Sun Tracking System for a Solar Panel
Extension Activities

SLED Science Learning through Engineering Design

Grade Level:	**Total Time Required:**
6	3 periods (90 minute each), approximate

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Lesson Objectives:

Students will be able to:

1. Demonstrate that the seasons in both hemispheres are the result of the inclination of the earth on its axis, which causes changes in sunlight intensity and length of day.
2. Identify the difference between direct and indirect rays of light.
3. Apply their understanding of indirect and direct rays to design a device that can be used to track the sun through the day and various times of the year.
4. Use various materials and typical engineering design components (examples provided).
5. Measure the angles associated with the inclination of the sun and position of the sun throughout the day.

Indiana Standards:

6.ESS.2 Design models to describe how Earth's rotation, revolution, tilt, and interaction with the sun and moon cause seasons, tides, changes in daylight hours, eclipses, and phases of the moon.

6-8.E.1 Identify the criteria and constraints of a design to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

Lesson Extension #1
Solar Dance

The Solar Dance activity (retrieved May 12, 2012 from http://www.uwyo.edu/capersupport/Galileos_Classroom/07c-Jupiter-solar_system_dance.pdf) provides basic information about planets, moons and distance. However it does not help students with understanding day and night, phases of the moon, or eclipses.

Materials:

- Six (or more) wide beam flashlights. Alternatively an unshaded lamp on a table may be used instead.
- Large mirror – preferably round or covered with a circular mask if another shaped mirror is used.
- Tubular map of the earth marked with the continents and countries (US, Japan, India, UK) for the "earth" to wear so that the rotations will be visible.

Orbital Motion:

1. For the sun, arrange at least 3 students with flashlights in each hand back to back in the center of the room. If more flashlights are available, additional students can enhance the "sun".

2. For the earth and the moon, choose two students. Give the moon the mirror to be held at chest height in front of them in a fixed direction. Put the tubular map on the earth.

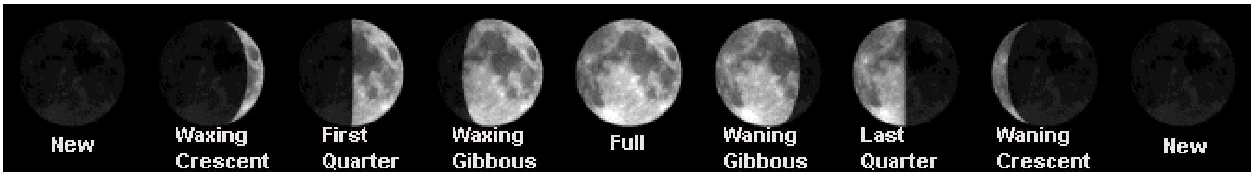
   Question: What difference would it make if the South pole was on top?

3. Ask the "earth" to orbit the "sun". In all likelihood they will do this so that only one side of their body is illuminated in an orbit. Ask the observers (rest of class) what changes need to be made to represent the real motion of the earth.

   Question: How many rotations are needed in an orbit to represent reality?
   Question: What is the direction of rotation of the earth and how does it relate to the sense of orbital rotation? What would be observed if they were reversed?

   Once consensus has been obtained, ask the "earth" to walk for the equivalent of a week to confirm the revised motion. If changes are still needed, repeat the process.

4. Ask the "moon" to orbit the "earth" while the earth stands still. Make sure the moon starts so that the earth can see an almost full moon initially. While the moon is completing an orbit, ask the earth to describe what light and its intensity is visible in the moon's mirror. Observe the phases of the moon and which side of the moon is the "new moon" and compare with the pictures. Ask the observers what changes need to be made to represent the real motion of the moon. This may take a little discussion depending on the moon's chosen path. Note: The time for the moon to orbit the earth is 28 days. Ask the students to explain the phases of the moon.



Question: Does the moon rotate on its axis?
Question: Which hand is illuminated first after the "new moon"?

After choosing a couple of adjustments, ask the moon to repeat their orbit with the earth reporting. Repeat this sequence until agreement on the path can be reached.

Question: Why is there a solar eclipse every orbit when the moon is full?
Question: Why doesn't it happen in reality?

5. Now allow the earth to orbit the sun while the moon orbits the earth. Note the motional complexity.

Addition to Solar Dance (Teacher's version)

Orbital Motion:

1. For the sun, arrange at least 3 students with flashlights in each hand back to back in the center of the room. If more flashlights are available, additional students can enhance the "sun".

2. For the earth and the moon, choose two students. Give the moon the mirror to be held at chest height in front of them in a fixed direction. Put the tubular map on the earth.

   Question: What difference would it make if the South pole was on top?
   Answer: The direction of the earth's rotation would be reversed and order of sunrise time across U.S. would be inverted.

