additional materials, resources and lessons in social science, literature, art, and writing.

We hope that these activities awaken and enhance teachers' and students' understanding of and appreciation for both ancient cultures and astronomy, and, that you look to the skies with "new eyes."

Acknowledgements

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Postcards From the Past

Orientation

In this activity, your students begin learning about archaeoastronomy much as the first skywatchers began learning about the sky: by observing and wondering. Your students will look at pictures of ancient observatories and archaeoastronomical structures and sites. They will write what they notice and what they wonder.

This activity invites students (and teachers) to observe carefully and ask questions. The National Science Education Standards state that "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science." Additionally, it provides teachers with valuable data about students' prior knowledge of, and interest in, this topic.

Note: This lesson was conceived and developed by Linda Block, and written for the NASA/Cassini *Reading, Writing, and Rings* curriculum by Alexa Stuart and Linda Block.

Activity: Students will observe photographs and drawings of petroglyphs, pictographs, and natural and human-made structures believed to be ancient observatories or of relevance to ancient astronomies and astronomers. They will discuss and record observations (*I notice…*) and questions (*I wonder…*) on chart paper.

Objectives: Students will practice careful observation and record observations and questions. Teachers will discover students' prior experience and knowledge. Students' questions will help teachers "personalize" the other activities in this unit for their classes.

Materials/Preparation:

- Select and print out the images you will use for this activity (between 6 and 8 images works well). See the list of websites at the end of this activity for sample images, but feel free to seek out any other images you find relevant. This activity was not created with any specific set of images in mind.
- **Do not** give the students information (written or otherwise) about the names, locations, or uses of the sites shown in the images.
- Cut out the pictures and tape each one to a large piece of chart paper, one picture to a sheet. The chart paper should be in portrait orientation to allow students to write their observations and questions below each picture. (Also, consider laminating the

pictures so that you don't have to create a new set each time you run this activity.)

- Under each image, write two column headings: "*I Notice…*" on the left and "*I Wonder…*" on the right.
- Decide how students will be partnered or placed in small groups for this activity. Also, decide on a rotation plan. Students can move from chart to chart, or they can stay put and charts can be passed from one group to the next. Think of how you will make sure that the rotation goes smoothly.
- Come up with a "signal" that will let students know when it is time to rotate. Many teachers give students "extra group points" for quick and smooth transitions.

Grouping: Small groups of 3-5 students for the "image tour" and discussion. Whole-group discussion before and after.

Time: Approximately 35-45 minutes for the "image tour" (observe, discuss, and write). Approximately 10-15 minutes for whole-group discussion, individual writing, and partner sharing.

What To Do

Tell the students that they will begin learning about ancient astronomy and astronomers—archaeoastronomy—by looking at some pictures, making observations, and asking questions. (See if they notice the two words—archaeology and astronomy—and if they can guess what this means.)

Look at one of the pictures and model orally and in writing for the students what you notice, know, and wonder about it. You may want to model one, and then do one more example as a whole class before having the students tour the images in their small groups. Overhead transparencies work nicely for whole-group modeling. You can select a couple of images from the set and make overheads to use for this step.

Hand out the charts with images, one to each group--or distribute the charts to stations around the room and have the groups move to them. Explain the directions to the students:

- Observe the image carefully and discuss your observations.
- In the first column, take turns recording what you notice under "*I Notice…*".
- Discuss questions that you have about the image.
- Record your questions in the second column, titled "*I Wonder…*".

- Be sure to write your questions and observations in complete sentences. Be sure to put question marks at the end of your question sentences.
- At the signal, one person in your group will take the chart to the next group (or, your group will move to the next chart).
- When you get your new chart, you will do the same activity again.

Brainstorm ideas for what to do if your students run out of space to write on any of the charts.

Give your students 5-7 minutes for discussion and recording on each chart, and then give the rotation signal.

After all groups are through, give your students a few minutes to read all of the charts. They can do this from their seats, if the charts are posted, or by circulating around the room.

Ask students to respond in writing (“quick write”) to the following prompts:

- What did you notice by doing this activity?
- What surprised you?
- What is something you now know that you did not know before this activity?
- What image did you find the most interesting, and why?

Students can share their log entries with partners and, time permitting, the whole group.

You can save the charts and have students add to them throughout the unit, or look back at them at the end to see how much they have learned.

Archaeoastronomical Image Sets

The URLs below lead to images relevant to this activity and that may be downloaded and printed for classroom use.

You are encouraged to gather a set of images for this activity that best suits your needs—from the websites below, from other websites that you find, or from other sources.

You may choose to assemble a set of archaeoastronomical images from sites around the world, from sites in a more confined region, culture, or time period, or in whatever other mix best suits your needs or preferences.

Whatever image set you assemble, you should number the images, and keep a list of their names, locations, and other relevant information.

Image URLs:

www.nationalgeographic.com/xpeditions/activities/images/season.jpg (Bighorn Medicine Wheel)

weather.msfc.nasa.gov/archeology/images/chaco/bonito.jpg (Pueblo Bonito, Chaco Culture National Historic Park)

sunearthday.nasa.gov/2005/multimedia/gal_006.htm (Fajada Butte, Chaco Culture National Historic Park)

sunearthday.nasa.gov/2005/multimedia/gal_015.htm (Casa Rinconda, Chaco Culture National Historic Park)

sorrel.humboldt.edu/~rwj1/ANA/ana4j.html (Sun Dagger Diagram, Chaco Culture National Historic Park)

www.solsticeproject.org/fajada.html (Sun Dagger Photograph (and others), Chaco Culture National Historic Park)

sunearthday.nasa.gov/2005/multimedia/gal_012.htm (Macchu Pichu, Peru)

sunearthday.nasa.gov/2005/multimedia/gal_030.htm (New Grange, Ireland)

sunearthday.nasa.gov/2005/multimedia/gal_072.htm (Brodgor, Scotland)

sunearthday.nasa.gov/2005/multimedia/gal_068.htm (El Castillo pyramid, Chichen Itza, Yucatan, Mexico)

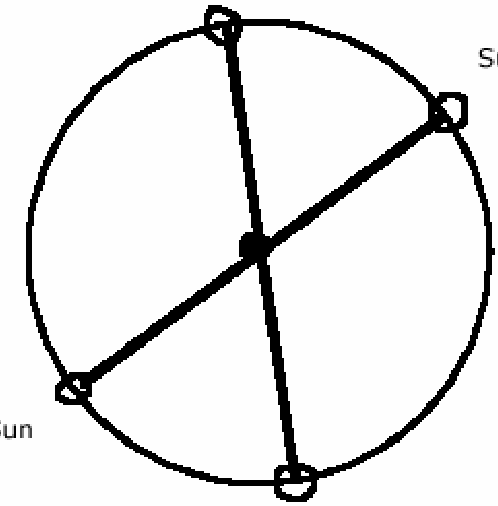
sunearthday.nasa.gov/2005/multimedia/gal_062.htm (El Castillo pyramid, Chichen Itza, Yucatan, Mexico)

sunearthday.nasa.gov/2005/multimedia/gal_059.htm (Nabta, Egypt)

sunearthday.nasa.gov/2005/multimedia/gal_034.htm (Stonehenge, England)

Schoolyard Medicine Wheel

Orientation



Activity: Make a schoolyard "medicine wheel" with sidewalk chalk on playground asphalt.

Objective: Learning the basics of the horizon, direction, and the risings and settings of Sun and stars.

Materials: A flat area at least 6 meters across—preferably asphalt or concrete—that has a good view of the sky; sidewalk chalk; string.

Grouping: Whole class.

Time: Activity 1 10-15 minutes to construct; Activity 2 10-15 minutes; Ongoing observation throughout the year.

Connection: The prehistoric Plains people of North America moved around a lot, following the bison and deer and other large, now extinct land mammals they hunted. Since they were always on the go, they didn't built permanent structures of stone, as the ancient Pueblo peoples did. This means that they didn't leave behind much archaeological evidence for us to learn about them by. One thing they did build that can be found today are the stone rings sometimes called "medicine wheels." For a long time, we didn't know what the medicine wheels had been built for, but a careful investigation has taught us that some may have been a calendar system based on observations of objects in the sky.

Teachers: Read the discussion of Civil and Astronomical Time on page 95.

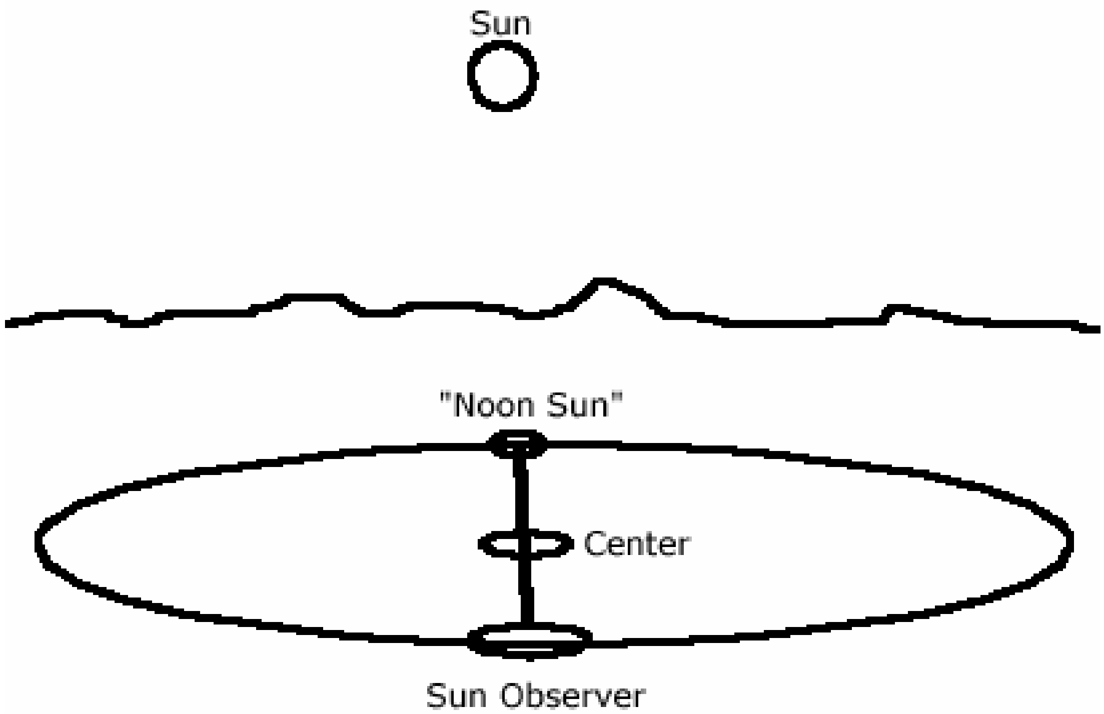
Part 1: Making the Circle

What to do:

1. Have you read <u>all</u> of these instructions? Yes No
2. Choose a spot in your school yard for your medicine wheel model. It should be a place where you can see the sky, and preferably on asphalt or concrete.
3. How big do you want your medicine wheel model to be? Diameter___________ (don't be timid--make it <u>at least 6 meters, if possible; otherwise, make it as large as you can.</u>)
4. Cut a piece of string to a length equal to the <u>radius</u> of the wheel. Radius___________ (diameter ÷ 2).
5. Tie a piece of sidewalk chalk to one end.
6. Mark the point where the center of the wheel is to be.

7. One student, the Center Holder, holds the end of the string without the chalk at the center point of the wheel.
8. Another student, the Circle Drawer, takes the end of the string with the chalk and pulls it tight. Double check that the length of the string is equal to the radius of the wheel you want to make.
9. The Circle Drawer walks around the Center Holder, keeping the string stretched tight, and draws the perimeter of the circle along the way. Mark the circle boldly, going around several times if needed.

Part 2: Marking the Noon Sun



What to do:

1. At noon[1], at least three students go to your medicine wheel model with a piece of chalk and a length of string equal to the diameter of the wheel.
2. Decide who will be the Observer, the String Stretcher, and the Line Drawer. Write your names here:
   - ❖ Observer__________________
   - ❖ String Stretcher_____________
   - ❖ Line Drawer________________
3. The Observer stands on the edge of the circle on just the right spot so that he/she sees the Sun directly above the center point of the wheel. It may help to draw an imaginary vertical line with a hand from the Sun straight

[1] Teachers: Read the explanation of civil and astronomical time on page 95.

down to the center of the wheel. If the center of the wheel is not directly below the Sun, the Observer needs to move along the circle to a position where it is.

4. The String Stretcher gives one end of the string to the Observer, then takes the other end across the wheel and stretches the string tight.
5. The String Stretcher moves the string until it crosses directly through the center point of the wheel, then stands in that position on the wheel.
6. The Line Drawer takes a piece of sidewalk chalk and draws a straight line across the wheel—from the Observer through the center point of the Wheel and then to the String Stretcher. The stretched string shows where to draw the line.
7. The Line Drawer draws a small circle around the Observer's feet and labels this position "Observer of Noon Sun."
8. The Line Drawer draws a small circle around the String Stretcher's feet and labels this spot "Noon Sun."
9. This completes one "spoke" of the Medicine Wheel: the spoke showing the direction of the Sun at noon.

Question: Which directions[2] (north, south, east, west, northeast, southwest, etc.) do you think this spoke points to? __________

[2] Teachers: Read the explanation of civil and astronomical time on page 95.

Part 3: Marking Other Astronomical Alignments

Here are some suggestions of other spokes that may be added to the medicine wheel model. Some of them require students to observe from the Wheel during after-school hours, so maybe a teacher-led star party is in order! Otherwise, the spokes can be added as an exercise of determining and constructing lines based on the expected angle along the horizon (the azimuth, which is the angle measured along the horizon from north, going clockwise) of the event.

Don't forget to label each spoke!

Sunrise and sunset today: These spokes are best created by actually observing the events. The steps for doing this are the same as for the Noon Sun spoke. Otherwise, the azimuth of sunrise and/or sunset on a given day must be looked up or calculated.

Equinox sunrise and sunset: Around the Autumn and Spring Equinoxes the Sun rises directly east and sets directly west. You can mark these two directions by using a magnetic compass[3].

North Star: The North Star, Polaris, is located near the "North Celestial Pole," and moves so little during the night that it's always almost directly northward. Again, you can use a magnetic compass to find north if you know how to use one (see footnote). The *correct* way to do this, of course, is to come out at night, find Polaris, and draw the spoke by sighting, as was done for Noon Sun.

Moon: Depending on where the Moon is, spokes pointing in the direction of the rising or setting Moon can be added. When you make a spoke for a moonrise or moonset, be sure to label it clearly and include the time and date.

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[3] Teachers: Read the description of magnetic versus geographic directions on page 96.

Star Risings or Settings: If students can come back at night (or better yet, if the class, lead by the teacher, can hold a "star party" around the medicine wheel model), then spokes can be added for the risings or settings of bright stars that can be identified near the horizon. Make spokes for the risings or settings of some bright stars—or as close to rising and setting as possible. Label each spoke with the name of the star and include the date and time.

Some suggested stars are:

- ❖ Aldebaran, in Taurus
- ❖ Spica, in Virgo
- ❖ Vega, in Lyra
- ❖ Altair, in Aquila
- ❖ Betelgeuse, in Orion
- ❖ Antares, in Scorpio
- ❖ Arcturas, in Bootes
- ❖ Sirius, in Canis Major (brightest star in the sky)

Note: A star-finder, or "planisphere," is a great tool for finding and identifying stars. Also, see page 99 for information on a good star-finding book.

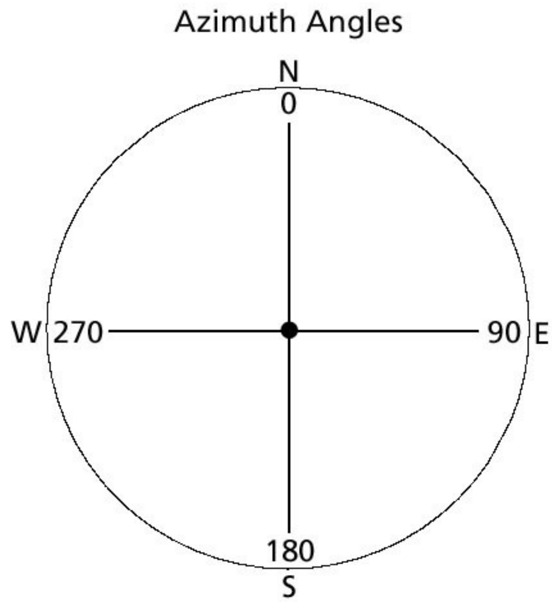
Questions

- ❖ What do you think are some purposes of medicine wheels?
- ❖ In what ways can a medicine wheel be used to tell directions?
- ❖ How can the medicine wheel be used to tell the time of year?
- ❖ In what ways might environment/geography affect this “tool”? What do you think might be an ideal location for a medicine wheel? Why?

Do the Math

Activity: Construct a diagram of a medicine wheel model using paper, pencil, protractor, ruler, and drawing compass. The spokes of this medicine wheel diagram will show the directions where the Sun rises and sets on the solstices (Summer and Winter) and the equinoxes (Spring and Autumn).

Definition: Directions around the horizon (north, east, south, west, and all the directions between them) are measured as angles of *azimuth*. Azimuth, measured in degrees, is the angle between the north point on the horizon to another point on the horizon in the clockwise direction.



The azimuth where the Sun rises and sets changes, and depends on the day of the year and the *latitude* of your location.

