Solar Energy:

Cooking with the Sun

TechXcite: Discover Engineering
Pilot Module

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Cooking with the Sun Module
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Activity 1: Absorbing Heat from the Sun

Time Required: 20 minutes

Materials List

Group Size: Entire Class

To share with the entire class:

- Infrared thermometer
- Black pan
- Silvered pan
- Oven gloves

Youth Worksheets:

- None

Learning Objectives

After this activity, students should be able to:

- Identify heat transfer by radiation.
- Explain that a black surface absorbs more solar radiation than a white surface.
- Explain that a white surface reflects more solar radiation than a black surface.

Introduction:

During this module you will be designing and building a solar oven. In the first activity, we will be looking at specific ways in which objects are heated up by the sun and determining what factors affect the amount of heat absorbed or reflected by the objects. We want to collect as much heat as possible in our solar ovens.

You may not know it, but you probably have experienced how a solar oven works. What happens when a car sits in the sun on a hot summer day? [Let the students think about this for a minute. Answer: It gets hot.] Can it get hotter than the outside air temperature? [Answer: Yes, because sometimes it's hard to get in the car at first.] The car is acting kind of like the solar ovens we are going to build.

The sun's rays enter the windows strike the interior of the car. Heat from the sun's rays is called solar radiation and is a form of energy. Depending on the color of the interior, some solar radiation will be absorbed and some will be reflected. The absorbed radiative energy is converted to heat in that material. This is called heat transfer through radiation. We have already set up a short experiment outside to test this.

[At this time, take the students outside to view the experiment.]

Vocabulary

Word	Definition
Radiation	Energy transferred through the movement of electromagnetic waves; heat transfer not requiring a medium.
Solar Radiation	The amount of power received on the Earth's Surface per unit area (Watts per square meter in the SI unit system)

Procedure

Before the Activity: 20 Minutes

On the day before the activity, spray paint one of the two pans black if it has not already been done for you by a previous class.

On the day of the activity, place the two pans outside in the sun a few hours before class. This exercise will work when there are some clouds but will work better on a sunny day.

During the Activity:

Once outside, show the students the two pans. Then, ask the students, “Which pan do you think will be hotter?” [Let students provide a few ideas as to why one will absorb more than the other. Then, take a vote.]

Explain to the students, “The hotter pan is the one that has absorbed more solar radiation. It is difficult to measure the temperature of a surface using a thermometer. If you hold it directly against the surface, the side of the thermometer against the surface will be at the surface temperature while the other side will be at the air temperature. The measurement will be somewhere in between. Instead, we will be using an infrared thermometer that measures the temperature of the surface by measuring the heat being given off by the surface in the form of radiation.”

Demonstrate for the students how to use the infrared thermometer. Position the infrared thermometer a few inches away from the surface of the pan you want to measure and point the infrared thermometer at the pan. The infrared thermometer will provide the temperature of the surface. The controls on the thermometers may vary.

Ask two student representatives to measure the temperature of each pan. The class should measure a significantly higher average temperature on the blackened pan than on the silvered pan.

Processing and Activity Closure:

After the measurements have been made, you can ask the class, “Which pan was hotter, the black or the white one? Was this what you expected?” [Answer: The black pan should have been hotter.]

Next, you can explain to the students, "When you see an object, you usually identify it by the color that it reflects back to your eyes. The reason the object appears as that color is that all other colors are absorbed. When you see white, you actually see a combination of all colors. Black is the absence of color. So when you see a white object, it actually reflects most of the light shining on it. A black object absorbs most of the light shining on it. That is why the black pan was hotter."

They may already have answered the following question on their own, but if it has not come up yet, ask the students, "When you go outside on a hot day, would you feel cooler if you were wearing a white shirt or a black shirt assuming both were made of the same material?" [Answer: A black shirt tends to be hotter.] A black shirt tends to be hotter. In general, a black object absorbs more heat through radiation than the same object would if it were white.

Finally ask the students, "If we want to collect as much heat as possible from the sun in our solar ovens, what color should the inside of the solar oven be painted?" [Answer: At least some of it should be painted black.] As we discuss the solar oven further, we will discuss which parts of it are most useful to paint black.