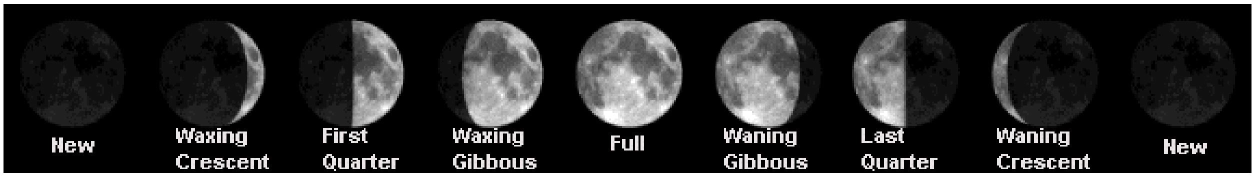
3. Ask the "earth" to orbit the "sun". In all likelihood they will do this so that only one side of their body is illuminated in an orbit. Ask the observers (rest of class) what changes need to be made to represent the real motion of the earth.

   Question: How many rotations are needed in an orbit to represent reality?
   Answer: 365 rotations per orbit

   Question: What is the direction of rotation of the earth and how does it relate to the sense of orbital rotation? What would be observed if they were reversed?
   Answer: Both are anticlockwise with respect to their axes of rotation. If reverse earth rotation, New York would see the sun rise and set after Indiana. If reverse orbital direction, the stars and constellations would be observed in opposite seasons.

   Once consensus has been obtained, ask the "earth" to walk for the equivalent of a week to confirm the revised motion. If changes are still needed, repeat the process.
   Answer: The distance around the orbit should be 1/52 of the full orbit

4. Ask the “moon” to orbit the “earth” while the earth stands still. Make sure the moon starts so that the earth can see an almost full moon initially. While the moon is completing an orbit, ask the earth to describe what light and its intensity is visible in the moon’s mirror. Observe the phases of the moon and which side of the moon is the “new moon” and compare with the pictures. Ask the observers what changes need to be made to represent the real motion of the moon. This may take a little discussion depending on the moon’s chosen path. Note: The time for the moon to orbit the earth is 28 days. Ask the students to explain the phases of the moon.



Question: Does the moon rotate on its axis?
Answer: No the moon does not rotate on its axis like the earth - we would see different parts of the moon if it did. We cannot see the back of the moon from earth.

Question: Which hand is illuminated first after the “new moon”?
Answer: The left hand will appear first after the new moon as the moon moves in an anticlockwise sense in its orbit like the earth. If the orbiting direction was reversed, the right hand would appear first.

After choosing a couple of adjustments, ask the moon to repeat their orbit with the earth reporting. Repeat this sequence until agreement on the path can be reached.

Question: Why is there a solar eclipse every orbit when the moon is full?
Answer: Because in our motion, the moon orbits the earth in the same as the plane of the earth’s orbit around the sun.

Question: Why doesn’t it happen in reality?
Answer: Because the plane of the moon’s orbit around the earth is different from the plane of the earth’s orbit around the sun. We only have an eclipse where the two planes cross and it will not always be at the full moon because the moon must be at that intersection in its orbit to be blocked by the earth (or the sun)

5. Now allow the earth to orbit the sun while the moon orbits the earth. Note the motional complexity.

Additional Resources for understanding earth/moon relationship:
http://astro.unl.edu/naap/lps/animations/lps.html

Lesson Extension #2
Building a Model of Sun and Earth

In order for students to better understand the reason why seasons change on a yearly basis, a simple model can be constructed from athletic balls. The model can be constructed from the following materials:

Description	Number
Large Ball (such as a softball)	1
Baseball Size Whiffle Ball	4
Straws	4
Stiff Wire (12 Gauge) 5" long	4
Tape	Roll

The whiffle ball is used to represent the Earth and is built by first cutting a straw in half and running it through two opposite holes in the whiffle ball. The straw represents the axis of the Earth. The straw is secured to the whiffle ball using tape (masking tape, transparent tape, or duct tape will be sufficient). Next, the wire is used to make a stand for the ball. Approximately an inch and a half of the wire is put into the straw. The wire is then bent to show the tilt of the Earth (approximately 23 degrees) and provide a stand for the earth model (see picture in Figure 2).

Four models of the Earth can be made in order to represent the Earth in each of the four seasons. An approximate location of the student's location can be noted on the whiffle ball. The students will be able to utilize a three-dimensional model of how the sun (softball), shines on the earth at various times of the year. The winter and summer position are the easiest to show initially.