What to do:

1. On the equinoxes, the Sun rises at the east point on the horizon and sets at the west point on the horizon (no matter what latitude you are at).
   - ❖ What is the azimuth, in degrees, of sunrise on the equinoxes (either Autumn or Spring, it doesn't matter)? What is the azimuth of sunset on the equinoxes? Write your answers here:

     Azimuth of Equinox sunrise __________

     Azimuth of Equinox sunset __________

2. On Summer Solstice in the Northern Hemisphere the Sun rises at an azimuth X degrees northward of the east point

on the horizon, and sets at an azimuth X degrees northward of the west point on the horizon.

The numerical value of "X" depends on your latitude.

❖ What is your latitude? _________

❖ What is the value of X for your latitude? _________ (use the table below to find X for your latitude; the table covers the range of latitude from 30 to 44 degrees)

Table of X

Your Latitude (degrees)	X
30	27
32	28
34	28
36	29
38	30
40	31
42	32
44	33

Use these equations to answer the next questions:

Azimuth of Summer Solstice Sunrise = 90 – X

Azimuth of Summer Solstice Sunset = 270 + X

Azimuth of Winter Solstice Sunrise = 90 + X

Azimuth of Winter Solstice Sunset = 270 – X

❖ What is the azimuth, in degrees, of Summer Solstice sunrise? What is the azimuth of Summer Solstice sunset? Write your answers here:

Azimuth of Summer Solstice sunrise ___________

Azimuth of Summer Solstice sunset ___________

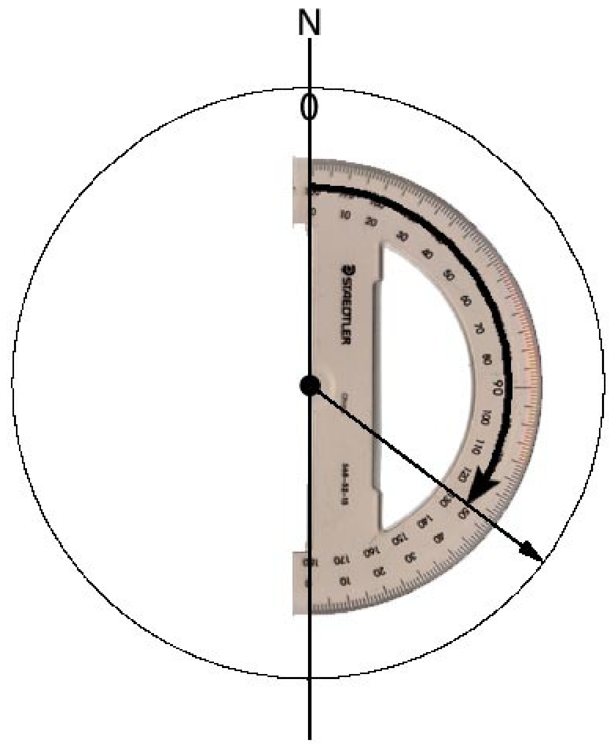
3. On Winter Solstice in the Northern Hemisphere the Sun rises X degrees southward of the east point on the horizon and sets X degrees southward of the west point on the horizon.

❖ What is the azimuth, in degrees, of Winter Solstice sunrise? What is the azimuth of Winter Solstice sunset? Write your answers here:

Azimuth of Winter Solstice sunrise ___________

Azimuth of Winter Solstice sunset ___________

4. Draw a circle on a sheet of paper using a drawing compass. Make the circle large, almost filling the paper.
5. Mark the center of the circle.
6. Using a straight edge ruler, draw a line that bisects (cuts in half) the circle vertically (from top to bottom, running through the center of the circle).
7. Mark the point where the vertical line intersects the top of the circle with an "N" for north.
8. Using a protractor and your calculated azimuths, mark the angles around the circle for all of them, measuring from the N mark—zero—clockwise.
9. Draw a line from the center of the circle to each azimuth mark.
10. Label each point on the circle (for example, "Summer Solstice sunrise," "Winter Solstice sunset," and so on).



Questions:

- ❖ If this were an actual medicine wheel model, where would you stand on the circle's perimeter to see the Sun rise over the center of the wheel on Summer Solstice?
- ❖ Where would you stand to see the Sun set over the Wheel center on an equinox?

Answers for Teachers

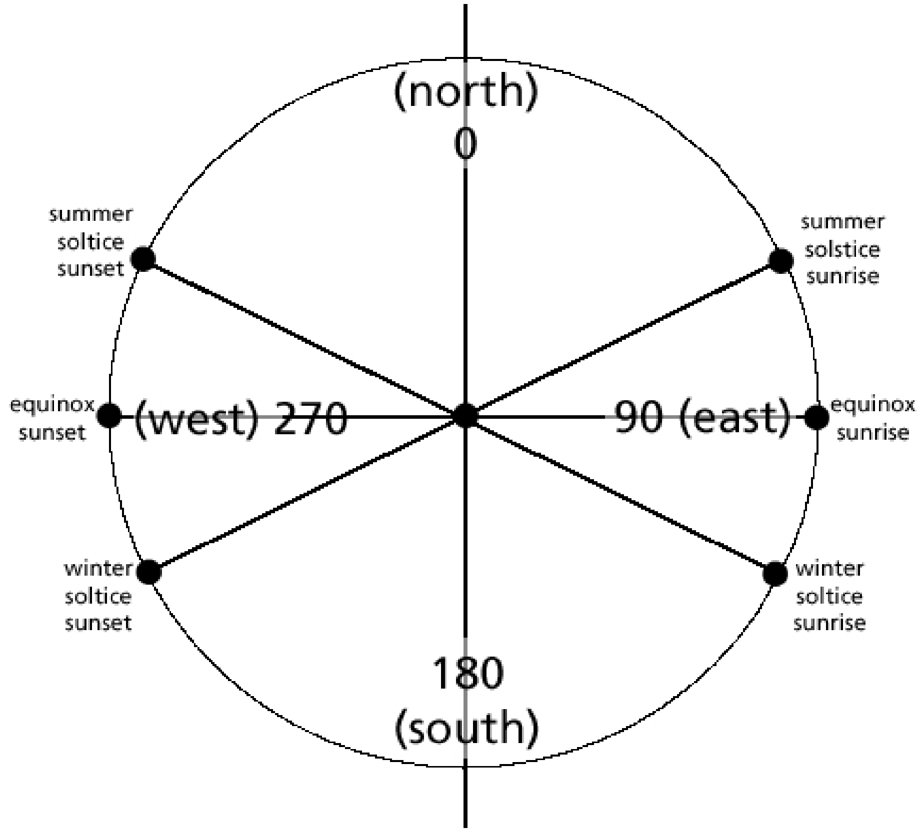


Diagram showing completed marked positions for sunrises and sunsets on the solstices and equinoxes

Question: If this were an actual medicine wheel model, where would you stand on the circle's <u>perimeter</u> to see the Sun <u>rise</u> over the <u>center</u> of the wheel on Summer Solstice?

> Answer: You would stand at the point on the wheel exactly opposite from the Summer Solstice sunrise mark, so that this mark and the center line up in your view. This turns out to be the point marked for the Winter Solstice sun*set*. So, you stand on the spot marked for Winter Solstice sunset and face northeast.

Question: Where would you stand to see the Sun <u>set</u> over the Wheel <u>center</u> on an equinox?

> Answer: You would stand at the point on the wheel exactly opposite from the equinox sunset mark. That is, you would stand on the east point of the wheel and look directly west. This point where you stand is also the point marked for equinox sun*rise*.

Medicine Wheel Writing Project: Proposing a Permanent Medicine Wheel Model

Plan a <u>permanent</u> medicine wheel model for your school.

What to do:

- Carefully observe this picture. This is a photograph of the Bighorn Medicine Wheel. It is located on high mountain ridge (about 2,900 meters above sea level!) in Wyoming. Write your observations and questions in the table below.

Right: Bighorn Medicine Wheel sunset, *photograph by Tom Melham*

I Notice…	*I Wonder…*

- Research actual medicine wheels.
- On a sheet of blank paper, or in your science log, carefully draw your plan for a permanent medicine wheel model for your school. Use the directions on the *Do the Math* pages to help you. What events or objects would you want your

medicine wheel to mark, and why? What materials would you use for construction? Why?

- Write a letter to your teacher or principal, persuading them to let you construct a permanent medicine wheel on the schoolyard, or nearby. Include what you know about medicine wheels, and why you think that this structure would be a valuable addition to your school. Include where you plan to make it, how big it will be, how it will be constructed (painted, made of rocks, or something else), and any other information relevant to your plan.
- Make sure that you have permission to do this project before doing it!

Medicine Wheels

Ancient peoples of the Great Plains of North America--predecessors, and perhaps ancestors, of the Crow, Blackfoot, Cheyenne and others—tended to be nomadic, following herds and food sources on a seasonal basis. The necessity of mobility required a culture that left behind little in the way of material memoirs. The general absence of heavier, more enduring constructs (such as pottery, metalwork, and permanent stone or adobe buildings), major garbage dumps, art works, and written records make study of these people difficult. A few artifacts remain, such as stone spearheads and bone needles, some panels of paintings, and discarded refuse consisting of bones, tools, and charcoal, but the archaeological picture developed from these is fragmentary.

One type of artifact, the stone ring, is a durable legacy left behind by the ancient plains people. Some stone ring sites in Alberta have been dated at 4800 years old—making their construction contemporary to that of the Egyptian Pyramids and England's Stonehenge.

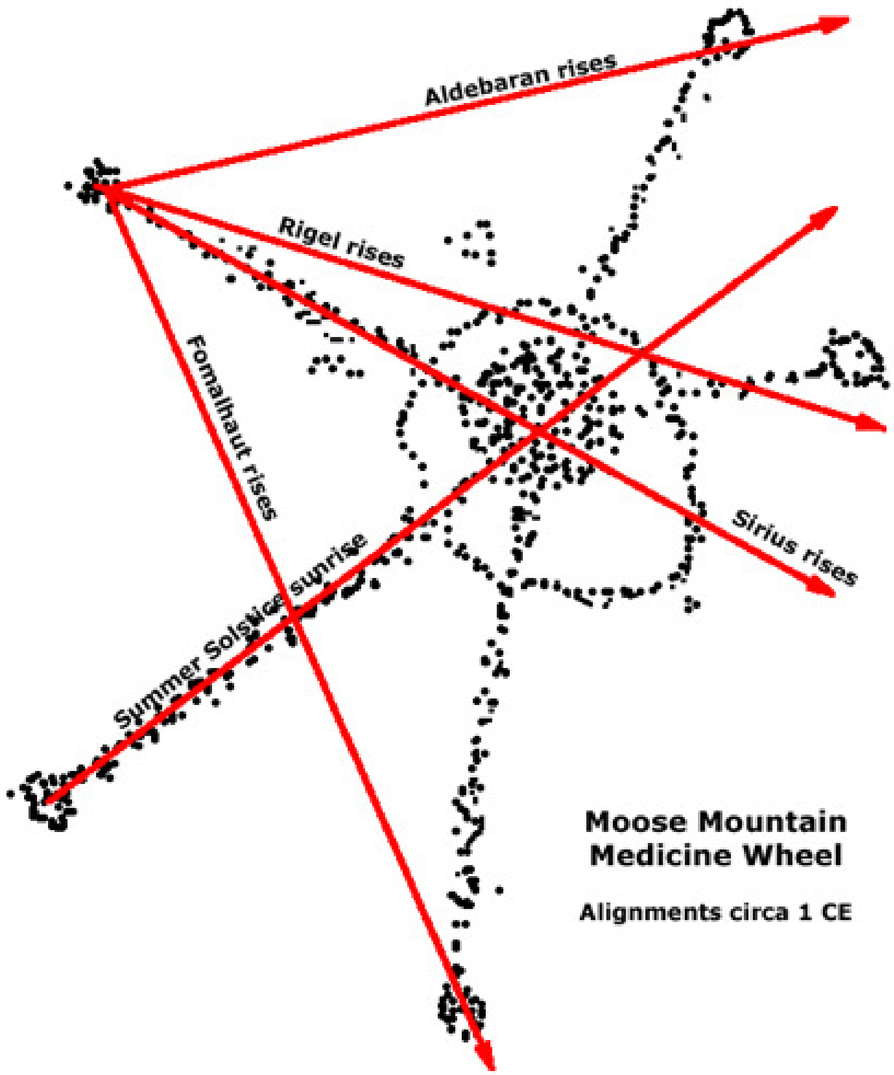
Left: Bighorn Medicine Wheel sunset, *photograph by Tom Melham*

Some stone rings were made around the bases of tipis and lodges, possibly as anchors for the lightweight, mobile dwellings. Other stone rings are associated with rituals for hunting or personal growth and strength. Stone rings are sometimes referred to as "medicine wheels."

Two of these medicine wheels--the Moose Mountain Medicine Wheel in southern Saskatchewan and the Bighorn Medicine Wheel in northern Wyoming—have been studied with another possible use in mind.

On the open plains of southern Saskatchewan, the Moose Mountain Medicine Wheel sprawls across a small rise. The wheel, made up of a central cairn of stones and several spokes radiating from it, is greater than 65 meters in extent, and has been dated to 2500 years old. Over so long a period of time the wheel may have had many uses.

One possible use was first noticed and studied by astronomer Jack Eddy in 1972-74. By using the end of one of the wheel's long spokes as a back-sight and looking across the central cairn, a Sun watcher may witness the Summer Solstice sunrise. From a second back-sight and through or along other petroforms an observer can, at certain times of the year, watch the rising of several prominent stars, including Aldebaran, Sirius, and Rigel. Later, another astronomer, Jack Robinson, found an alignment for the star Fomalhaut. The Aldeberan alignment would have shown that star's heliacal rising on the same day as the Summer Solstice. (A helical rising is when a star is seen to rise briefly before the light of the rising Sun outshines it. Observations of stars' heliacal risings can be used as calendrical markers since the event is only witnessed for span of a few days at the same time each year.)

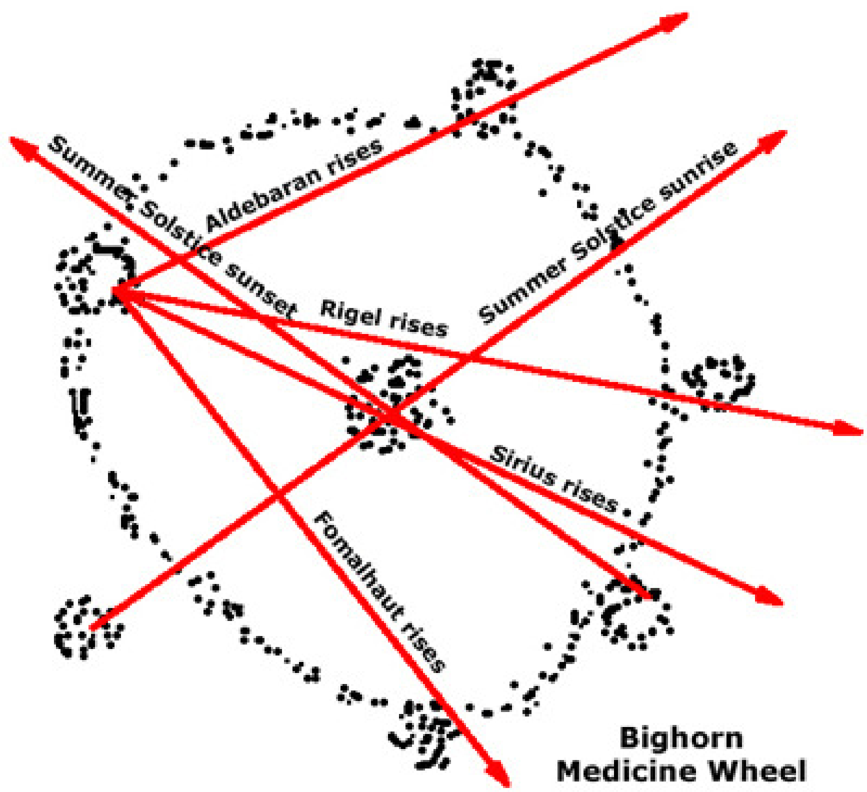


The wheel in the Bighorn Mountains of Wyoming is more recent, somewhere between 300 and 800 years old, and is still used by Native Americans for rituals. The site lies at an elevation of nearly 2900 meters on a spur of 3300-meter Medicine Mountain, overlooking much of the Bighorn Basin. The term "medicine wheel" comes from this particular site.

The stone circle, nearly ten meters in diameter and quite round, looks like a giant wagon wheel laid out on the ground, complete with hub and spokes.

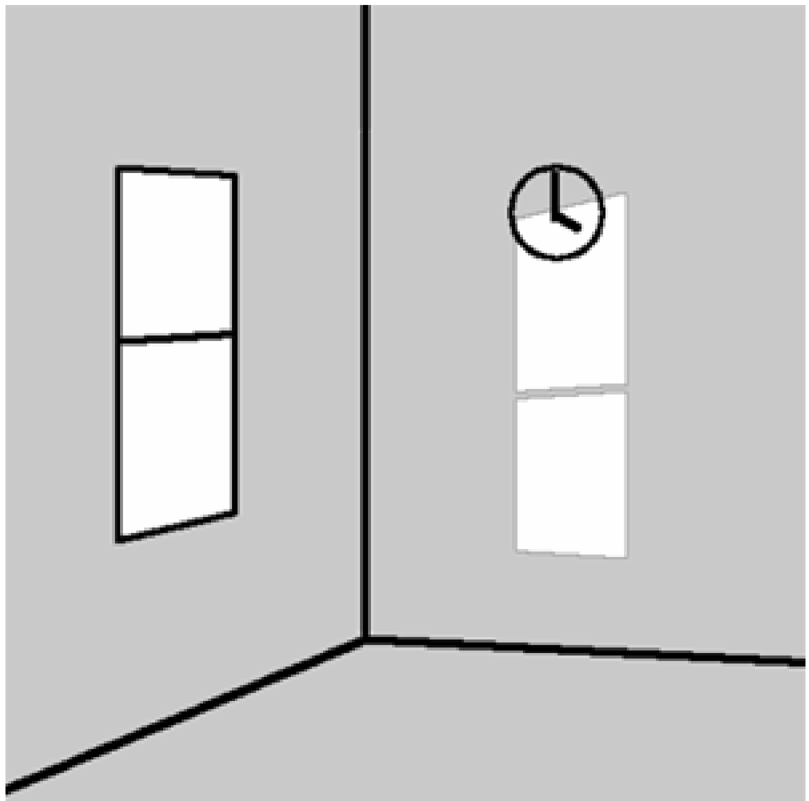
At the hub stands a tall cairn of rocks. Several shorter cairns are positioned along the circle of stones, each connected to the hub cairn by one of the spokes. Other spokes, twenty-eight in all (suggesting the days in the lunar cycle to some), radiate from the hub. Celestial alignments for most of the spokes, if they exist, have yet to be determined.