During the next activity which is also outside, allow the students who did not use the infrared thermometer during this demonstration to come over and make the measurements themselves if they would like to.

Embedded Assessment
None

Authors (Contributors): David Kahler, Paul Klenk, Gary Ybarra

Activity 2: Where is the Sun?

Time Required: 30 minutes

Materials List

Group Size: 3

Each group needs:

- 12” wooden skewer
- Protractor
- 12’ measuring tape
- Compass

To share with the entire class:

- Level

Youth Handouts

Student Handout: Where is the Sun?
Sample Class Datasheet

Learning Objectives

After this activity, students should be able to:

- Measure the solar angle at their location at the current time (both time of year and time of day).
- Measure the solar azimuth at their location at the current time (both time of year and time of day).
- Explain that a solar oven would need to be moved throughout the day to always face the sun.

Introduction:

As was discussed in the first activity, during this module you will be designing and building a solar oven. Now, you will be measuring the direction and angle of the sun in order to figure out where to place your solar ovens to maximize the energy they receive from the sun.

A solar oven is heated by capturing the sun’s energy. Would you point something that was trying to capture the sun’s energy such as a solar panel or a solar oven in the same direction in the morning as you would in the afternoon? [Answer: No, the sun rises towards the east and sets towards the west.] Therefore, a solar oven or solar panel that moves with the sun can capture more energy than a solar panel that is left in one place. Since we will be testing our solar ovens during this program [most likely in the afternoon], we need to measure the direction of the sun at the current time of day to know which direction we should point our solar ovens when testing them.

Does the time of year affect the position of the sun in the sky?
[The answer is yes. The sun is higher in the sky in the summer and lower in the sky in the winter. If they don’t get this, you might ask the students the following question.]

What causes the seasons?
[Answer: The tilt of the earth as it travels around the sun causes the seasons. This causes the sun to appear higher in the sky in the summer and lower in the sky in the winter.]

The position of the sun can be determined with two parameters – the local time and the day of the year. In this case, the local time is not simply the time in the time zone, but the time specific to your exact longitude. As we will see in this activity, true noon will not occur exactly at noon. True noon is the time that the sun is due south and casts the shortest shadow. Beginning at dawn, the sun moves higher and higher in the sky until true noon. Then, it begins to move lower and lower always moving from east to west. Throughout the year the sun rises in the east, but in the winter it rises further south and does not rise as high. As summer approaches, the sun rises further north and rises higher. In order to use your solar oven at a different time of year, you might find it useful to test the position of the sun in the sky at that time of year as well.

How would you describe the location of the sun right now?
[Answer: Students may have a number of answers for this. They may point at it. They may say it is in a certain direction. They may start comparing its current location in the sky to various reference points.]

Solar engineers locate the sun in the sky using two different measurements.

1) The **solar azimuth** is the angle the current direction of the sun makes with due south. You will be using a compass to find this angle. Since it is difficult to point a compass towards the sun exactly, you will be using the shadow of a vertical stick to find this angle.
2) The **solar angle** is the vertical angle between the sun and the horizon. In order to determine the solar angle, you will be using a vertical stick and then drawing on the handout. [Instructors Note: This value is also known by the terms altitude and elevation, but the students will likely find these terms more difficult because they contradict the more standard definitions of solar elevation and solar altitude. You do not need to bring these up in the lesson unless a student brings them up, but if you are searching for more information on the topic, you may find these terms useful.]

Vocabulary

Word	Definition
Solar Azimuth	The angle between the line from the observer to the sun projected on the ground and the line from the observer to due south.
Solar Angle	The vertical angle between the location of the sun in the sky and the horizon.
Magnetic Declination	The angle that separates true north from magnetic north.
Latitude or Parallels	The angle on a sphere above or below the equator. These lines are parallel with one another and can be formed by slicing the sphere parallel to the equator.