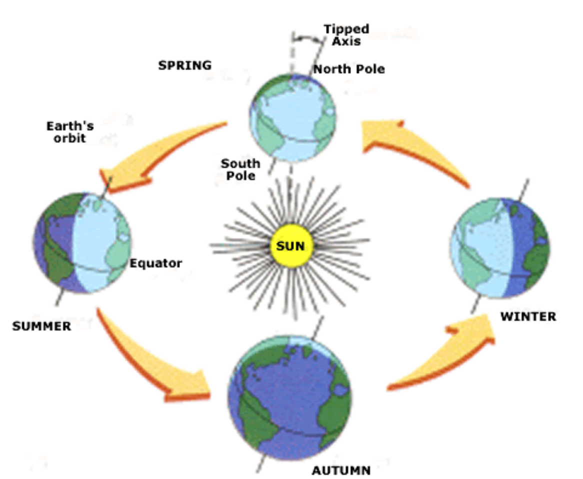


Figure 1. Earth rotation around the sun at the four different seasons.
Image retrieved December 10, 2012 from http://www.learner.org/jnorth/tm/mclass/Glossary.html.

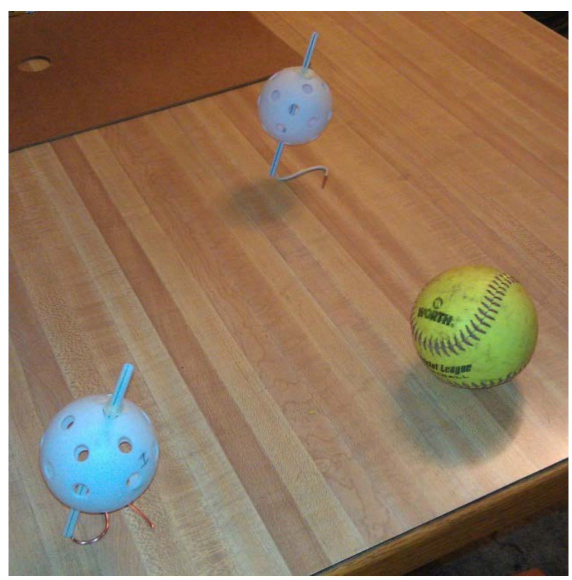


Figure 2. Simple model of earth/sun relationship at the four seasons.

Lesson Extension #3
Shadows

Shadows (Student Version)

Materials:

- Opaque paper to cover south facing window with penny sized hole in center
- Tape to secure paper to window
- Roll of butcher paper to cover shadowed region of floor (at least 3 feet wider- with extension to edges of morning and evening location of window shadow
- Pencils and paper
- An LED flashlight (focused beam is best – available at Radio Shack and other electronic stores)
- Scissors
- 2 Sheets of cardboard or firm drawing paper per student to draw and cut out scenes for shadow.
- Two ¾" or larger binder clips as stands for cutouts
- Yard stick
- A sunny day!

Procedure:

A. Sun Tracking

1. Use a penny as template and cut out a penny sized hole in the center of a large sheet of paper.
2. Tape paper on south facing window at start of the day. Place the long roll of paper on the floor in the shadow so that the sun spot is approximately centered on the paper and there is at least 3 feet of paper on each side of the spot.
3. Each student draws a spot in the center of a sheet of paper and then ask them to draw their prediction of the track that the spot will follow during the day. Ask the students to compare their answers and justify their predicted track.
4. Circle the sunspot on the paper on the floor and trace out the 3 or 4 most popular predictions. You may wish to use different colors for different predictions.
5. Every half an hour, mark the new location of the sun spot on the floor. After doing part C, discuss with students the difference between what they observed and their predictions
6. Does the size of the spot change during the day? Why?

B. Shadow geometry - Lengths

1. In this examination of the behavior of shadows, we will use standard paper size of 8.5" x 11" as a scale. (5.5" = a page folded in half top to bottom)
2. Create two shadow scene cutouts.
   #1: a "*test*" shape – tall narrow rectangle (1" x 5.5")
   #2: a creative one of student's choice. Attach the binder clips as stands to the bottom the rectangle.

3. Place 2 blank sheets of paper lengthwise touching one another. Place the rectangle *test* at the center of the pages. Hold the yard stick vertically at the edge of the front sheet and use the flashlight to create a shadow behind the rectangle and move the flashlight up and down the yard stick. Note how the length of the shadow varies.
4. Adjust the height of the flashlight so it creates a shadow whose length matches the length of a sheet of paper. Measure the height of the flashlight beam.
5. Add a second sheet of paper behind the first and repeat step 4 to create a shadow whose length is two sheets of paper. Measure the height of the beam.
6. Fold a sheet in two horizontally and cut along the fold. (5.5”) Fold the other half again and cut (2.75 ”) Replace the “shadow” sheets with the half page and measure the height that corresponds to shadows of this length. Repeat with the ¼ sheet.
7. Record observations and calculations in the following table.