The Bighorn Medicine Wheel, because of its good condition and frequent use, proved most useful in Dr. Eddy's alignment survey. As with the Moose Mountain Medicine Wheel, one cairn at the perimeter of this wheel follows a spoke through the central cairn in an alignment for the Summer Solstice sunrise. A second cairn serves as a back-sight and combines with other cairns to provide alignment markers of the risings of Sirius, Rigel, Aldeberan, and Fomalhaut.



Classroom Solar Calendar

Orientation



Activity: Observe how sunlight shines into a classroom (or any room that gets sunlight) at different times of the day and different times of the year. Look for repeating patterns as well as changes in the behavior. Keeping a log to describe and sketch observations of when and where certain easily recognized patterns appear, students will turn the room into a solar calendar that may survive into the future for other classes to use. The classroom calendar can become a sort of time capsule—one made of light, shadow, and a record of observation left behind by a class.

Objectives: 1) Students will engage in an ongoing investigation to find patterns of sunlight and shadow and how they change over time. This will help them better understand the cycles of the Sun. Students rarely have the opportunity to engage in long term observations or investigations. This on-going activity provides an opportunity for them to observe change with time firsthand. 2) Students will develop and enhance their scientific thinking skills—especially observation, reasoning from evidence, and looking for patterns. 3) They will write for an authentic purpose: to keep a detailed and specific record of observations.

Materials: A room that receives sunlight through a window for some period of the day; a notebook; a large piece of paper; keen observational skills!

Grouping: Whole class or individual project.

Time: Part 1, occasional note taking and casual observation over the course of a day; Part 2, 30-60 minutes to create the calendar record, then casual observation and note-taking throughout the school year.

Connection: Some ancient cultures carefully observed the direction and pattern of sunlight entering buildings through windows or shining through natural rock openings onto other rocky features and learned how the patterns of light and shadow were different at different times of the year. In some cases, the observers may have purposely built shapes in windows, walls, doors, and other architectural features to create desired light and shadow patterns for special days of the year, such as the solstices and equinoxes.

Part 1: Observing and Recording Patterns of Light and Shadow

What to do:

1. If you can find a room in your school (hopefully your own classroom) that sunlight enters through the windows, you can use the room to create a solar calendar!
2. Take note of how sunlight comes into your classroom. Can you tell when the first ray of sunlight begins to enter the room during the day? When the last ray disappears? During the day, can you find any interesting patterns of sunlight and shadow? Do any remarkable patterns show up at certain times, or shine on special parts of the room?
3. Create a notebook of any observations you make. Include any of the observations on the following list, but feel free to add ideas to the list. Write down the exact time and the date for each observation, and write a detailed description and a careful drawing of the special pattern or alignment you have observed.
   - ❖ First ray of sunlight for the day
   - ❖ Last ray of sunlight for the day
   - ❖ Interesting patterns made by sunlight and shadow at certain times
   - ❖ Special alignments of sunlight rays and objects in the room at certain times
4. Once you start recording observations, go back each day to each of the places you have observed, at the exact same times that you made the original observation. If you notice anything about the pattern that is different from your original observation, add a description of the change.

Tips:

- ❖ Look for patterns of light or shadow that are formed with the room's permanent structures—those parts of the room that don't get moved around, like walls, floor, doorways, windows, all clocks. Don't use moveable objects like tables, chairs, pictures and posters on the wall, and the like.

- Make your descriptions detailed enough so that someone else could read them and know exactly what part of the room you are talking about.
- Patterns of light cast by windows, especially window corners, make good shapes to mark special alignments with.

Questions:

- What interesting patterns of light and shadow did you find in your classroom?
- How could you use your observations to tell the time of day in your class without looking at a clock?
- What did you notice from day to day about the patterns you found?
- What do you think is going on?
- What are some possible explanations for the changes you observed?

Sample Page of Observation Notebook

Name: *Brigit Jones*

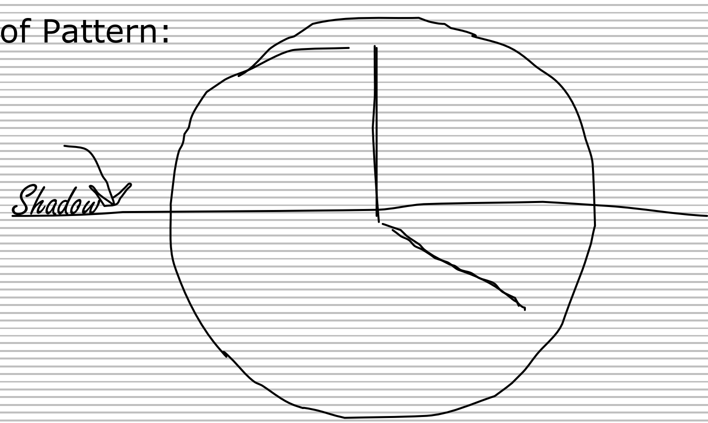
Date: *January 3, 2004*

Time: *4:00 o'clock PM, Pacific Standard Time*

Location: *Roosevelt Elementary School, Room 12*

Description of Pattern: *At exactly 4:00 o'clock in the afternoon on January 3rd, the shadow made by the top of the window near the northwest corner of the classroom exactly cuts the dial of the wall clock in half. I noticed this pattern because the straight line made by the shadow goes exactly through the center of the clock where the clock hands also cross.*

Drawing of Pattern:



Part 2: Creating a Classroom Calendar

What to do:

1. Looking over your notebook of observations and descriptions, find your favorite one—maybe one in which it was easiest to see a pattern or alignment, or one that made the most unusual or memorable shape.
2. On a large piece of paper (as large as you think is appropriate), create a Classroom Calendar to leave behind for future classes. This "calendar" will include a complete description of the light and shadow pattern, a careful drawing of the pattern, and a map of the classroom with a careful diagram showing how the Sun's light enters the room (through which window, hitting which part of the room). The exact date(s) and time of the pattern must also be included.
3. Observe the pattern of shadow and light you have recorded over the course of the year. If you notice any changes, be sure to record them in your notebook, and on the Classroom Calendar.
4. Write a letter to future students to slip into the front of your notebook. Introduce yourself and your notebook. Describe in detail how the calendar works for time, seasons, or special days. For example, "*In January at precisely 11:00 AM, the Sun casts a shadow….*" Give directions so future classes will be able to use your calendar!

You are creating a sort of time capsule: a record of your observation for future "generations" to see and use, and possibly to compare their own observations to. You might eventually be thought of by future students as a "student ancestor," or "ancient Sun observer" who left behind your work and your observation. Discuss with your teacher good ways to present and preserve your work to future generations....

Do the Math

Activity: Measure and construct a scaled drawing of the room in which you have observed a special light and shadow alignment with an object or location in the room. This accurate room map may be included in the Classroom Calendar you created in Part 2.

1. Using a tape measure or other tool, measure the length and width of the room, in meters, rounding to the nearest tenth of a meter. Write down the dimensions:

   Room Length _______

   Room Width _______

   If your room is not a simple rectangle, it may help to sketch a rough shape of the room and record your measurements on the sketch.

2. Choose a scale for you final map of the room. The scale of the map described in this example is one centimeter per meter—in other words, one centimeter on this map represents one meter in the actual room.

3. Carefully draw your scaled map, drawing the length of each wall accurately at your map scale. Use a protractor or square to make sure that walls that make a right angle with each other are drawn at right angles on your map.

   Tip: If any of the walls in the room do not meet at right angles, there are at least a couple of methods to draw them on your map.

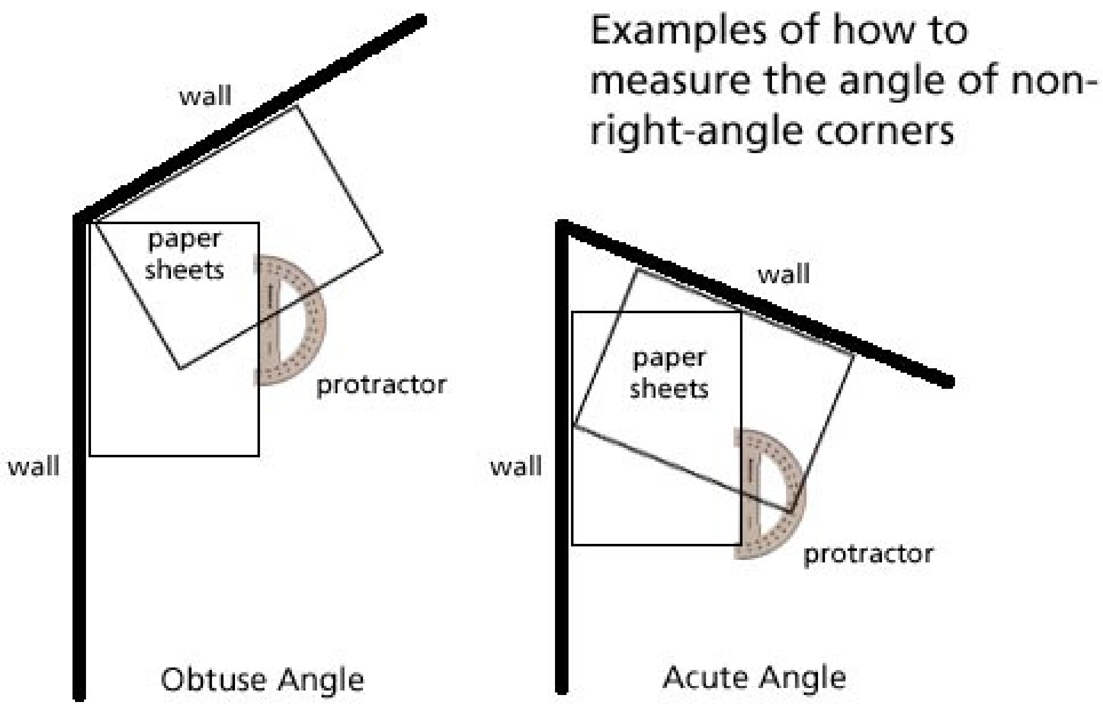
   Method 1:

   Draw all of the right angle walls on your map first, and then connect any loose ends with a straight line. This will only work if your room is a quadangle with at least two right angles. If you have a very oddly shaped room, try Method 2.

   Method 2:

For each non-right-angle corner in your room, place two rectangular pieces of paper in the corner, on the floor, one flush with one wall, the other flush with the other wall. See the picture below, which shows how to lay down the paper for both obtuse and acute angled corners.

With a protractor, measure the angle between the edges of the pieces of paper on the sides away from the walls. This angle is equal to the angle of the corner.



4. Accurately <u>measure</u> and then <u>draw</u> on your scaled map the following:
   - ❖ Doors (both edges)
   - ❖ Windows (both edges)
   - ❖ The object or feature of the room where your observed special alignment takes place.

- ❖ Extra: If you know which window—or better, which part of which window—the sunlight making your observed alignment shines through, measure and map its location also, then draw a straight line between it and the observed alignment spot.

Question: At what angle does the beam of sunlight making the alignment pattern enter the room at the observed time?

Solar Calendar At Home

Try this at home! Find a spot in your bedroom or other room in your house where sunlight comes through the window, and do this activity. You can draw or photograph the patterns.

The Sun Dagger

The ancestral Puebloan people of the American Southwest used the landscape in making highly accurate observations of the progress of the Sun's motion during the year. Sometimes, Sun watchers would use the profile of the desert horizon to mark the passage of the Sun; other times they would use the effect of shadows and light to inform them of certain dates. Many of their building sites are located near observation posts where a striking view of the solstice sunrise or sunset will align with a specific feature of a wall across the canyon—a niche or a tower, for example.

Several ancient Chacoan buildings seem to be built so carefully that light enters windows during solstices and shines on opposite walls, which are sometimes further marked with murals or carvings. And some of the artworks found in the canyon are placed in such a way as to use the shadow falling on an exact location to create very precise time markers.

The best known of these artworks can be found in Chaco Canyon. The site known as the *Sun Dagger* on Fajada Butte, the prominent land feature rising from the center of the canyon floor, was rediscovered in 1977 by artist and archeologist Anna Sofaer.

Right: Fajada Butte, site of the Sun Dagger. *Photo credit IDEUM*.

While she was recording images for a catalog of ancient art works, Sofaer noticed an unusual figure of light passing through the center of the petroglyph she was photographing. Around midday, a "dagger" of light, coming through a gap between two of three large vertical stone slabs, fell exactly onto the center of a spiral carved onto the sandstone. She noted that the date was a few days before Summer Solstice. Subsequent observation showed her that this petroglyph and the dagger of light shining between the stone slabs marked the Summer Solstice.

Through continued research on the site, Sofaer and her colleagues discovered several other special dates marked by the Sun Dagger, including the Winter Solstice, the equinoxes—and *possibly* the 18.6

year cycle of the Moon's rising and setting extreme points, or lunar standstills. Sofaer's research led to many other important discoveries in archaeoastronomy, and in Chaco Canyon and its culture in general.

As important as any other discovery connected to the Sun Dagger is the association between the astronomical observation posts and works of art. Often, calendrical stations will have prominent artwork associated with them. In some southwestern cultures the spiral is a representative of the Sun, and in others it is the turtle or perhaps an anthropomorphically shaped being with a shield-shaped torso. Researchers have used these artworks as clues to alert them that a Sun watching station may be nearby.

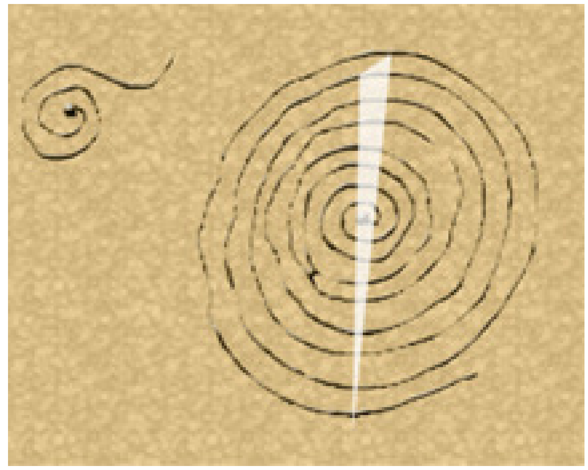
At Piedro del Sol, another Sun watching station in Chaco Canyon, the spiral indicates where an observer is to place their head in order to see the Summer Solstice sunrise at a unique spot on the local horizon.

At Painted Rock, an artifact from a contemporary culture in what is now central Texas, light falls on a pictograph pointing out the time of year, much as it does on Fajada Butte.

Other extensions of the Sun Dagger discovery have been an overall understanding of the value of celestial, and especially solar, observation to the ancestral North Americans, a possible explanation of their sophisticated architecture, and insight into the depth of their scientific concerns. The tracking of lunar standstills and the recording of unusual phenomena such as eclipses, comets, and supernovae are some examples of their curiosity about the sky.

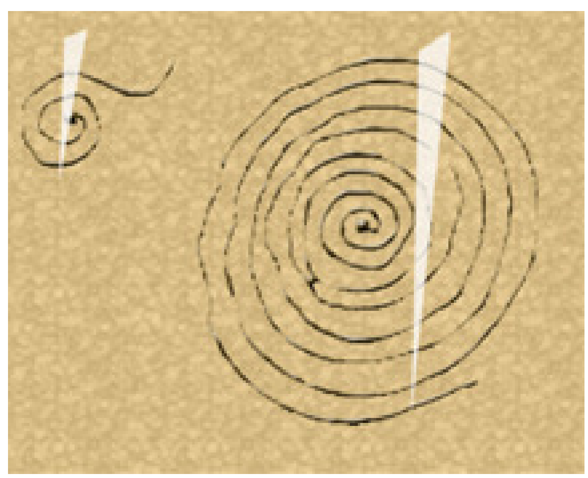
The Sun Dagger was the first discovery of its kind in this area, and it is leading to a greater understanding of these ancient peoples and their neighbors. Unfortunately, today the Sun Dagger no longer functions as a seasonal marker. Erosion caused by a huge influx of curious visitors and scientists have caused the great stone slabs to shift. Today, the site is closed an off limits to visitors.

On **Summer Solstice**, a dagger of light coming from between one pair of the three rock slabs pierces the center of the large petroglyph spiral.