Summer/Winter Solstice	The time at which the sun is directly overhead of the Tropic of Cancer/Capricorn (respectively). The day on which this event falls is also referred to as the solstice and is the longest/shortest day of the year (respectively).
Spring/Fall Equinox	The time at which the sun is directly overhead of the equator. The day on which this event falls is also referred to as the equinox and has approximately the same amount of daylight as night. The term equinox is a word derived from Latin meaning equal night.
Tropic of Cancer	23° 26′ 22″ north of the equator. This is the most northern point on the globe that receives sunlight from directly overhead (solar angle can reach 90 degrees).
Tropic of Capricorn	23° 26′ 22″ south of the equator. This is the most southern point on the globe that receives sunlight from directly overhead (solar angle can reach 90 degrees).

Procedure

Before the Activity: 10 Minutes

Find a location where students can place their sticks vertically into the ground. An ideal location is next to a level sidewalk such that the shadow of the stick falls onto the sidewalk. Use the included level to locate a portion of sidewalk that is approximately level.

Look up the solar azimuth and solar angle (shown as altitude on this website) for the day and location you will be doing this activity. The appendices provide this data and were calculated for Ashville, NC, and for Greenville, NC, on September 15 to provide one set of data for students to compare their numbers to. Select the location that is nearest to you. This data was obtained from the following website maintained by the United States Navy. If you do this experiment on a different date or far from one of those locations, you may want to visit the website and generate a table for your location. Note that this website does not take into account Daylight savings time. If it is the summer, and Daylight savings time is in effect, add 1 hour to each of the times on the table generated by the website.
http://aa.usno.navy.mil/data/docs/AltAz.php
Make copies of this table for each of the student groups.

Finally, look up the magnetic declination for your location to find out how much the compass varies from true north. The following map shows that the magnetic declination for North Carolina is approximately between 4-8 degrees west of north.
http://www.spacecom.com/customer_tools/html/body_mag_dec_map.htm

The National Oceanic and Atmospheric Administration (NOAA) provides an online calculator for the magnetic declination at specific locations. You will just need the current date and your zip code.
http://www.ngdc.noaa.gov/geomagmodels/struts/calcDeclination

For a declination west of north such as the 4 to 8 degrees west of north declination in North Carolina, the declination you provide to your students will be positive. For a declination east of north, the declination you provide to your students will be negative.

During the Activity:

The students may already be outside following the first activity of the module. If that's the case, feel free to give the students the handouts and materials and let them follow along.

While students are working, watch the students making their measurements to ensure the sticks are vertical. Also, encourage the students to take care while making their measurements.

After the students have collected their data, you can go back inside to analyze it. Be sure to tell the students what value they should use for the magnetic declination.

Processing and Activity Closure:
Each group of students should take their measurements and use the worksheet to determine the solar azimuth and solar angle. Groups should submit their values for (solar azimuth and solar angle) to the class data table by writing it on a class datasheet or writing their data on the chalkboard. The students can then average the class data for the day. Students can compare their data to the tabulated angles provided either in the appendix or printed out by the instructor prior to class.

The following sun applet shows the movement of the sun's position at noon throughout the year. If you have access to a computer, students may find this useful in developing an understanding of how the solar angle at noon is related to the time of year.
http://cwx.prenhall.com/bookbind/pubbooks/lutgens3/medialib/earthsun/earthsun.html

If you have time, students can graph the published data on the same graph. The x-axis should be the solar azimuth and have a range of 90 to 270 degrees and the y-axis should be the solar angle. The published data will be the only data at multiple points throughout the day, but the students will observe where in the path of the sun their measurements were taken. Once the published data is graphed, some students will have a better comprehension of the true noon, the time at which the sun is highest in the sky.

Embedded Assessment
Collect and copy pages 11-13 from each group. Use the student calculations on these pages to ascertain whether they can properly calculate the solar angle and solar azimuth.

Authors (Contributors): David Kahler, Paul Klenk, Gary Ybarra

Student Handout: Experiment - Where is the sun?