Shadow Length (pages)	**Height of Flashlight (inches)**	**Height of Flashlight (pages)**	**Height of rectangle / Shadow Length**	**Beam Angle**
0.25				
0.5				
1				
2				
3				

8. Construct a right angle triangle on a sheet of paper with the same ratio of height/length for each row in the table. Measure the angle that corresponds to the angle between the light beam and the paper with your protractor and enter it in the table.
9. What do you learn about angles and triangles from your Height/Length and angle columns?
10. Which shadows correspond most closely to the equinox, summer solstice, and winter solstice sun angles?
11. Make a new table and *predict* the values
    a. if the *test* rectangle had a height of one page.
    b. If the distance between the *test* rectangle and the flashlight was increased to 2 paper lengths.
12. Check your predictions with a couple of measurements.

C. Shadow geometry - Angles

1. Replace the *test* rectangle with a pencil (not too short!)in the center of the original two page paper arrangement. Hold the flashlight level with the front edge of the paper in position so that you create a shadow that makes a 90° angle with the far edge of the papers. Mark the position of the flashlight on the front sheet.

2. Align the yard stick with the edge of the front sheet with its center at the mark. Move the flashlight to the right along the yard stick until the shadow makes a 45° angle with the far edge of the papers. Do you need to add another sheet - if so how many? Note the distance you have moved the flashlight along the yard stick. Surprised??
3. Do you start from the right or the left of the central mark to make the shadow move clockwise?
4. Find another position for the flashlight so that you can make a 45° angle shadow that is visible only on the single back sheet of paper. What happened when you moved the flashlight to and fro along the paper edge, in and out of the paper, or up and down.
5. On a new sheet of paper using the center of the bottom edge as a starting point, draw lines that make angles of 64° (solstice) ±40° (equinox Lafayette latitude) and ± 17° (solstice) with both *side* edges of the paper. How do these angles relate to the angles shown in the figures in the tracker design section of the lesson plan?
6. Replace the back sheet of the standard setup with this sheet you just made. Use a ruler to extend the lines you have drawn onto the front sheet all the way to the edge. (You may have to add sheets, or mark on your surface) Place the yard stick along the bottom edge of the front sheet. Measure the distance between the flashlight and the central mark on the sheet and the lines you have just drawn. How do these values compare with the quantities shown in the flashlight height column in your table from part B.
7. Move the flashlight along the yard stick so that the flashlight and its shadow align with one of the longest solstice lines. Raise it to a height where the shadow just reaches the side of the paper. Starting from this point, move the flashlight at this height along the yardstick.
   Ask: Did you start at sunrise or sunset?
   Which solstice does this correspond to?
   Does this show how the sun's shadow moves at this solstice?
8. Choose the equinox line and repeat step 7.
9. Check the position of the sun spot from part A. Do you want to change your prediction for the path of the sun spot? Now move the flashlight so that it matches the observed track of the sun spot today and show how you expect the sun spot to move for the rest of the day. With the understanding generated from the observations you have now made, move the flashlight in such a way as to mimic your predicted path of the spot.
10. Plot a predicted path for the sunspot on the winter and summer solstice using the paper of part **A.**

D. Shadow Patterns

Use the experience you have gained to make a cutout to explore the shadow patterns that come from houses, trees, fences, etc as the sun moves. Have fun with your creations.

<u>Shadows (Teacher Version)</u>

Procedure:

A. Sun Tracking

1. Use a penny as template and cut out a penny sized hole in the center of a large sheet of paper.
2. Tape paper on south facing window at start of the day. Place the long roll of paper on the floor in the shadow so that the sun spot is approximately centered on the paper and there is at least 3 feet of paper on each side of the spot.
3. Each student draws a spot in the center of a sheet of paper and then ask them to draw their prediction of the track that the spot will follow during the day. Ask the students to compare their answers and justify their predicted track.
4. Circle the sunspot on the paper on the floor and trace out the 3 or 4 most popular predictions. You may wish to use different colors for different predictions.
5. Every half an hour, mark the new location of the sun spot on the floor. After doing part C, discuss with students the difference between what they observed and their predictions
6. Does the size of the spot change during the day? Why?