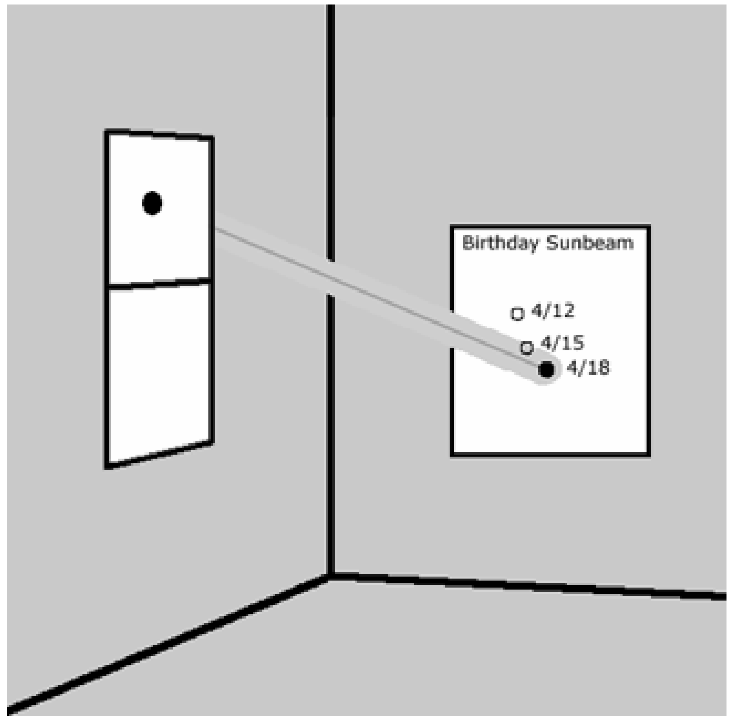
On **Winter Solstice**, two daggers of light, coming through both gaps between the three rock slabs, bracket the large petroglyph spiral.

On the **equinoxes**, a small dagger of light pierces the center of the small petroglyph spiral, and a second, while a larger dagger falls on the larger spiral.



Birthday Sunbeam

Orientation



Activity: Using a shadow spot formed by sunlight entering the classroom (or any room into which sunlight enters each day), track the apparent motion of the Sun caused by the Earth's orbital motion around the Sun. Day by day, and throughout the school year, build a Sun track, as a class following the progress of the Sun's annual motion. To make a personal connection to the activity, spots marked on a student's birthday can be labeled with the student's name, for the class and future classes to view.

Objectives: 1) To better understand the apparent motion of the Sun. 2) To engage in a long-term systematic observation.

Materials: A room with a wall that sunlight shines on for at least some of the day; a large piece of butcher paper; colored markers; pencil; a sticker dot; a large chart—the Observation and Question recording sheet—labeled "I Notice" and "I Wonder", to be posted near the Birthday Sunbeam chart.

Grouping: Whole class or individual project.

Time: Part 1, establishing location, casual observation over the course of a day; Part 1, setup, 15 minutes; Part 2, "daily" (Monday, Wednesday, Friday is fine) marking of Sun-track, 1-2 minutes at a specific time of day over the course of at least a month.

This activity should be run for at least a month, but is best as a school-year-long project. For most of that time, very little class time is needed: a student or students assigned to make observations for a given day or week would spend only a moment.

Connection: Ancient Sun observers became well aware that the place that the Sun appears at a given time of the day changes throughout the year, but in a cycle that repeats precisely each year. The position of the Sun, and any shadows created by it, changed throughout the year, but could be relied upon to return to the same spot on a specific day. This most basic form of solar calendar was very important to cultures who depended on agriculture, and whose important season-related ceremonies were required to occur on specific dates.

Part 1: Setting Up

What to do:

1. Find a place in your classroom (or at home) where sunlight enters through a window and shines on a part of a wall that is easily within your reach.
2. Write down the exact time of day when the sunlight shines on the wall. This is your daily observation time.
3. Stick a small disk of paper, cardboard, or a sticker dot—two or three centimeters or so in diameter—on the window glass so that you can see its shadow falling on the wall. Keep in mind that you will mark the position of the dot's shadow at the daily observation time each day.
4. On the wall where the sunlight and dot shadow fall, clear a space where you will make your daily observation markings. A large piece of butcher paper, firmly and smoothly attached to the wall with thumbtacks or masking tape, will work well (as long as you can move the paper later on, if necessary).
5. Set your Observation and Question recording sheet ("I Notice…I Wonder…") on the wall or on a table nearby. Below is an example of this sheet.

	I Notice…	***I Wonder…***
Jan 25		
Jan 27		
Jan 29		
Etc.		

Example of Observation and Question recording sheet

chabot space & science center

Part 2: Tracking the Sun Shadow

What to do:

1. At the daily observation time, mark the position of the dot's shadow with a bold color (like red), but draw your mark small—no bigger than a centimeter or so (if the shadow of the dot is larger than this, then just mark the center of the shadow). Label each mark with the date, using a fine pencil. <u>Write small</u>.
2. Continue making daily observations for as long as you can. If observations are not made every day, that's okay—you may not be able to make weekend observations anyway. Try to make a mark every weekday, or at least Monday, Wednesday, and Friday, of each week.
3. Record at least one observation ("I Notice") and one question ("I Wonder") on your Observation and Question recording sheet.
4. As the weeks go on, mark special days on the Sun-Dot observing wall: students' birthdays, beginning and end of Winter break, Spring break, and special annual days (like Groundhog Day, Autumn and Spring Equinox, Winter Solstice, etc.).

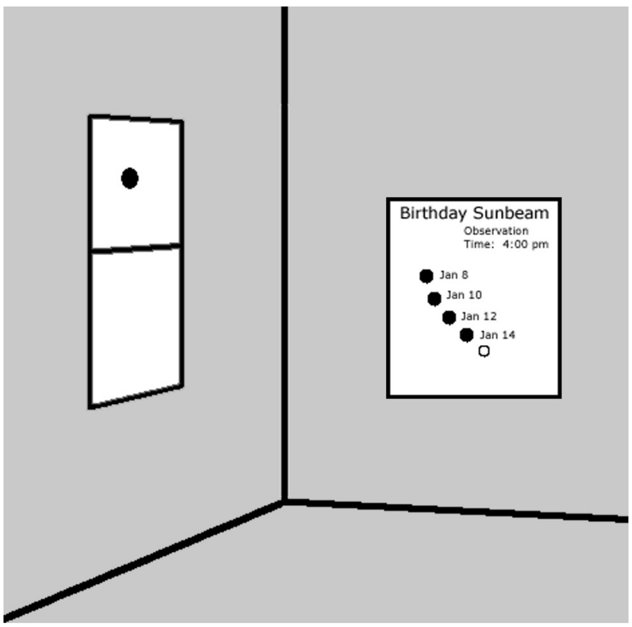
Depending on how long you can make observations, a pattern may appear in the Sun dot marks.

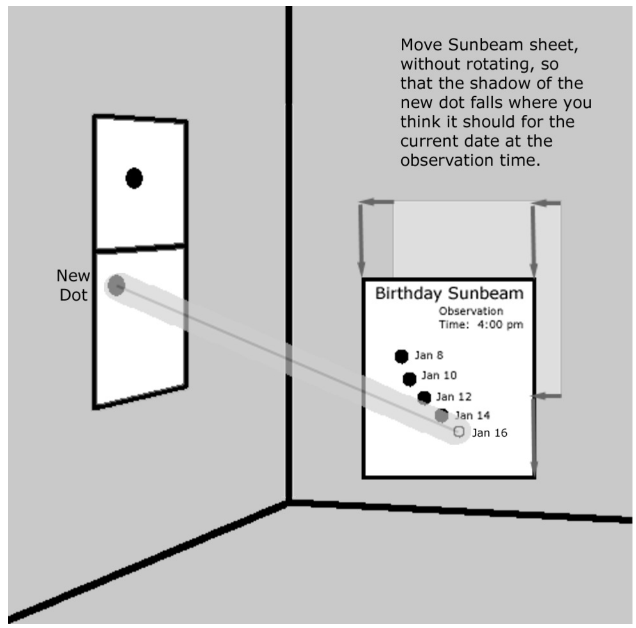
Important: Once you begin observing, make sure that both the window dot and the marking paper are not moved or disturbed!

Important: If, as time goes on, you find that the shadow of your window dot no longer shows up at the daily observation time, **don't panic**! It is possible to correct for this. Here is an example of how to do it:

Let's say that you made dot shadow marks at 4:00 pm every day from Jan 8 to Jan 14, every other day, but then you came to mark the shadow on Jan 16 and found no sunlight shining on the sheet where you need it.

Solution: Find a surface (preferably on the same wall or floor that you've been using) where there is sunlight shining at 4:00 pm, move or replace the original shadow dot so that you can see its shadow, then carefully move the sheet, without rotating it, so that the shadow of the new dot falls on the spot that is your best guess for where the Jan 16 dot should have been.





Questions:

❖ What do you notice about the position of the daily sun dot?

❖ If it does move, which way does it go? How far does it move each day?

❖ Over the weeks and months, does a shape or pattern appear? What is the shape or pattern?

❖ What might be some explanations for any changes you see? If you see a pattern, what do you think explains that pattern?

- ❖ Look back at your observations and questions. What are some things you now understand that you did not understand before?
- ❖ What are some questions you still have?
- ❖ Which questions do you think you'll be able to answer by continuing to carefully observe?
- ❖ Which questions do you think you'll need to research to find the answer?

You might expect that at a given time of the day, the Sun will always return to the same spot in the sky, and so any sunbeams or shadows would be in the same spot every day at that time.

The height in the sky that the Sun reaches at a given time of the day changes with the season: in the summer, the Sun is higher at a given time than in winter. This means that at a given time of the day, the Sun's position changes from day to day.

Do the Math

Activity: Measure and calculate the average daily motion at which the sunbeam shadow moves.

1. Starting with the sunbeam mark with the *second earliest* date, write down that date in the Data Table, column 1, row 1.
2. Measure the distance, in millimeters, between this mark and the mark with the first (*earliest*) date. Write down the answer in column 2, row 1.
3. Calculate how many days there were between the dates of these two marks and write down the answer in column 3, row 1.
4. Calculate the *average daily motion* that the sunbeam moved between the two marks, using this formula:

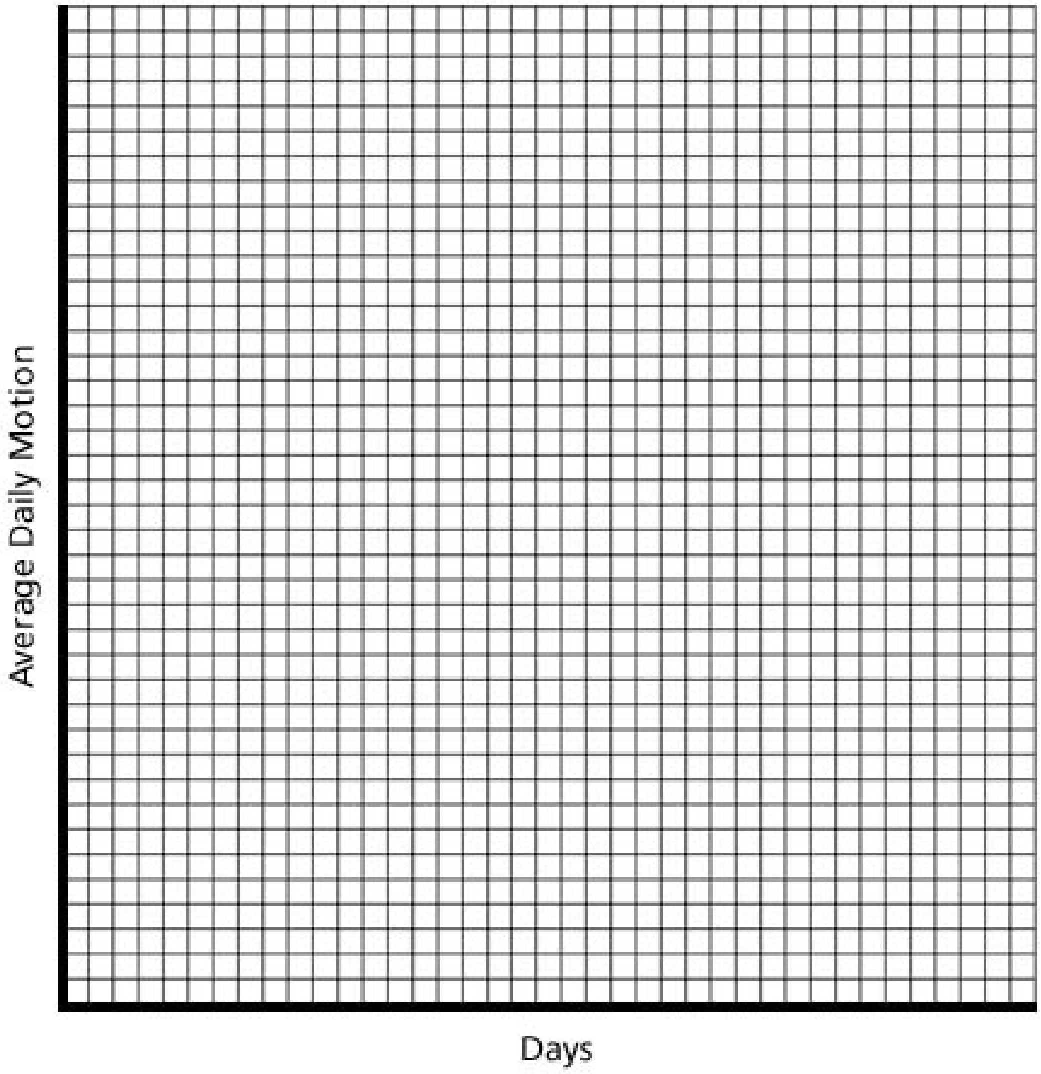
   Average Daily Motion = Distance Moved ÷ Number of Days
5. Repeat the steps above for each pair of neighboring marks. For example, in row 2, do the math for the third date compared to the second date, in row 3 do the math for the fourth date compared to the third date, and so on.

Data Table

Date	**Distance Moved Since Previous Mark (millimeters)**	**Number of Days Since Previous Mark (days)**	**Average Daily Motion**

Question: What are the mathematical units of "Average Daily Motion"?

6. Graph the Average Daily Motion numbers you calculated. The horizontal axis is time (days) and the vertical axis is the Average Daily Motion.



Sample Graph

Questions:

- Does the Average Daily Motion stay the same? Does it change?
- If it changes, in what way?
- What do you think is happening?

Leaving a Time Capsule

If you can leave the Birthday Sunbeam chart and window dot (unmoved!) and your Observations and Questions sheet until the next year, then the class that comes after you will have a chance to see your work, and notice whether or not any patterns that you found repeat the next year.

Write a note to future students. Describe what you did, what you discovered, and what questions you still have. Leave this with the charts.

The Analemma

If the relationship between Sun and Earth were "perfect"—Earth pursuing a perfectly circular path around the Sun and with no tilt in its axis of rotation—the Sun's position in the sky could be used as a reliable marker of time, day after day after day. In such a world, the Sun would appear at the same spot in the sky at exactly the same time each day, and any shadows or light beams cast by Earth-bound objects would likewise serve as reliable clock-hands.

But Nature's approach to perfection doesn't require circular motions and square alignments…. Earth's tilt on its axis and the elliptical shape of its orbit cause the Sun's position in the sky at a given time each day to change.

The seasonal trek of the Sun over the latitudes between the Tropics of Cancer and Capricorn, caused by the changing orientation of Earth's poles as it revolves, makes the Sun's position in the sky shift north-to-south, and south-to-north, over a year.

Following an elliptical orbit around the Sun that brings it alternately closer to and farther from the Sun, Earth's velocity changes, speeding up as it falls closer to the Sun, and slowing down as it climbs away from the Sun. This changing orbital speed causes a corresponding change in the behavior of the Sun's apparent motion, the Sun's apparent position in the sky cyclically slowing down or speeding up. This causes a variation in the east-west position of the Sun in the sky at a specific time of day—and, again, a corresponding variation in the position of a shadow or sunbeam.

Right: The analemma—the pattern of the Sun's variation in position in the sky at a specific time of day throughout the year.

Combining the annual north-south and east-west variations in the Sun's position for a given moment of the day, a pattern emerges: the figure-eight trace called the "analemma." If you were to photograph the area of the sky containing the Sun at the same time (by the clock) on days throughout the year, the shape of the analemma would become apparent.

The same characteristic pattern will be seen in the behavior of sunbeams or shadows cast by Earth-bound objects, whether it is the shadow of the tip of a gnomon, a hole projecting a beam of light, or the shadow cast by a paper dot in a window. Given observations over a long enough span of the year, the figure-eight analemma pattern will become apparent on the Birthday Sunbeam plot.

Tetherball Gnomon

Orientation

Activity: Using a tetherball pole (or an alternative) and the shadow the Sun casts, determine the exact directions of north, south, east, and west.

Objective: To better understand the motion of the Sun in relation to the Earth, and how geographic directions are defined.

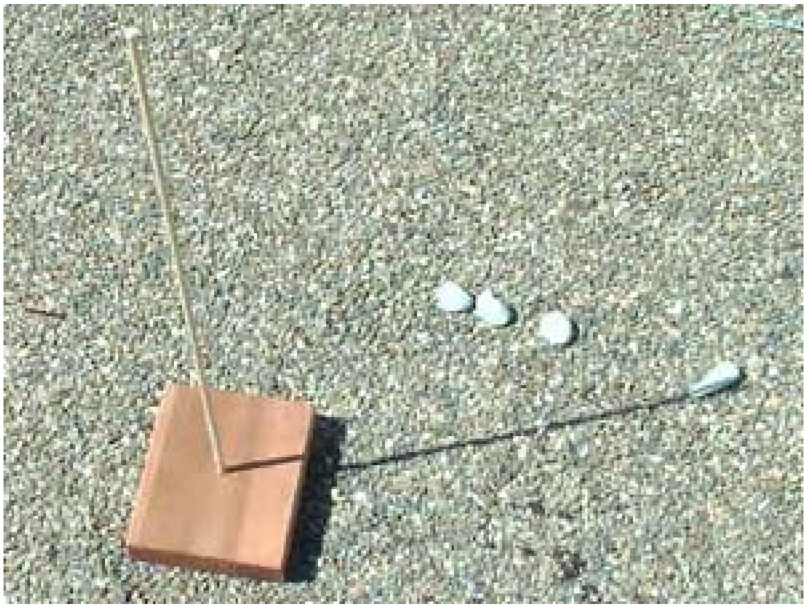
Materials: A tetherball pole, or other vertical stick; string; sidewalk chalk; rocks (option used for a dirt surface, if asphalt or concrete are not available).

Grouping: Whole class or individual project.

Time: Part 1, initial marking with whole class, 10 minutes, and subsequent markings by one or two students, less than 5 minutes every half hour over a four-hour period; Part 2, 10 minutes.

Connection: Many ancient cultures around the world used a simple device called a *gnomon*, for a number of purposes. A gnomon is a straight, vertical pole or stick planted in the ground. When the Sun is out, the gnomon casts a shadow whose direction and length depend on the Sun's position. Some cultures used the gnomon to determine the dates of the solstices and the length of the year. Ancestral Puebloan observers may have used the gnomon to determine the "cardinal" directions: north, south, east, and west.

Part 1: Observing With the Gnomon



Many schools—particularly elementary schools—have tetherball courts. If you don't have one, you can mount a straight stick or pole vertically on a flat, horizontal surface (asphalt or concrete work best, but sticking a pole into dirt works also).

The best tetherball pole to use is one that is in <u>full sunlight</u> for <u>most of the day</u>, one that is <u>vertical and unbent</u>, and one that is built on asphalt or concrete.

If you are going to use a tetherball pole in asphalt or concrete, you will use sidewalk chalk to mark shadow positions. If your gnomon's shadow will be cast on dirt, you can use small stones instead.

What to do:

1. Sometime in the morning (no later than 10:00 AM), the class should begin the observation by marking the position of the tip of the gnomon's shadow (marking with chalk on asphalt, or setting down a small stone on dirt). Label the mark with the actual time of the day.
2. Carefully sketch your gnomon in your log. Mark the changes you see on your diagram or illustration. Be sure to write the time next to the "rocks" or time marks.

Questions:

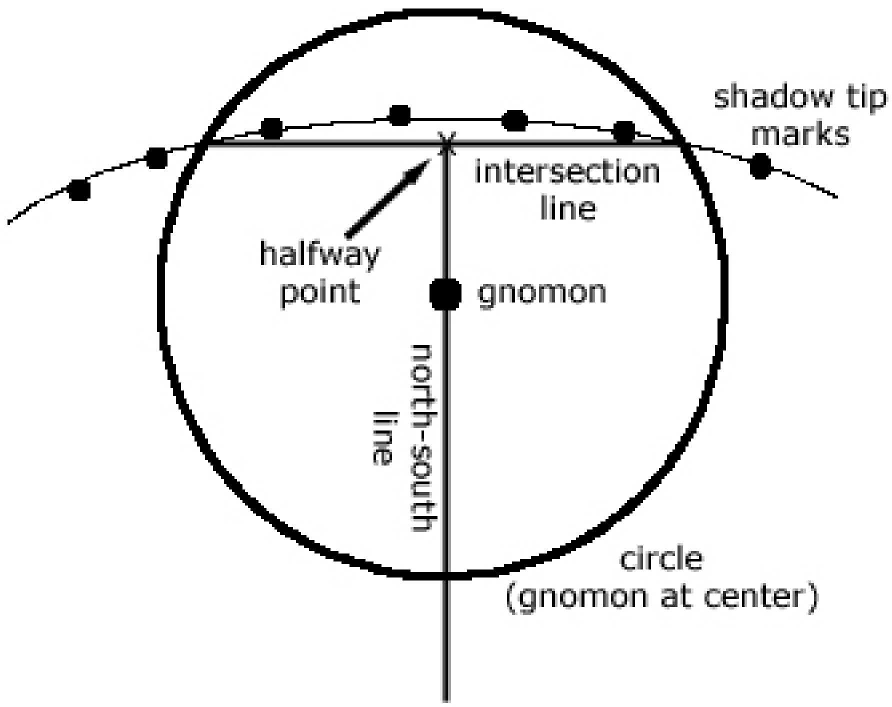
- ❖ What direction is the tetherball pole's shadow pointing? How long is it?
- ❖ What direction would you expect it to point at sunrise? Sunset? Noon? Midnight?
- ❖ Predict how you think the direction and length of the shadow might change as the day goes on.

3. From this time until at least 2:00 PM, a student or students will come out and make additional marks every half hour, marking the position of the gnomon's shadow tip. Label each mark with the time of day. Students will also keep a record of the gnomon's shadow by recording a sketch in their logs.

Part 2: Finding North

The path of the Sun through the sky each day is symmetrical around the north-south line; the half of its path from sunrise to noon is a mirror image of the other half, from noon to sunset. Likewise, the path of the gnomon's shadow tip is also a symmetric curve, mirrored in the north-south line. This symmetry can be used to draw the north-south line.

What to do:



1. After the final observation, as a class draw a line (or lay down a length of string) connecting the marks you have made through the day.
2. Get a piece of string, tying one end around the base of the gnomon and the other end around a piece of sidewalk chalk. The string's length (from gnomon to chalk) should be <u>longer</u> than the <u>shortest distance</u> from the gnomon to the line of observed shadow positions.
3. Holding the string tight, use the string to guide the chalk and draw a perfect circle on the ground, so that the <u>chalk cuts your line of shadow positions at two points</u>—preferably as far from one another as possible. See the diagram above. If you need to adjust the length of the string before drawing the circle, do so.

The two points where the circle cuts the line of shadow positions are equally distant from the gnomon (the length of the string), and so are mirror images of each other in the north-south line. The north-south line you are constructing runs through a point exactly halfway between these two mirror image points, and also through the gnomon itself.

4. Using a stretched string or a straight edge, draw a straight line between the two points where your circle cuts through your line of shadow positions.
5. Draw a mark exactly halfway along this straight line—“bisect” the line.
6. Draw a straight line from the halfway point you just marked to the base of the gnomon. This line runs directly north-to-south.

   Question: Which way is north and which way is south? Label north and south.
7. Draw another straight line through the gnomon that is perpendicular to the north-south line. Question: Which directions does this line run? Label the ends of this line with the directions they point.

Questions:

❖ Do you believe that this activity has really shown you the directions of north, south, east, and west? Why?

❖ Why do you think it would be important for an ancient culture to know these directions? What might be another reason?

Part 3: Additional Activities

Make a Solar Clock: When your day's observations are done, try this: Look at the times when each mark was made and try to estimate the whole hour times of the day (9 o'clock, 10 o'clock, 11 o'clock, etc.) between your shadow mark times ("interpolate"—guess the times between measurements). Mark and label the whole hour times as best you can. You've just made a sundial clock.

Guess the Shadow Positions: Looking at the line you have drawn connecting the shadow positions, use another color of chalk and try to extend that line before and after the times that you observed ("extrapolate"—or guess the shadow tip positions outside of your measurements). These new lines are your best guess of where the shadow tip will fall at times earlier and later in the day. Come back the next day, early in the morning and then later in the afternoon, and check to see if your guess was right.

Shortest Shadow: At what time of day was the gnomon's shadow at it's shortest? Is this a special time of day? What direction does the shadow point at this time? Measure the length of the gnomon's shadow when it was shortest, and write down that length, the time it was that shortest length, and the date. Keep this sheet of paper safe, and come back on different days throughout the school year at the time you recorded (shortest shadow) and measure the shadow's length again. Keep a log of dates and shadow lengths.

Questions:

- ❖ Over the year, do you notice any difference in the length of the gnomon's shortest shadow? How does it change?
- ❖ When during your observing time was it shortest? Longest?

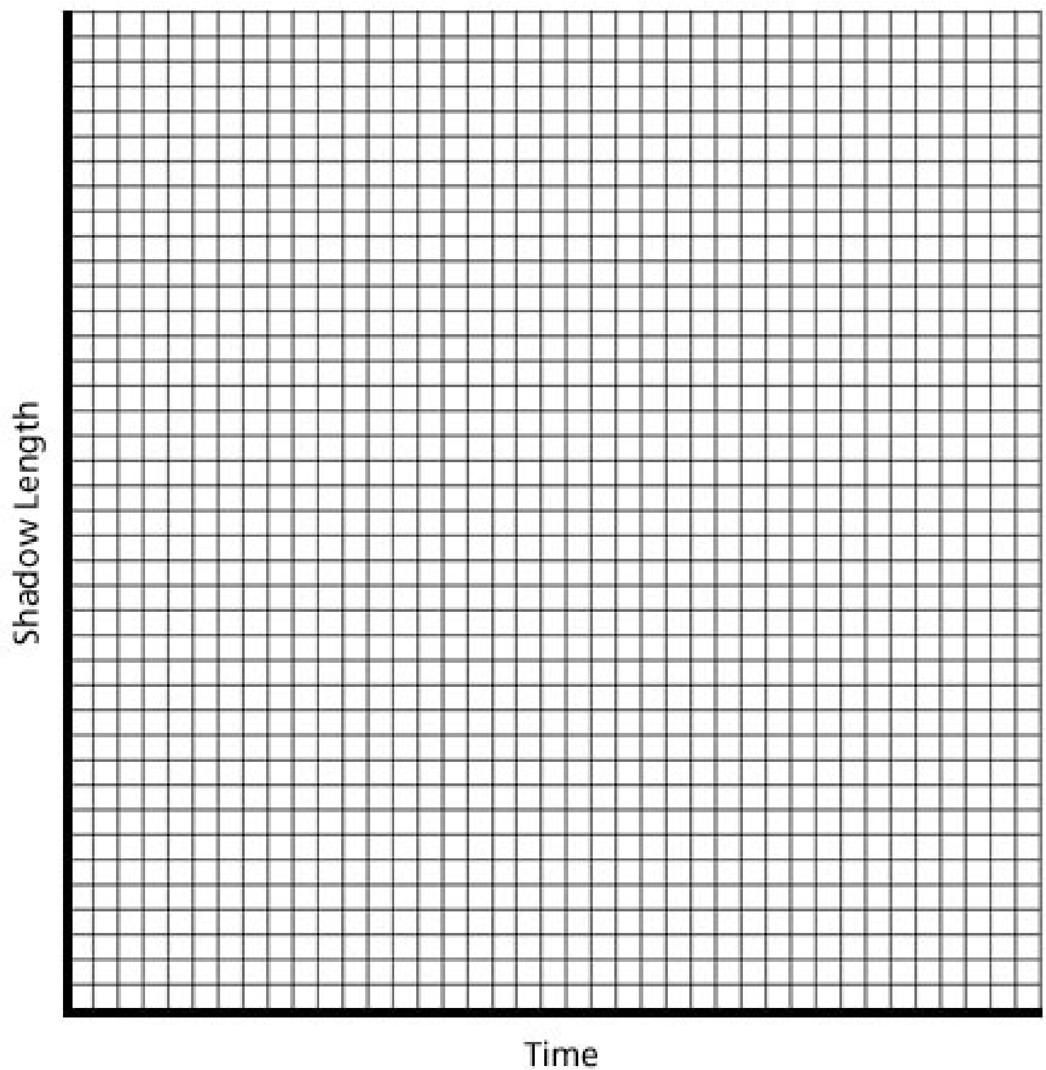
Do the Math

Activity: Make and use a graph of the Tetherball Gnomon's shadow length at different times.

1. Prepare a graph, labeling the horizontal axis as time and the vertical axis as shadow length. (See the sample blank graph on the next page.)
2. Scale the axes of your graph appropriately so that their end values are close to the minimum and maximum times and shadow lengths in the table you filled out in Part 1. For example, if your recorded times start at 10:23 AM and end at 1:15 PM, you might label the time axis to start at 10:00 AM and end at 2:00 PM.
3. Graph the data points (shadow lengths versus time) from the table you filled out in Part 1.
4. Try to draw a smooth line or curve (whatever fits best) through the data points you have graphed.

Questions:

- ❖ Can you use your graph to predict what the shadow length will be at any time during the period of observation?
- ❖ Can you use your graph to figure out the exact time when the shadow was shortest?
- ❖ What's special about this time?



Sample Graph

Making a Permanent Tetherball Gnomon

Plan a permanent Tetherball Gnomon for your school.

What to do:

- Get permission from your teacher and principal to do this project.
- Research actual direction-finding gnomons.
- Decide where to make it.
- Decide how to build it. Will you paint the lines? Will you use other materials? What will you use for a gnomon, and how will you set it up?
- Plan how you will construct it. Make detailed drawings, including accurate measurements. If you plan to use an existing tetherball pole, include its height and base your drawing dimensions on it.
- Get final approval from your teacher and principal before you begin to build it.

Gnomons and Direction Finding

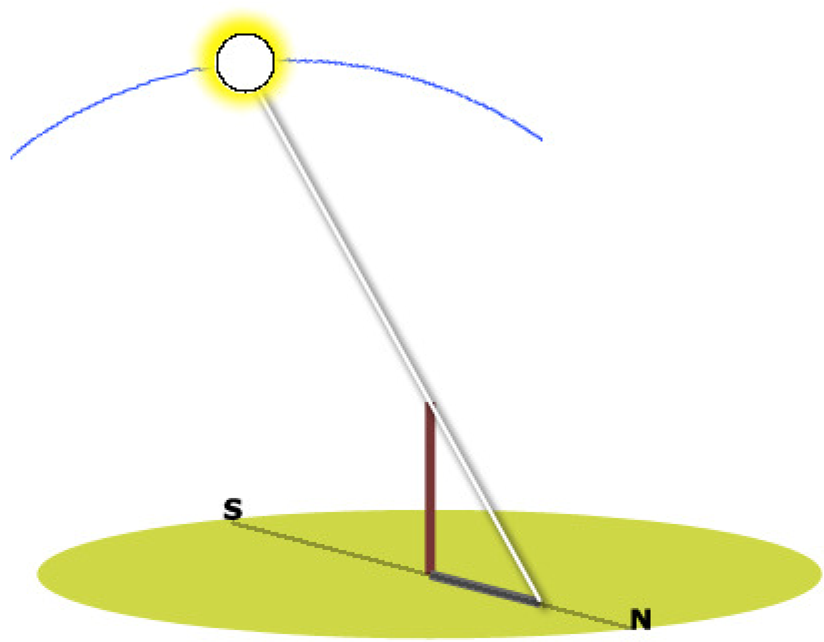
The simple device called a *gnomon* is usually associated with the shadow-casting element of a time-telling sundial, but long before the dial face of the sundial was invented, the gnomon was used for purposes other than marking the hour of the day.

In many ancient cultures, including the Chinese, Greeks, Babylonians, and tribesmen of Borneo, the shadow cast by a simple vertical stick or pole was used to determine the days of solstice, establish the cardinal directions, and measure the length of the year.

Finding the solstices and measuring the length of the tropical (solar) year were accomplished by measuring the length of the gnomon's shadow at solar noon, the moment when the Sun is at its highest point in the sky and the shadows it casts are shortest for the day. On Summer Solstice, when the Sun reaches its greatest noontime height in the sky for the entire year, the noon shadow reaches its shortest length. Alternately, the longest noon shadow of the year corresponds to the day when the noontime Sun is at its lowest point for the year, indicating Winter Solstice.

Then, the length of the year was a simple counting of the days between, say, one Summer Solstice and the next.

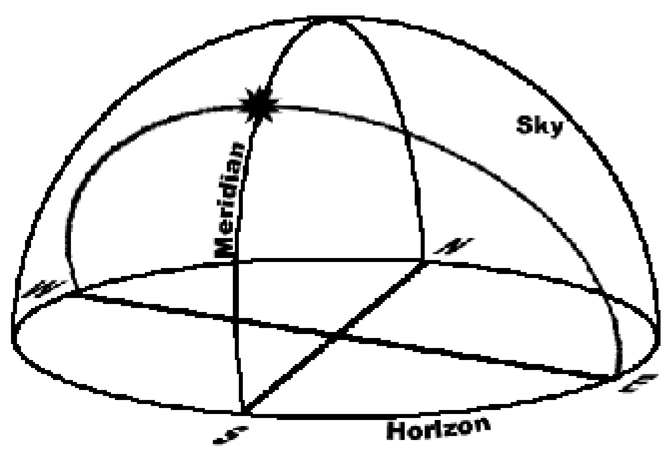
The other use to which gnomons have been put—maybe for thousands of years—is the establishment of direction. The concept of directions on the horizon has been used in numerous aspects of many cultures, everything from rituals to architecture to navigation. Even today, our sense of direction is embedded deeply in our perception of the world around us.



The directions of north, east, south, and west are common to most sky-watching cultures, being defined by the rotation of the Earth, north and south being the directions of Earth's poles. Because the human being cannot sense which direction the Earth is spinning, the determination is made by observing the daily apparent motion of objects in the sky—primarily, the Sun and stars.

At night, in the Northern Hemisphere, the star Polaris, which is conveniently positioned almost directly over the Earth's North Pole, serves as a visual marker for the north direction. Being so close to the celestial pole, its apparent daily motion is so small and slow as to be unnoticeable to the human eye, making it a reference as constant and reliable as the clear weather.

The Sun's daily apparent motion is…*quite* apparent. The drama of the Sun's rise, it's blazing climb to noon heights, and the trek from its apex to its flashy departure at sunset is as opposite in character to Polaris' twinkling stillness as can be. Nevertheless, the Sun also points the way north, in its own way.