   Predicted track: Note it

   a. *starts on the right as you face the window. The spot is the extension of the beam of sunlight. When sun is in East, the spot will be towards the West.*
   b. *is curved. There is motion in two dimensions. The bigger change is side to side reflecting the east to west motion of the earth's rotation. The smaller change is towards and away from the window reflecting the up and down motion of the sun as it rises and sets. This is governed by the earth's tilt angle.*
   c. *moves towards the window as the sun's angle to the surface of the earth increases. If the sun ever got to 90° the spot would disappear! This only happens at the equator on the equinox.*
   d. *is largest at dawn and sunset and smallest at true noon (remember time zones and daylight saving). The spot edges reflect the edges of the sun. The longer the distance to the spot, the bigger the spot. Light travels in parallel straight lines.*

   Spot size = $d * \tan \Theta$

   Where d is the hole width and Θ is angle of sun with respect to vertical

   Noon at the equator $\Theta = 0$

   Sunset at the equator $\Theta = \sim 90°$

B. Shadow geometry - Lengths

1. In this examination of the behavior of shadows, we will use standard paper size of 8.5" x 11" as a scale. (5.5" = a page folded in half top to bottom)
2. Create two shadow scene cutouts.

#1 A "*test*" shape – tall narrow rectangle (1" x 5.5")

#2 a creative one of student's choice. Attach the binder clips as stands to the bottom the rectangle.

3. Place 2 blank sheets of paper lengthwise touching one another. Place the rectangle *test* at the center of the pages. Hold the yard stick vertically at the edge of the front sheet and use the flashlight to create a shadow behind the rectangle and move the flashlight up and down the yard stick. Note how the length of the shadow varies.
4. Adjust the height of the flashlight so it creates a shadow whose length matches the length of a sheet of paper. Measure the height of the flashlight beam.

5. Add a second sheet of paper behind the first and repeat step 4 to create a shadow whose length is two sheets of paper. Measure the height of the beam.
6. Fold a sheet in two horizontally and cut along the fold. (5.5") Fold the other half again and cut (2.75 ") Replace the "shadow" sheets with the half page and measure the height that corresponds to shadows of this length. Repeat with the ¼ sheet.
7. Record observations and calculations in the following table.

Shadow Length (pages)	**Height of Flashlight (inches)**	**Height of Flashlight (pages)**	**<u>Height of rectangle</u> Shadow Length**	**Beam Angle**
0.25	27.5	2.5	2	63.4°
0.5	16.5	1.5	1	45°
1	11	1	0.5	26.6°
2	8.3	0.75	0.25	14.0°
3	7.3	0.67	0.167	9.5°

8. Construct a right angle triangle on a sheet of paper with the same ratio of height/length for each row in the table. Measure the angle that corresponds to the angle between the light beam and the paper with your protractor and enter it in the table.
9. What do you learn about angles and triangles from your Height/Length and angle columns?
   Answers: entries 1 & 3 are complementary angles (sum 90°). Draw beams for each case. The height of the flashlight can then be determined by determining the number of shadow lengths equal one page (the horizontal distance between the test rectangle and the edge of the page). The height of the flashlight is the sum of this many test rectangle heights plus one.
10. Which shadows correspond most closely to the equinox, summer solstice, and winter solstice sun angles?
    Answer: 45, 63.4 and 14.0 respectively.
11. Make a new table and *predict* the values
    a. if the *test* rectangle had a height of one page.
    b. If the distance between the *test* rectangle and the flashlight was increased to 2 paper lengths.
12. Check your predictions with a couple of measurements.

C. Shadow geometry - Angles

1. Replace the *test* rectangle with a pencil (not too short!)in the center of the original two page paper arrangement. Hold the flashlight level with the front edge of the paper in position so that you create a shadow that makes a 90° angle with the far edge of the papers. Mark the position of the flashlight on the front sheet.
   Answer: Midpoint of front edge.
2. Align the yard stick with the edge of the front sheet with its center at the mark. Move the flashlight to the right along the yard stick until the shadow makes a 45° angle with the far edge of the papers. Do you need to add another sheet - if so how many? Note the distance you have moved the flashlight along the yard stick. Surprised??

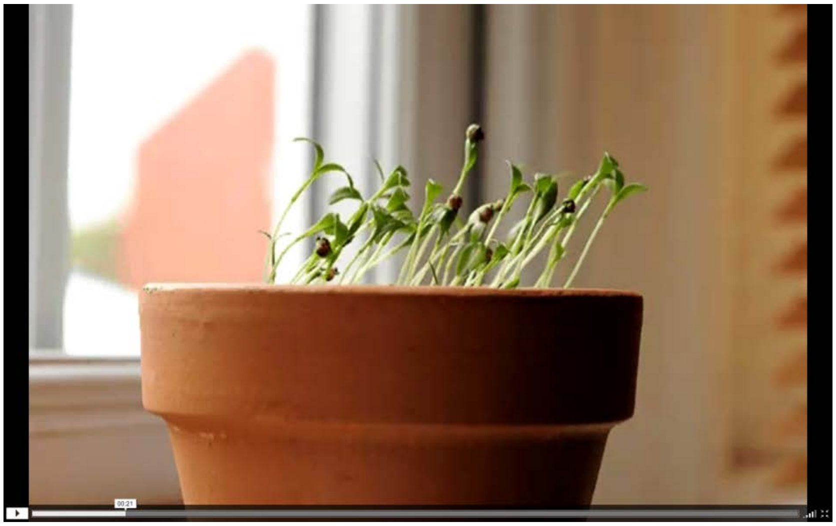
Answer: move 11" and must add one sheet. Intersection at mid-point of added sheet.

3. Do you start from the right or the left of the central mark to make the shadow move clockwise?
   Answer: move from right to left – this is the original definition of clockwise!
4. Find another position for the flashlight so that you can make a 45° angle shadow that is visible only on the single back sheet of paper. What happened when you moved the flashlight to and fro along the paper edge, in and out of the paper, or up and down.
   Answer: Move the flashlight higher vertically at the same horizontal distance. In and out or sideways motion changes the shadow angle!
5. On a new sheet of paper using the center of the bottom edge as a starting point, draw lines that make angles of 64° (solstice) ±40° (equinox Lafayette latitude) and ± 17° (solstice) with both *side* edges of the paper. How do these angles relate to the angles shown in the figures in the tracker design section of the lesson plan?
   Answer: They are complementary (the sum of the two is 90°.
6. Replace the back sheet of the standard setup with this sheet you just made. Use a ruler to extend the lines you have drawn onto the front sheet all the way to the edge. (You may have to add sheets, or mark on your surface) Place the yard stick along the bottom edge of the front sheet. Measure the distance between the flashlight and the central mark on the sheet and the lines you have just drawn. How do these values compare with the quantities shown in the flashlight height column in your table from part B.
   Answer: Comparable angles mean comparable relative distances. (22.6", 9.2", 3.4"if measure height from top of test)
7. Move the flashlight along the yard stick so that the flashlight and its shadow align with one of the longest solstice lines. Raise it to a height where the shadow just reaches the side of the paper. Starting from this point, move the flashlight at this height along the yardstick.
   Ask: Did you start at sunrise or sunset?
   Answer: If started on right, this is sunrise and correct. Shadow moves in opposite sense to flashlight motion
   Which solstice does this correspond to?
   Answer: summer solstice.
   Does this show how the sun's shadow moves at this solstice?
   Answer: No. It is still incomplete. Must move flashlight up as well, so as to maintain a constant distance between the flashlight and the pencil throughout the motion to reproduce the sun's real motion.
8. Choose the equinox line and repeat step 7.
9. Check the position of the sun spot from part A. Do you want to change your prediction for the path of the sun spot? Now move the flashlight so that it matches the observed track of the sun spot today and show how you expect the sun spot to move for the rest of the day. With the understanding generated from the observations you have now made, move the flashlight in such a way as to mimic your predicted path of the spot.
10. Plot a predicted path for the sunspot on the winter and summer solstice using the paper of part **A.**

E. Shadow Patterns

Use the experience you have gained to make a cutout to explore the shadow patterns that come from houses, trees, fences, etc as the sun moves. Have fun with your creations.

Lesson Extension #4
Phototropism



http://www.flickr.com/photos/jakeperks/2441258936/

As a lesson plan extension, viewing plants as they react to the sunlight during the day is an exercise to understand how the sun moves across the sky. There are a number of plants that are very phototropic and track the sun. Special seeds may be purchased from: www.fastplants.org, or the teacher may experiment with different herbs and flowers that track the sun during the day.

Science Content:

Just as we respond to changes in our environment, plants respond and adapt to changes in their environment in order to survive and be successful. Plants need light for energy that they use for growth and survival. Plants take energy from light and convert it to chemical energy in a process known as photosynthesis. Since a source of light is so important to a plant's ability to survive, plants have special responses to light. An example of one of the ways a plant responds to its environment is by growing towards its source of light. This is known as Phototropism. If the source of light is the sun, it is known specifically as heliotropism."

Useful Websites

1. http://www.schoolsobservatory.org.uk/astro/esm/shadows
   Animated video of shadow of stick over day includes position of sun and commentary.