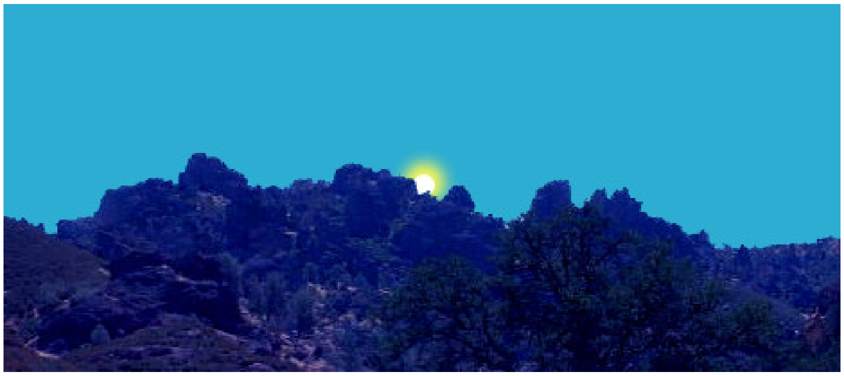
By the very definition of what's north and what's south, at noon the Sun is located on the meridian—the imaginary north-south line that passes directly overhead in the sky. It is halfway between its rising point on the eastern horizon and its setting point on the western horizon, and at its highest point in the sky for the day. At this time, for an observer in the Northern Hemisphere, the Sun is directly south and a gnomon's shadow points directly north. If an observer knows the exact moment of solar noon, then knowing which way is north is as easy as noting what direction a gnomon's shadow is pointing at that time.

If an observer does not know the moment of noon, then careful marking of the gnomon's shadow over a period of time provides the necessary information: the mark indicating the shortest shadow of the day points north.

A number of geometric methods for accurately determining the north-south line from gnomon shadow tracing are possible. The method described in the *Tetherball Gnomon* activity is believed to have been used by ancient Puebloans in the American Southwest, a thousand or more years ago.

Horizon Calendar

Orientation



Activity: Locate and record a "horizon calendar" at your school by carefully observing and recording the horizon and the Sun at sunset (or sunrise, for early risers) over a period of weeks or months.

Objective: To better understand the motion of the Sun and how we use it to measure time.

Materials: Piece of paper (or use pre-made horizon template); pencil; a special spot from which to observe sunset over a horizon; sunglasses; clock.

Grouping: Whole class.

Time: Part 1, 15 minutes; Part 2, 15 minutes; Part 3 (teacher only), 5 minutes around sunset (or sunrise), once per week for at least 3 weeks (a month, semester, or whole school year is even better); Part 4, 20 minutes.

Connection: Ancient sky watchers, including the ancestral Puebloans and later the Hopi, noticed that the Sun's position on the horizon at sunrise and sunset changed throughout the year, and in a repeating pattern. They became accomplished at telling the time of year based on the Sun's rising or setting points on the horizon, using geographic features on the horizon as position markers. For example, a particular peak or notch in the horizon's profile may have been identified as the point where the Sun sets on a specific day of the year.

What helped the sky watchers in the American southwest was the fact of the desert landscape: there were many vantage points from which an observer could see a distant horizon whose features didn't change much even over thousands of years. The more distant the actual geographic features of the horizon, the more accurately observations of the Sun's setting and rising positions could be made.

Important Notice to the Teacher

CAUTION: It cannot be overemphasized that looking at the Sun directly can be harmful to your eyes. Eye damage from bright sunlight can be permanent! Also, sunglasses will not protect the eyes from damage by the direct rays from the Sun.

Because this activity requires direct observations of the Sun, it is strongly recommended that the teacher perform the actual sunset or sunrise horizon position measurements and present them to the class on the large, group-made horizon calendar profile. Students can record the positions in their personal calendar profiles by copying from the group calendar.

Seasonal Changes in Sunrise and Sunset

The points on the horizon where the Sun rises and sets changes in a cycle that repeats yearly. At Summer Solstice, the horizon points of sunrise and sunset are at their farthest positions northward (for the Northern Hemisphere), and at Winter Solstice the farthest points southward are reached. At the equinoxes, the Sun rises directly east and sets directly west of the observer. The times of sunrise and sunset also change, with the Sun rising early and setting late in the summer, rising late and setting early in the winter, and at around 6:00 AM and 6:00 PM (standard time), respectively, on the equinoxes.

Part 1: Select a Site

The Horizon Calendar is an at-school activity, even though the observation time is at sunrise or sunset, after normal school hours. Your teacher will make or supervise the actual recordings of Sun position. The activity is not time-consuming, but must be conducted over a period of at least a few weeks. It is best as a semester unit, or even a project for the entire school year.

Also, the best time of year to run this activity is around the equinoxes: March and September. At these times, the Sun's sunrise/sunset positions change by the greatest amount from day to day. However, running this activity around a solstice (December and June) can be very interesting, but you would definitely need to run the activity for at least a month, with the day of solstice midway during the activity.

What to do:

1. As a class, find a spot that you will use as the observing site for the project. Look for a place
   - ❖ that can be <u>easily returned to day after day</u>;
   - ❖ that has an easily identified spot that can be found and stood on; and
   - ❖ that has a good view of <u>horizon* in the west</u>.

   * The actual shape of the horizon can be made up of geographic features, both nearby and distant, large vegetation (like trees; things that won't grow much during a year—and hopefully won't be pruned much), buildings and other structures. The farther away and more permanent the objects, the better.
2. As accurately as you can, draw a <u>detailed map</u> of the observing site. Include everything in the area to a distance of at least 10 meters, and mark the chosen observing spot. <u>Include enough detail so that anyone</u>

could use the map to easily find the exact spot chosen to observe from.

3. If possible, mark the actual observing spot in a special way, such as setting a large rock, brick, or other heavy object there, or planting a small plant, or something else that will last as a mark for the weeks or months of your observations.

Part 2: Draw the Horizon Calendar

What to do:

As a class, go to the observing spot. Each student, and the teacher, will do the following:

1. Sitting at the observing spot, find the direction of west as near as you can. If you have a magnetic compass and know how to use it, great![4] Otherwise, make your best guess.
2. Draw a straight, horizontal line across the middle of your drawing sheet, as a reference line, and mark the midpoint. (You may also use the pre-made horizon template provided.) The midpoint mark is the west point on the horizon.
3. Carefully look at a length of horizon at least 10 fist-spans across (hold up your fist at arm's length and measure off 5 fists to the left and 5 fists to the right of the westward point).
4. With a pencil, carefully draw a detailed <u>profile</u>, or silhouette, of the horizon. Draw every detail as carefully as you can. Take the time and care to make your horizon profile is as much like the real thing as possible.
5. Hold up your drawing to the horizon to compare; make corrections as needed.
6. The teacher will choose one of the horizon calendars drawn by the students and use it to make a larger version on a bigger piece of paper. This will become the horizon calendar for the whole class.

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[4] Read the description of magnetic versus geographic directions on page 96.

Part 3: Observing (Teacher)

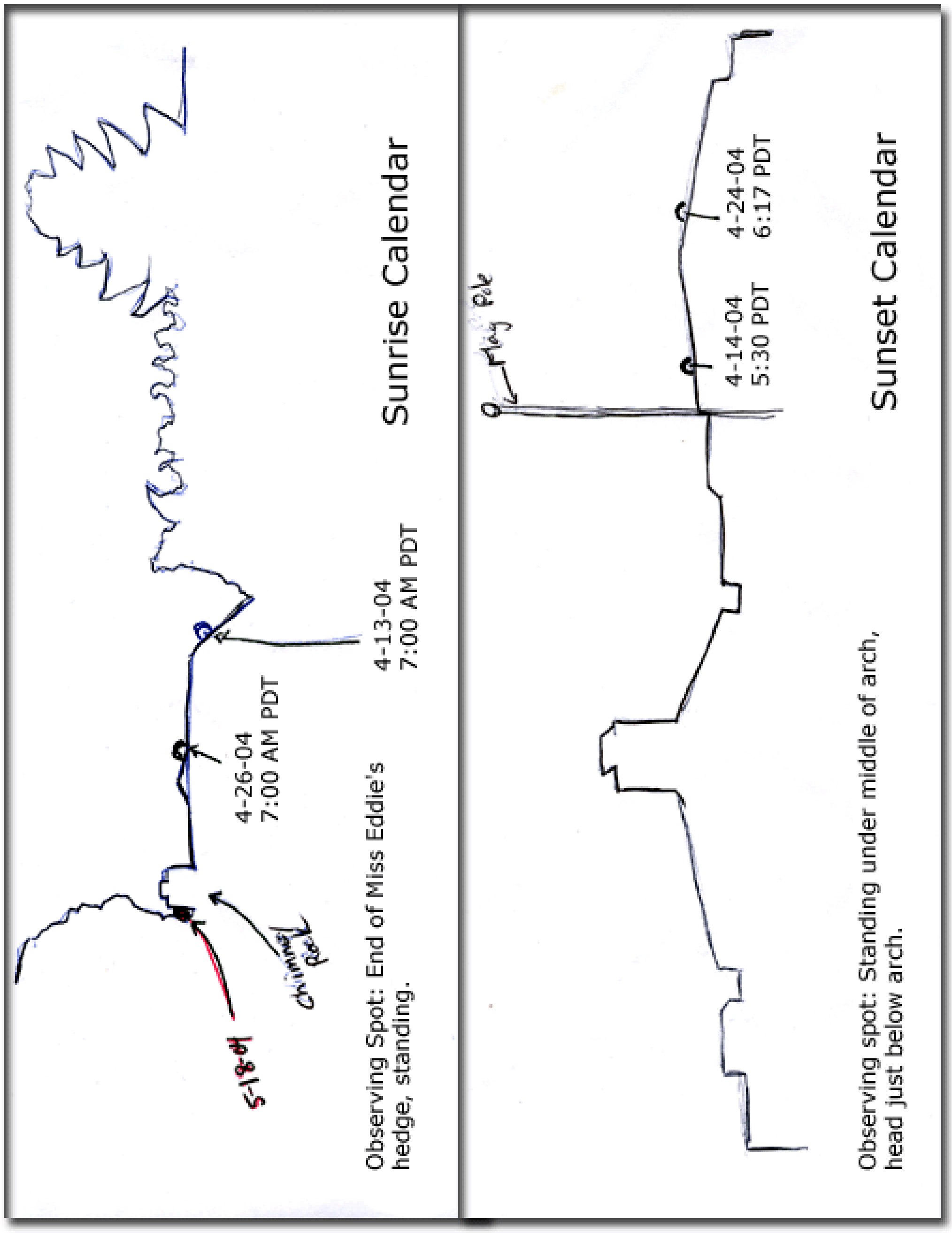
This part of the activity will be done by the teacher. It requires looking toward the Sun, which can harm the eyes if precautions are not taken.

What to do:

1. Once per week on the same day, go out just before sunset, sit at the observing spot, and wait for the Sun to set.

   Remember not to look at the Sun directly. When you observe the Sun's position on the horizon as it sets, look at it with glances, squinting your eyes, and even wearing extra-dark sunglasses with UV protection (and remember that even these sunglasses will not protect your eyes fully). Never stare at the Sun.

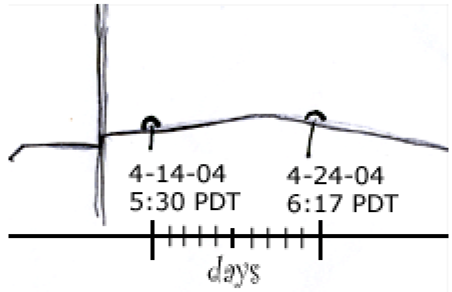
2. When half of the Sun's disk has set, observe its location on the horizon and mark the spot on the horizon calendar. Use a pencil, in case you need to make an adjustment. Mark the position as accurately as you can.
3. Record the exact time and date of that sunset on the horizon calendar.
4. Each day you make a mark, record it on the large class horizon calendar, and instruct the students to record that mark on their own horizon calendars.
5. Students can also record observations and questions—"I Notice…I Wonder…"—on a whole-class chart and in their logs.



Example of a Horizon Calendar (both sunrise and sunset)

Part 4: After the Observations

When your teacher has finished all of the observations, you will have a horizon calendar with marked positions for the Sun on all the dates you observed.



What to do:

1. For each pair of sunset positions, figure out how many days there were between them.
2. On the horizontal reference line on your horizon calendar, make small marks dividing the line between two sunsets with the number of days between them, each mark representing one day. Do this for each pair of sunset marks.

Questions:

- Did the Sun always set at the same spot on the horizon?
- If the position on the horizon of sunset changed, which direction did it move (left or right, north or south)? What else do you notice about its motion?
- Was the time of sunset the same every evening? If not, how did it change? Was the time getting earlier or later?
- In what ways could someone else could use your work—your site map, horizon calendar, and sunset observations?
- How do you think accurate horizon-calendar observations would be made by an observer who lives in a heavily wooded area or on a small island with no distant horizon features other than the ocean?

Horizon Calendar Template

Sunrise/Sunset Calendar? (circle one)

Observing Location (precise!):

Line spacing above equals one fist at arm's length, each.

Your Sun Symbol

chabot space & science center

Do the Math

Activity: Explore how the time of sunrise or sunset changed from day to day during your observations.

Did you find that the time of sunrise or sunset changed over the days of your observations? If so, do the math below to calculate how much.

1. For each pair of Sun horizon marks, calculate the change in rise or set time between them (subtract the smaller time form the larger time). Write the answer in the appropriate row of column 2 on the table on the next page.
2. For each pair of Sun horizon marks, calculate the number of days between those two observations. Write the answer in column 3.
3. To calculate the average change per day, divide the change in sunrise or sunset times (minutes) by the number of days between the pair. Write the answer in column 4.
4. For each pair, write down in column 5 whether the time of sunrise or sunset is getting earlier or later.

Sunrise or Sunset Calendar (Circle one) Time Table

Sunrise/Sunset marks	**Difference in rise or set times (minutes)**	**Difference in rise or set dates (days)**	**Average change per day (minutes per day)**	**Getting earlier or later?**
1 and 2				
2 and 3				
3 and 4				
4 and 5				
5 and 6				
6 and 7				
7 and 8				
8 and 9				
9 and 10				

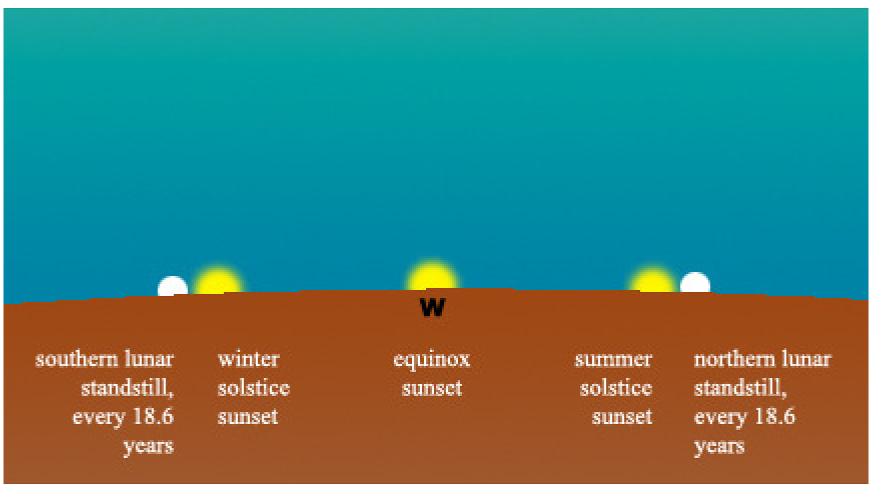
Questions:

- ❖ What are the <u>units</u> of the average daily change?
- ❖ In what way are the times of sunrise or sunset <u>changing</u>, if at all?
- ❖ Is the <u>average change</u> in rise or set time (minutes per day) always the same amount?
- ❖ Is it always getting earlier? Later? Is it getting earlier in some cases and later in others? Is there a pattern?
- ❖ How do you think the changing time of sunrise or sunset might behave at other times of the year? Spring, Summer, Autumn, Winter?

Desert Horizons

In the open deserts of the American Southwest and the Mexican Northwest the skies dominate the land and the people under them. Early inhabitants of the region were dedicated sky watchers and developed science and art that expressed their interest in the heavens. Even a short visit to this area can leave one with a sense of the vastness and importance of the sky, Sun, Moon, stars and planets. Likewise, a visitor may notice the landforms of towers, cliffs, mesas, and gaps in the desert horizon for their unique profiles.

In this land, sky observers could position themselves in special locations from which the unique profile of the skyline acted as a foreground behind which the procession of objects in the sky would move, rise, and set. This allowed the positions and motions of Sun, Moon, stars, and planets to be compared, marked, and examined over many repetitions of their cycles.



Left: Diagram showing the relative setting positions of Sun on the solstices and equinox, and the Moon at its northern and southern standstills.

Short cycles such as the Sun over a day, the Moon over a month, or even the Sun and stars over the seasonal cycle of a year will become clear to a patient observer. However, given enough time, other, longer cycles can be detected. The cycles of eclipses and lunar standstills—the period between the most northerly moonrise or moonset and the most southerly—are examples.

Other events, such as comets or supernovae, also occurred and were sometimes recorded—perhaps in hope that they were a rare sighting in a long cycle, or perhaps for the sheer spectacle of their beauty. In all cases, the majesty of the sky and the singular appearance of the land invited the ancient desert people to study the sky, and from their careful observations develop calendars, art forms, and lifestyles that expressed their attention to and appreciation for what they saw.

Building a Landscape—Sun and Shadow Diorama

Orientation

Activity: In this activity, you will create a *small natural landscape*, or a *model of a human-made structure*, that will create special patterns or alignments at special times of the year.

You will use a specially prepared "Horizon Table" that represents the Earth's horizon and, with your solar observatory structure placed at the center, you will test it with a portable lamp that represents the Sun and can be positioned to simulate the Sun's point on the horizon at sunrise or sunset on an equinox or solstice.