2. http://www.liverpoolmuseums.org.uk/nof/sun/suntracker.html#
   Effective animation of sun position as a function of date and location (select 40N 86W)

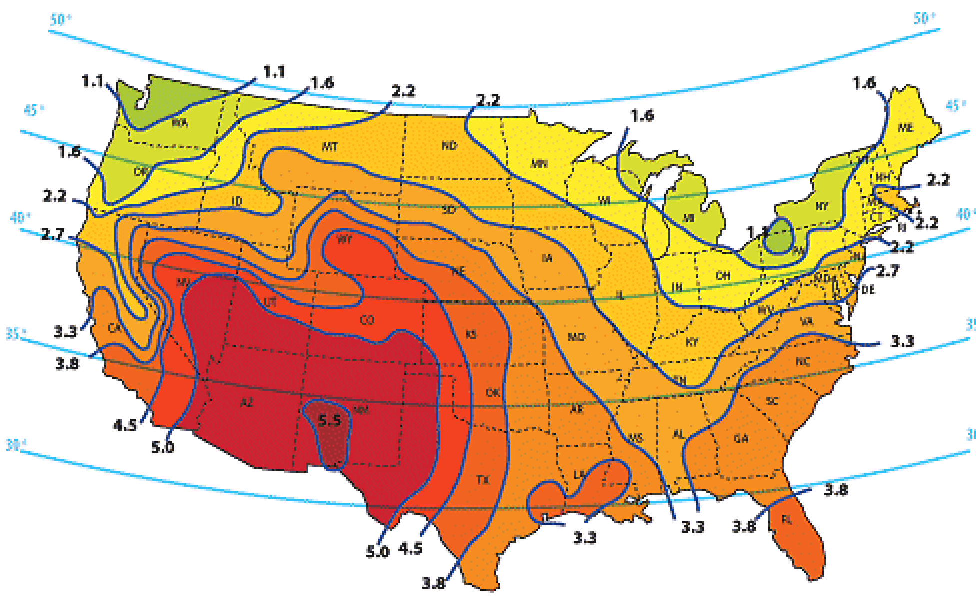
3. http://www.schoolsobservatory.org.uk/astro/esm/season3
   Shadow demonstration of why the sun's angle to the earth determines how the amount of heat we receive.

4. http://www.archaeoastronomy.com/
   Revolving season picture and rotating earth picture

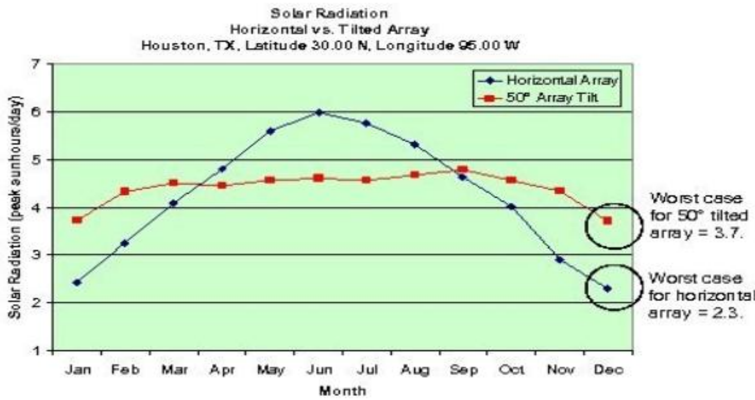
5. http://www.cabrillo.edu/
   then Search for Solar Radiation to find a useful set of power points on solar radiation and collectors.

6. http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/Table.html
   Average Radiation received by collectors by month over range of collector orientations

7. Image retrieved May 5, 2012 from http://www.solarcraft.net/images/insolationmap.gif

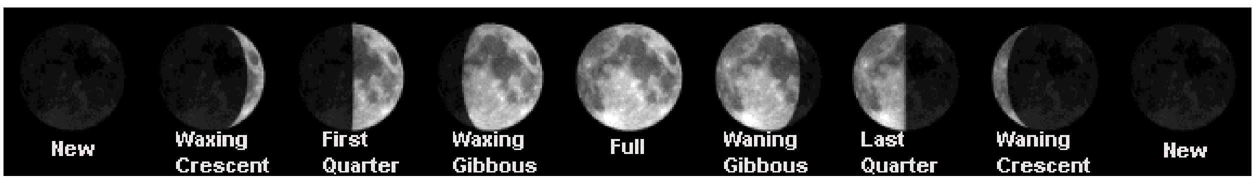


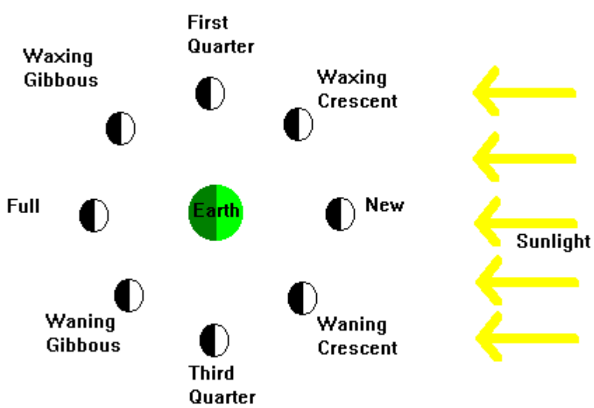
8. Image retrieved May 5, 2012 from http://www.oynot.com/solar-radiation.html