Objective: To better understand how ancient Sun observers used natural geographic features as well as constructed objects to tell time by the changing patterns of shadow and light.

Materials: Clay, clay-modeling tools, a wooden or cardboard base to build the diorama on, a table (preferably square or circular), a hand-held lamp (a work lamp is good).

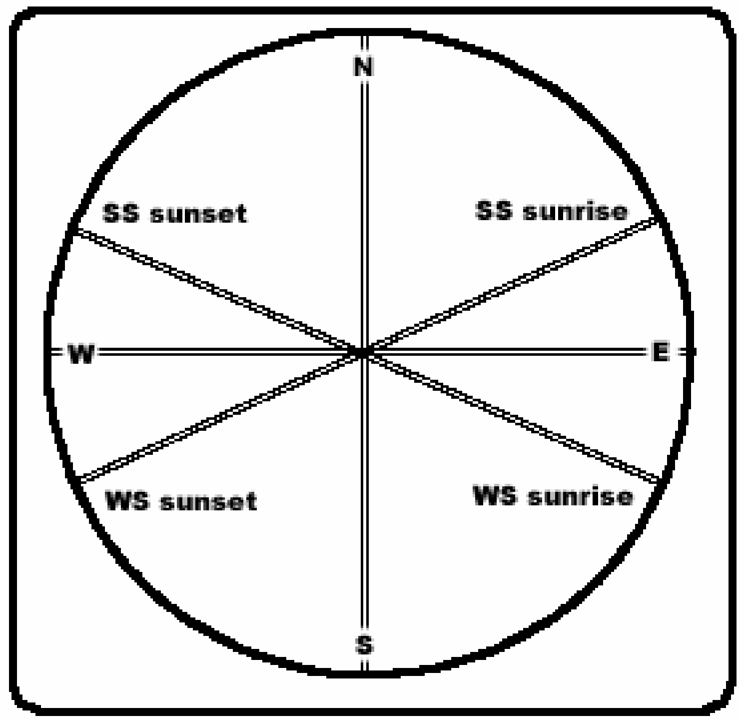
Grouping: Part 2, individuals or small groups; Part 3, whole class.

Time: Part 1 (teacher only), 20 minutes; Part 2, 15-30 minutes; Part 3, 30 minutes.

Connection: Ancient Sun observers made use of natural geological structures (rock formations, hills, and other enduring terrestrial features) and also arranged stones, built markers, erected buildings, and carved or painted special designs on stone. They did this to mark solar alignments that they observed at different times of the year, particularly around solstices and equinoxes. Beams of sunlight and shadow would make patterns, or illuminate special locations, on important calendar days.

Part 1: Preparing the Table (teacher)

1. Cover a table with butcher paper, taping it down firmly.
2. Draw a large circle on the butcher paper, just fitting within the size of the table. Use a string, pen, and anchor to draw the circle, if necessary. (It doesn't have to be a perfect circle, so free-hand drawing is okay.)



3. Draw two lines through the center of the circle that are perpendicular to each other (quarter the circle).
4. Mark the cardinal compass directions, north, east, south, and west, in a clockwise direction, where the lines cross the perimeter of the circle.
5. Mark the sunrise and sunset solstice points on the circle. These points are 30 degrees to either side of both the east and the west directions. Use a protractor and string or straight edge to measure the angles.

   Specifically:

❖ sunrise-at-Summer-Solstice (SS sunrise) is 30 degrees counterclockwise from east;

❖ sunset-at-Summer-Solstice (SS sunset) is 30 degrees clockwise from west;

❖ sunrise-at-Winter-Solstice (WS sunrise) is 30 degrees clockwise from east;

❖ sunset-at-Winter-Solstice (WS sunset) is 30 degrees counterclockwise from west.

Note: 30 degrees for the solstice points are correct for latitudes near 35 degrees, but are good approximations for most places in the United States. If you prefer directions more accurate to your latitude, see the *Do the Math* section in the *Medicine Wheel* activity.

6. Mark the sunrise and sunset equinox points on the circle. These are simply the east and the west points, for both equinoxes.
7. A hand-held lamp can be used to simulate the Sun at sunrise or sunset by placing it just above the edge of the table at the desired position along the marked horizon circle.

Part 2: Making the Diorama (student)

1. Get materials!
   You will use clay for your landscape or model structure, and build on a cardboard base. Be sure to write your name on your cardboard base.
2. Get ideas!
   Research ancient solar observatories and solar observation sites. Find out how they worked and what they were supposed to do. You can attempt to build a functioning model of an existing ancient solar observatory, or design your own. You can choose to sculpt only features found in a natural landscape (buttes, spires, notches), or you can engineer a building whose windows, doors, or shape create the special light or shadow patterns. Be creative!

   Whatever you choose to do, **your diorama should be made to do the following**:

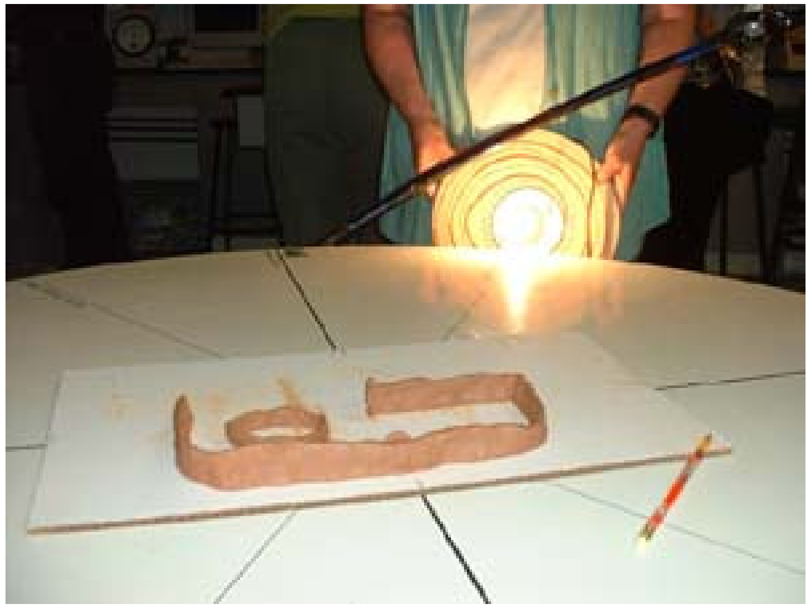
   - ❖ Make a special alignment at the equinoxes, either at sunrise or sunset (the lamp will be positioned on the horizon at either the east or west).
   - ❖ Make a special alignment at sunset on Summer Solstice (the lamp will be positioned 30 degrees north of the west point).
   - ❖ Make a special alignment at sunrise on Winter Solstice (the lamp will be positioned 30 degrees south of the east point).

3. Build! Have fun building your landscape or solar observatory!
4. As you build, you can test your structure to see the patterns of light and shadow on the solstices and equinoxes. Use the "Horizon Table," which your teacher has set up, to check to see if your diorama is working correctly.
5. You may want to change or re-position parts of your structure, and test again.

Above all, have fun!

Part 3: Testing the Model

What to do:

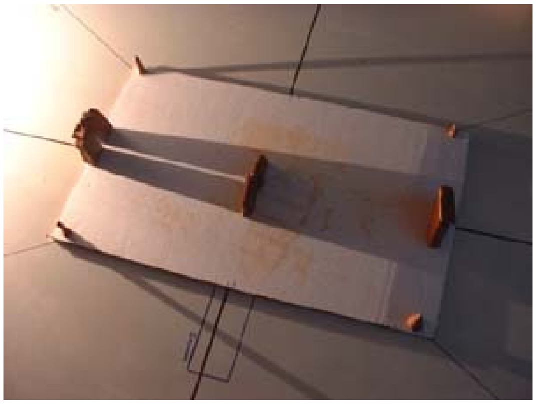


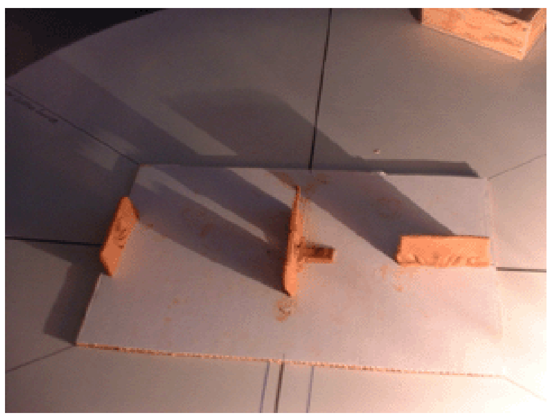
1. Set your diorama at the center of the table. Make sure it is rotated in the proper direction (aligned properly with north, south, east, and west).
2. Test it! To meet the test requirements, place the Sun-lamp at the positions on the horizon to simulate:
   - ❖ a sunrise or a sunset (as you have chosen) at <u>equinox</u> (lamp bulb placed exactly east or west);
   - ❖ sunset on Summer Solstice (lamp bulb placed 30 degrees north of the west); and
   - ❖ sunrise on Winter Solstice (lamp bulb placed 30 degrees south of the east).
3. If some part of the test fails, go back and change your diorama to fix the problem.

Did your diorama work the way you intended? Did the desired alignment of light or shadow with the structural parts of the diorama happen for the correct simulated sunrises or sunsets? Were the patterns created by the alignments unmistakable and remarkable in a way that would make someone else say, "Yes, I see that; it works!"

If you can answer all of these questions with a "yes," then you were successful in this activity. If not—you can always go back and change your diorama to make it work….

Here are some examples of dioramas that were successful:





Questions:

If you were an ancient astronomer making solar observations to determine the times of the year:

- ❖ Would you use natural geographic features only? Why?
- ❖ Would you make special marks or structures in addition to using natural geographic features? Why?
- ❖ Would you build your light and shadow observatory from scratch? Why?
- ❖ Imagine different situations where you would make different decisions on how to make your observatory—natural features or built structures. What are they?

Do the Math

Activity: Create a special diorama to experiment with shadows and their lengths.

1. Create a simple diorama with three "spires" made of clay, side by side. Make one spire 50 millimeters high, make the second spire 30 millimeters high, and make the third spire 10 millimeters high.
2. Place your diorama on the testing table.
3. Have a helper hold the Sun lamp at the edge of the table, at a height where you can see the tips of the shadows made by all three spires.
4. Asking your helper to hold the lamp steady, and not to move it, quickly measure the lengths of all three shadows, in millimeters. Tip: You can also use a pencil to mark the positions of the shadow tips quickly, and then measure the distances from the spires' bases to these marks—this will let you make your measurements more carefully.
5. Enter your measurements on the table below, in the Shadow Length column. Tell your helper that he or she can rest now….

Spire Height (mm)	Shadow Length (mm)	Ratio Shadow Length ÷ Spire Height
10		
30		
50		

6. Calculate the *Ratio* of the Shadow Length divided by the Spire Height. For example, if the shadow cast by the 10 mm spire is 30 mm long, then their Ratio is 30 ÷ 10 = 3. Write down your answers in the Ratio column.
   - ❖ Were the ratios you calculated for the three spires about the same, or very different?
7. Do this activity again, but this time have your helper hold the Sun lamp at a much different height.

- ❖ Were the ratios you calculated this time all about the same, or different?
- ❖ Were they different from the ratios you calculated the first time?

Question: What can you conclude about the length of shadows, compared to the objects that cast them, when the light is at a given height?

Thank your helper.

Checklist for "Build a Landscape"— Science Notebook Write-Up

As you look over your investigation, be sure you have the following:

Focus Question:

What would you like to find out?

> *Example: "Can I find a way to build a structure that shows light and shadow patterns for the Winter Solstice sunrise and sunset?"*

Materials:

(Make a list)

Plan/Procedure/Starting Point:

What are you going to do?

> *First? Second? Next….*

Data Collection:

❖ Observations / Questions

"I notice…", "I wonder…", "What happens if…?", "Can I find a way to…?"

❖ Illustrations with text—carefully sketch your "landscape" and use words to identify and describe specific features.

Evidence:

❖ What happened?

Example: "When we tested our model, we noticed…."

❖ What do the data show?

Example: "Our alignments work for Winter Solstice sunrise, but not for…."

❖ Why do you think it might be like that?

"We think we got these results because…" "Our idea is….."

Reflections/Conclusions:

- ❖ What did you find most surprising or interesting?
- ❖ In what ways have you changed your ideas as a result of your experiment?
- ❖ What are three or more questions that you have now?
- ❖ What would you like to try next? Why?

*Hint: Read your write-up out loud to be sure it makes sense. Check that your illustrations have clear text explanations, and arrows pointing to specific features. Share your work with another student or group. Would they be able to replicate (copy) your experiment? Listen to their questions. Make changes, if needed, to make your writing more specific and accurate.

Maya Astronomy

In many ways the Maya of Central America stand out as the most advanced of all medieval civilizations. Maya culture, comprised of city states connected by culture, language, and trade, had no beasts of burden, no wheel, and metallurgy limited to goldsmithing. Other cultures may have accomplished more in the way of industry, but the Maya succeeded in ways that would not be matched for centuries.

The ravages of conquest destroyed most of Maya literature and delayed understanding of their written language, but scraps of some of their texts survive that give us a peek at their varied and fascinating ideas and beliefs. From deciphering the surviving texts we are learning that the Maya had developed the only phonetic alphabet in the New World.

The Maya developed mathematics to a more advanced degree than anyone else in the world at the time. They were the first to develop the concept and use of zero, many hundreds of years before the Arabs did. Their place value arithmetic allowed for rapid calculations of very large numbers.

Maya interest in astronomy, both supported by and providing an outlet for their mathematics, is only now becoming recognized as one of their greatest cultural expressions. Their trade routes and roads, agricultural innovation, and the ruins of their magnificent buildings have left behind solid examples of their achievements.

Right: The Sun Temple at Dzibilchaltun. At Spring Equinox, the sunrise is framed by the temple's central doorway. *Photo credit IDEUM*

The Maya constructed buildings that incorporate astronomical alignments that would not have been possible unless they combined several disciplines—in particular mathematics, astronomy, and architecture. Through these we have learned to appreciate the depth of their civilization.

One example of astronomical construction is the terraced pyramid El Castillo, also called the Temple of Kukulkan, in Chichen Itza.

Constructed after the occupation of the Yucatan by the Toltecs, El Castillo is constructed such that on the day of equinox, the zig-zag shadow formed by one corner of the pyramid is cast on a balustrade, presenting the appearance of the spine of the Maya feathered serpent deity that connects with a stone sculpture of its head at the bottom of the stairs.

Left: El Castillo, also called the Temple of Kukulkan, at Chichen Itza. *Photo credit IDEUM*

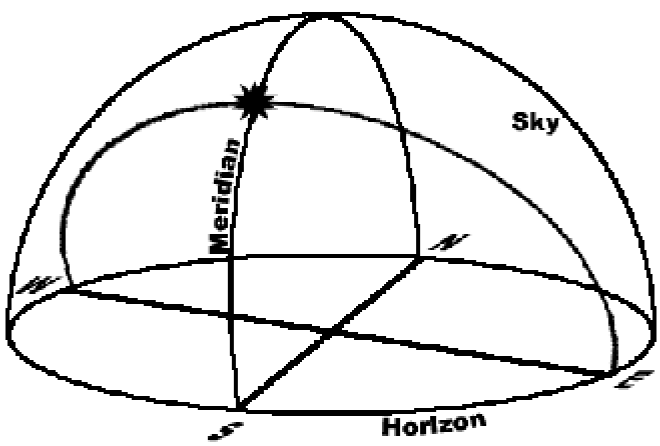
Considerations and Background Discussions

Civil and Astronomical Time

The difference between "civil" time—that which we read from a clock—and "astronomical" time that is determined by the positions of celestial objects can be important to distinguish.

On a clock reporting *civil* time, for example, 12:00 PM is defined as noon, or midday; noon on one day to noon on the next is separated by exactly 24 hours. Even during Daylight Savings Time, when we advance our civil clocks by one hour, we still refer to 12:00 on the dial as noon. Also, we synchronize the clocks within a given time zone to a standard time, so that clocks at the eastern edge of the zone read the same time as clocks far to the west.

Astronomical noon, however, is defined as the moment when the Sun reaches its highest point in the sky on a given day—or, equivalently, when the Sun crosses the "meridian," an imaginary line in the sky running north to south and directly overhead that divides the sky into eastern and western halves. At that moment, the Sun is directly south of an observer located north of the Tropic of Cancer (most of the Northern Hemisphere). Also, astronomical time has no standardized time zones; when astronomical noon occurs for a given observer, noon has not yet arrived for people west of that observer, and noon has already passed for those to the east—even, technically, if those people are only a few meters away from the observer!



Telling time by the Sun is not as mechanically regular as with a clock. Due to effects of the Earth's elliptical orbit around the Sun and the fact that Earth is tilted with respect to its orbit, the time of astronomical noon, when the Sun crosses the meridian, varies throughout the year; as compared to a clock, the Sun usually runs fast or slow, by up to 16 minutes.

If you are making observations of the Sun's position—or the position of the shadow it casts—to determine direction, it is important to take into account the difference between civil and astronomical time. If you rely on a clock to tell you when to make a noon-time observation or mark, you can be off by as much as 16 minutes—or even an hour and 16 minutes during Daylight Savings Time!

The *Schoolyard Medicine Wheel* activity is vulnerable to this in one respect. Students are directed to create a spoke on the Medicine Wheel that indicates "Noon Sun." The resulting spoke is fine if all that it is meant to represent is the direction of the Sun at noon, by the clock, on a given day. If, however, the spoke is also meant to show the north-south direction, then it needs to be created at the current day's astronomical noon, not noon by the clock. Sometimes the difference is not so great, but other times it is significant.

The *Tetherball Gnomon* activity for finding geographic north by the Sun is unaffected by time considerations. It uses a geometric method based on direct observation of shadow motion.

Magnetic North versus Geographic North

Most of us have picked up a magnetic compass, let its needle settle down to a fixed direction, and claimed, "There's north." And for gaining a general sense of the directions of north, south, east, and west, the compass can usually be treated that way.

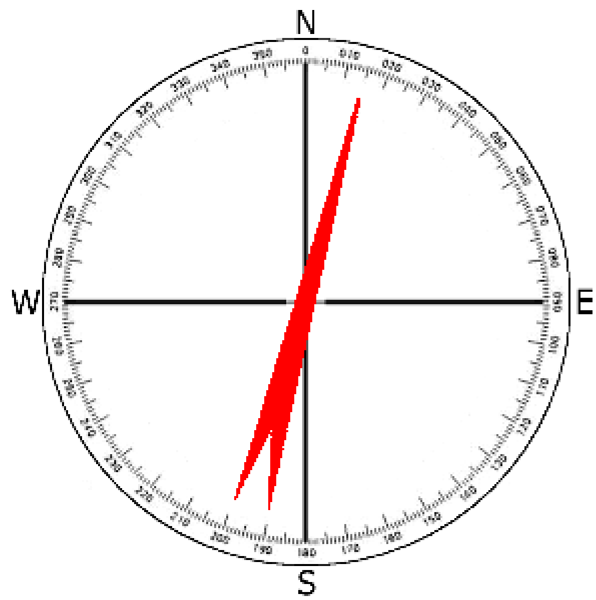
However, a magnetic compass does not point to what most of us understand as north—"geographic" north—but rather to magnetic north. Geographic north (and south) are the directions to the Earth's geographic poles, or the locations where Earth's axis of rotation intersects its surface.

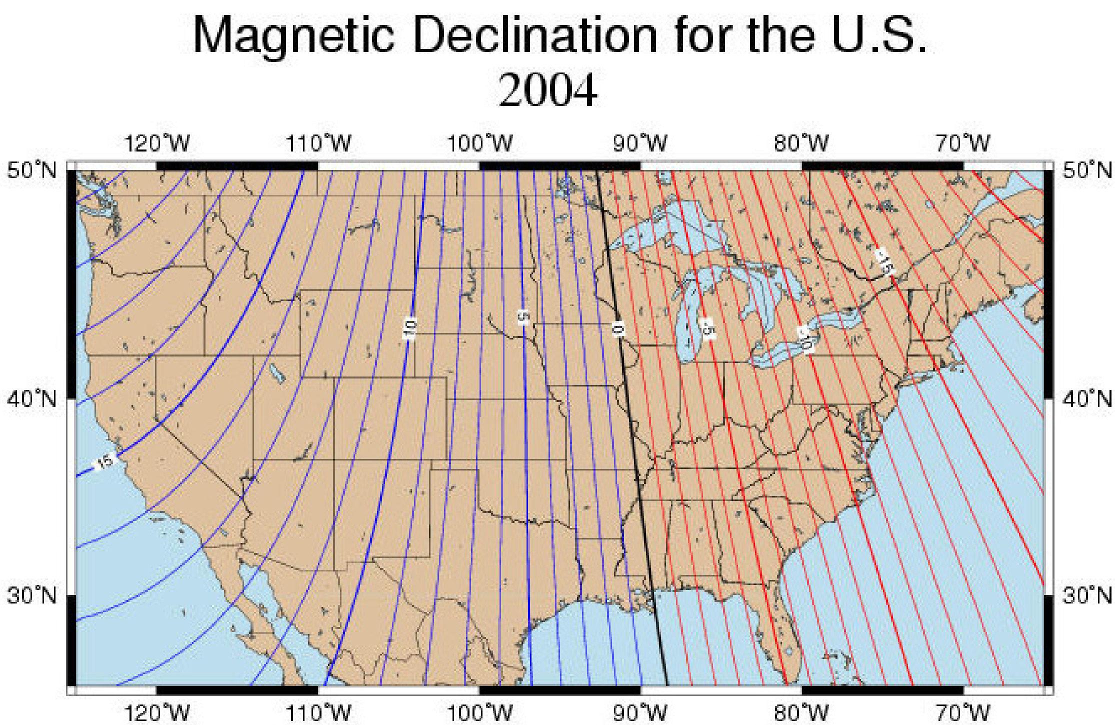
The poles of Earth's magnetic field—to which a magnetic compass needle aligns—are not in the same locations as the geographic poles. If that's not bad enough, the magnetic poles are not fixed; in the past century they have moved many hundreds of miles.

In order to determine geographic north using a magnetic compass, you must take into account the difference in direction between the geographic and magnetic poles: how many degrees east or west (right or left, respectively) from geographic ("true") north the magnetic needle is pointing.

This deviation—called "magnetic declination"—varies for different locations on Earth. To find the magnetic declination for your location, consult a Magnetic Declination map or table[5] (an example is shown below).

In the San Francisco Bay Area, the magnetic declination is currently "15 degrees east," meaning that magnetic north points 15 degrees to the east (to the right) of true north. So, in this region, to find true north you need to offset (rotate) the compass dial so that the needle points 15 degrees east of the zero mark. Once you do this, then the NESW markings on the compass dial should be properly aligned with the geographic directions.





Read magnetic declination from the contour lines on the map. Positive numbers represent eastward declinations, negative represents westward

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[5] See the USGS Geomagnetism Home Page link on page 102.

Additional Resources

This section offers sources of relevant extension or alternate activities to *Sunwatchers of the Southwest*.

GEMS Teachers' Guides, Lawrence Hall of Science

University of California at Berkeley, Lawrence Hall of Science. Website: www.lhsgems.org. Email: gems@berkeley.edu. Phone: (510) 642-7771. Fax: (510) 643-0309.

- *"Investigating Artifacts: Making Masks, Creating Myths, Exploring Middens."* For grades K-6. Use "Exploring Middens" as a hands-on activity to show how we learn about ancient cultures through archaeological research.
- *"The Real Reason for the Seasons: Sun-Earth Connections."* Explore the annual solar cycle and its effects on Earth from the perspective of the actual motions of Sun and Earth.

Project Star, Learning Technologies, Inc.

Learning Technologies, Inc. Website: www.starlab.com/psprod.html. 40 Cameron Avenue, Somerville, Massachusetts 02144 U.S.A. Phone: 1-800-537-8703 (U.S. only) or 1-617-628-1459. Fax: 1-617-628-8606

- *Sun-Tracking Plastic Hemisphere Kit.* Explore the apparent daily and seasonal motion of the Sun across the sky by marking and tracking its progress directly.

Books

- *Skywatchers*, Anthony F. Aveni, Revised edition 2001, ISBN 0-292-70504-2 (hardcover), 0-292-70502-6 (paperback)
- *Prehistoric Astronomy in the Southwest,* J. McKim Malville and Claudia Putnam, Revised edition 1993, ISBN 1-55566-116-5
- *Living the Sky: The Cosmos of the American Indian,* Ray A. Williamson, 1984/1987, ISBN 0-8061-2034-7
- *To Know the Stars,* Guy Ottewell, 1984, ISBN 0934546126
- *Science Notebooks: Writing About Inquiry,* Brian Campbell and Lori Fulton, 2003 Heinemann, ISBN 0-325-00568-0
- *Primary Science: Taking the Plunge,* Wynne Harlan, Second edition 2001 Heinemann, ISBN 0-325-00386-6
- *Traditions of the Sun: The Sun-Earth Connection at Chaco Culture National Historic Park,* Center for Science Education @ Space

Sciences Lab, University of California, Berkeley—An introductory book about archaeoastronomy at Chaco Canyon written for 4th-6th grade students. An on-line version is available at: www.traditionsofthesun.org/books.html.

Useful Websites for Teachers

General

Traditions of the Sun:
→ www.traditionsofthesun.org/

Center for Science Education @ Space Sciences Lab, University of California, Berkeley:
→ cse.ssl.berkeley.edu/

Stanford Solar Center:
→ solar-center.stanford.edu/

A diagrammatic and mathematical site discussing some astronomy of the Sun and Moon:
→ www.jgiesen.de/sunmoonpolar/

Stonehenge

A discussion of some astronomy as it relates to Stonehenge:
→ williamcalvin.com/bk6/bk6ch2.htm

Stonehenge archaeoastronomy:
→ www.tivas.org.uk/stonehenge/stone_ast.html

Astroarchaeology

The U.K. way of arranging the discipline:
→ www.astroarchaeology.org/context/history.html

North America

A museum based site on prehistoric North American people:
→ www.mnsu.edu/emuseum/prehistory/northamerica/index.shtml

Chaco Culture

The website from the people who first studied the Fajada Butte Sun Dagger:
→ www.solsticeproject.org/celeseas.htm

This site has some good general images of various Chacoan sites and subjects:
→ www.ratical.org/southwest/images/

A website developed to report a conference held about Chaco Culture and research held in 1996. The "Chaco Canyon Tour" is especially

helpful:
→ www.colorado.edu/Conferences/chaco/open.htm

An interactive browser of Chaco Canyon, including interactive maps, videos, and 360 degree panoramic viewers:
→ www.traditionsofthesun.org

Other Websites

NSTA—Astronomy With a Stick:
→ www.nsta.org/awsday

Center for Archaeoastronomy
→ www.wam.umd.edu/~tlaloc/archastro/

National Park Service--Chaco Canyon:
→ www.nps.gov/chcu/

Ancient Astronomy:
→ www.utsc.utoronto.ca/~shaver/ancient.htm

The Anasazi:
→ www.desertusa.com/ind1/du_peo_ana.html

Learning Technologies, Inc.:
→ www.starlab.com/

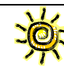
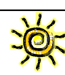
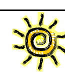
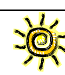
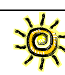
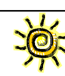
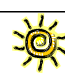
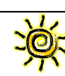
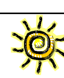
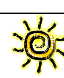
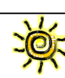
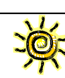
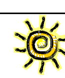
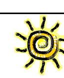
USGS Geomagnetism Home Page:
→ geomag.usgs.gov/

Educational Standards Alignment

	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
National Science Education Standards Grades K – 4							
1. Science As Inquiry							
Content Standard A: As a result of activities in grades K – 4, all students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry.							
Abilities Necessary To Do Scientific Inquiry:							
Identify questions that can be answered through scientific investigations.	☀	☀	☀	☀	☀		
Design and conduct a scientific investigation.				☀	☀	☀	
Use appropriate tools and techniques to gather, analyze, and interpret data.	☀	☀	☀	☀	☀		
Develop descriptions, explanations, predictions, and models using evidence.	☀	☀	☀	☀	☀	☀	
Think critically and logically to make the relationships between evidence and explanations.	☀	☀	☀	☀	☀	☀	☀
2. Physical Science							
Content Standard B: As a result of their activities in grades K – 4, all students should develop an understanding of:							
Position and Motion of Objects							
The position of an object can be described by locating it relative to another object or	☀	☀	☀	☀	☀	☀	☀

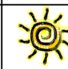
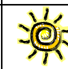
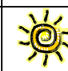
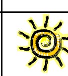
	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
the background.							
An object's motion can be described by tracing and measuring its position over time.	☼	☼	☼	☼	☼	☼	☼
3. Life Sciences							
Content Standard C: As a result of their activities in grades K – 4, all students should develop an understanding of : Organisms and environments							
Humans depend on their natural and constructed environments.	☼	☼	☼	☼	☼	☼	☼
4. Earth and Space Science							
Content Standard D: As a result of their activities in grades K – 4, all students should develop an understanding of :							
Objects in the Sky							
The sun, moon and stars all have properties, locations, and movements that can be observed and described.	☼	☼	☼	☼	☼	☼	☼
Changes in the Earth and Sky							
Objects in the sky have patterns of movement. The sun, for example, appears to move across the sky in the same way every day, but its path changes slowly over the seasons.	☼	☼	☼	☼	☼	☼	☼
5. Science and Technology							
Content Standard E: As a result of activities in grades K – 4, all students should develop: Abilities of technological design							

	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
Understandings about science and technology Abilities to distinguish between natural objects and objects made by humans							
Abilities of Technological Design:							
identify a simple problem						☀	
propose a solution						☀	
implement a proposed solution						☀	
evaluate a product or design						☀	
communicate a problem, design, and solution						☀	
Understandings About Science and Technology:							
Science is one way of answering questions and explaining the natural world							☀
Tools help scientists make better observations, measurements, and equipment for investigations.							☀
Distinguish between natural objects and objects made by humans							
Some objects occur in nature; others have been designed and made by people to solve human problems and enhance the quality of life	☀			☀	☀	☀	☀
6. History and Nature of Science							
Content Standard G: As a result of activities in grades K – 4, all students should develop understanding of: Science as a human endeavor							

	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
Science as a human endeavor							
Science and technology have been practiced by people for a long time							
Men and women have made a variety of contributions throughout the history of science and technology							
Although men and women using scientific inquiry have learned much about the objects, events, and phenomena in nature, much more remains to be understood.							
National Science Education Standards Grades 5 - 8							
1. Science As Inquiry							
Content Standard A: As a result of activities in grades 5 – 8, all students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry.							
Abilities Necessary To Do Scientific Inquiry:							
Identify questions that can be answered through scientific investigations.							
Design and conduct a scientific investigation.							
Use appropriate tools and techniques to gather, analyze, and interpret data.							
Develop descriptions, explanations, predictions, and models using evidence.							

	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
Think critically and logically to make the relationships between evidence and explanations.	☼	☼	☼	☼	☼	☼	☼
3. Earth and Space Science							
Content Standard D: As a result of their activities in grades 5 – 8, all students should develop an understanding of : Earth in the solar system							
Earth in the Solar System:							
Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.	☼	☼	☼	☼	☼	☼	☼
4. Science and Technology							
Content Standard E: As a result of activities in grades 5 – 8, all students should develop: Abilities of technological design Understandings about science and technology							
Abilities of Technological Design:							
identify appropriate problems for technological design						☼	
design a solution or product	☼			☼		☼	
implement a proposed design	☼	☼	☼	☼		☼	
evaluate completed technological designs or products						☼	
communicate the process of technological design							

	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
Understandings About Science and Technology:							
Many different people in different cultures have made and continue to make contributions to science and technology.							☀
Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.							☀
Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constrains limit choices in the design, for example, environmental protection, human safety, and aesthetics.	☀	☀	☀	☀	☀	☀	☀
5. Science in Personal and Social Perspectives							
Content Standard F: As a result of activities in grades 5 – 8, all students should develop understanding of: Science and technology in							

	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
society							
Science influences society through its knowledge and world view.							
Technology influences society through its products and processes. Social needs, attitudes and values influence the direction of technological development.							
6. History and Nature of Science							
Content Standard G: As a result of activities in grades 5 – 8, all students should develop understanding of: Science as a human endeavor Nature of science							
Nature of Science:							
Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.							
In areas where active research is being pursued and in which there is not a great deal of experimental or							

	Schoolyard Medicine Wheel	Classroom Solar Calendar	Birthday Sunbeam	Tetherball Gnomon	Horizon Calendar	Sun & Shadow Dioramas	General
observational evidence and understanding, it is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered. Different scientists might publish conflicting experimental results or might draw different conclusions from the same data. Ideally, scientists acknowledge such conflict and work towards finding evidence that will resolve their disagreement.							
It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists. Scientists may disagree; however they do agree that questioning, response to criticism, and open communication are integral to the process of science.							☼
National Mathematics Education Standards Grades 3 -5							
Measurement Standard							
Understand measurable attributes of objects and the units, systems, and processes of measurement	☼		☼	☼	☼	☼	
Apply appropriate techniques, tools, and formulas to determine measurements	☼		☼	☼	☼	☼	
Data Analysis Standard							

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Design investigations to address a question and consider how data-collection methods affect the nature of the data set						☀	
Collect data using observations and experiments	☀	☀	☀	☀	☀	☀	
Develop and evaluate inferences and predictions that are based on data. Propose and justify conclusions and predictions that are based on data and design studies to further investigate the conclusions or predictions.	☀	☀	☀	☀	☀	☀	
Problem Solving Standard							
Build new mathematical knowledge through problem solving	☀			☀		☀	
Solve problems that arise in mathematics and in other contexts	☀			☀	☀	☀	
Connections Standard							
Recognize and apply mathematics in contexts outside of mathematics	☀	☀	☀	☀	☀	☀	
Representations Standard							
Use representations to model and interpret physical, social, and mathematical phenomena	☀					☀	
National Mathematics Education Standards For Grades 6 - 8							
Geometry Standard							
Recognize and apply geometric ideas and relationships in areas outside	☀	☀	☀	☀	☀	☀	

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the mathematics classroom, such as art, science, and everyday life.							
Measurement Standard							
Understand measurable attributes of objects and the units, systems, and processes of measurement	☀	☀	☀	☀	☀	☀	
Apply appropriate techniques, tools, and formulas to determine measurements	☀	☀	☀	☀	☀	☀	
Data Analysis and Probability Standard							
Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them	☀	☀	☀	☀	☀	☀	
Develop and evaluate inferences and predictions that are based on data	☀	☀	☀	☀	☀	☀	
Problem Solving Standard							
Solve problems that arise in mathematics and in other contexts	☀	☀	☀	☀	☀	☀	
Apply and adapt a variety of appropriate strategies to solve problems	☀			☀	☀	☀	
Mathematical Connections Standard							
Recognize and apply mathematics in contexts outside of mathematics	☀	☀	☀	☀	☀	☀	
Representation Standard							
Use representations to model and interpret physical, social, and mathematical phenomena	☀	☀	☀	☀	☀	☀	