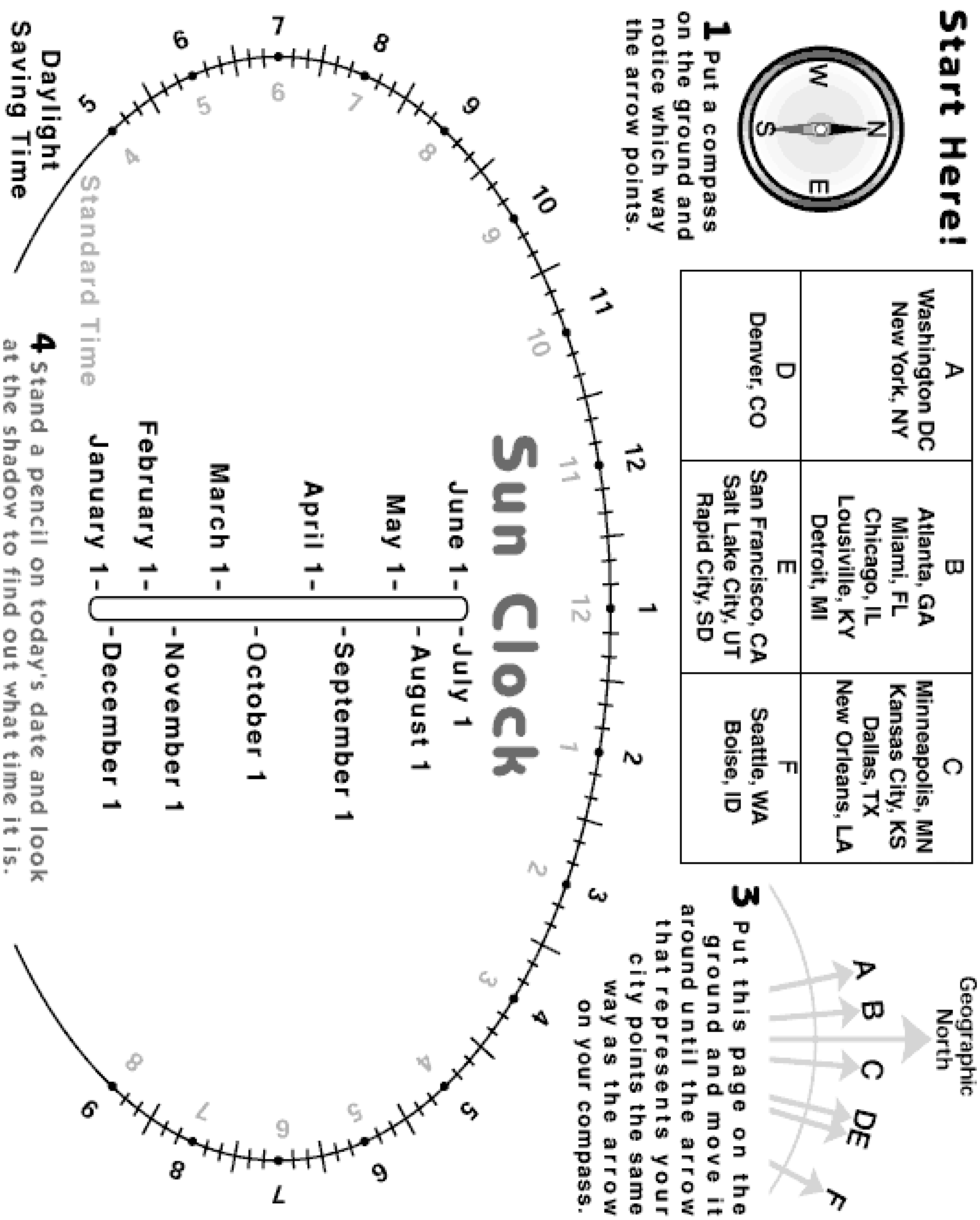
9. http://aa.usno.navy.mil/data/docs/RS_OneDay.php
Calculator for sunrise/sunset

10. http://www.uni.edu/morgans/astro/course/Notes/section1/new2.html
Phases of the moon.





11. Image retrieved May 5, 2012 from
http://www.exploratorium.edu/science_explorer/clock_diagram.html



12. Image retrieved May 5, 2012 from http://www.georgefcram.com/education/gr1.jpg