Name: ____________________________________

Date: ______________________

Measuring the current Solar Azimuth and Solar Angle

1. Use the level to find a section of concrete that is relatively level. Your instructor may already have done this.
2. Insert your wooden stick into the soil right next to the concrete making sure that the shadow from the stick falls onto the concrete.
3. Use the measuring tape to make sure that exactly 8 inches of the stick is above the level concrete.
4. Use the protractor to make sure that the stick is perpendicular (at a 90 degree angle) to the concrete in all directions. This will ensure that the stick is exactly vertical.
5. You are now ready to take your measurements.
6. In the data table below, there are a number of rows. You only need to fill out the first row. If you take measurements at different times or dates for your location in the future, you can put your data in other rows. This could help you utilize your solar oven at other times during the year.
7. At the top of your data table, write the city and state in which you are taking the measurement. This is your location on Earth since the location in the sky is different depending on where you are on Earth.
8. Write the value provided by your instructor for the magnetic declination at your location. The magnetic declination is the amount true north varies from magnetic north.
9. In the first two columns, write down the time and date of the measurement.
10. Measure the length of the shadow from the base of the stick to the end of the shadow. Write the length in inches in the third column where it says "Shadow Length."
11. Place your compass on the ground. The red arrow on the compass points north. Orient your compass so that the red arrow is pointing exactly away from the vertical stick. Take a second stick and lay it on the ground so that it is touching the base of the first stick and is directly in line with the arrow of the compass. Make sure the first stick remains vertical.
12. Now, use your protractor to measure the angle between the shadow and the second stick. Write that angle in the fourth column where it says "Shadow Angle." We are measuring this angle relative to north. If it is in the morning, the shadow will be on the west side of north, and you should write the angle as a negative number. If it is in the afternoon, the shadow will be on the east side of north, and the angle will be positive.

Data Analysis
In your groups, it is now time to utilize the data you have collected and calculate the solar azimuth and the solar angle.

Compute the solar azimuth by adding the value for the magnetic declination provided by your instructor and then adding 180° to the angle to account for the fact that the shadow points in the direction opposite the direction of the sun. Write the solar azimuth in the appropriate column on the data table.

(Shadow Angle) + (Magnetic Declination) + 180 = Solar Azimuth

____________ + _________________ + 180 = ___________

The solar angle can be calculated using the Solar Angle Handout below. This graph represents a side view of the experiment. The vertical stick extending 8 inches above the sidewalk is shown on the left side of the sheet of paper. Along the bottom, mark how far the shadow extended as a dot on the horizontal axis. Now connect the dot with the top of the line representing the vertical stick. You now have drawn a right triangle. Use your protractor to measure the angle in the lower right hand corner. This is the solar angle.

If you are interested in exploring this further, the solar angle can also be calculated using something called trigonometry. To do this, you can use the inverse tangent function. Since we know the height of the stick is 8 inches and the length of the shadow the solar angle is:

$$\tan^{-1}\left(\frac{8}{ShadowLength}\right) = SolarAngle$$

You could use this equation with sticks of various heights by substituting the length of the stick for the number 8.

Solar Angle Calculation Handout

The solar angle can be calculated using the Solar Angle Handout. These two lines represent a side view of the experiment. The vertical line extending 8 inches above the sidewalk is shown on the left side of the sheet of paper. It is exactly 8 inches long. Along the bottom, mark how far the shadow extended as a dot on the horizontal line. Now connect the dot with the top of the line representing the vertical stick. This will run over some of this text. You now have drawn a right triangle. Use your protractor to measure the angle in the lower right hand corner. This is the solar angle. Please write this angle below

Solar Angle (°) = _______

8 Inch vertical stick

Mark the length of the shadow you measured

Data table

Location: _______________

Magnetic Declination: _______________ (Provided by instructor)

Date	Time	Take Shadow Measurements		Use Your Measurements to Calculate Sun's Location	
		Shadow Length (in)	Shadow Angle (°)	Solar Angle	Solar Azimuth

Activity 3: What Insulates?

Time Required: 45 minutes

Materials List

Group Size: 3

Each group needs:

- Hot plate or small water heater
- Mason jar (1 quart)
- Two pieces of Foam Core Board (cut to approximately 1' x 1')
- Multimeter with thermocouple
- Outer corrugated cardboard piece (12" x 37")
- A sample insulating material

To share with the entire class:

- Insulating material set (rubber foam, newspaper, any other material students want to test)
- Scissors
- Duct Tape

Youth Worksheets

- Testing Types of Insulation Student Handout

Learning Objectives

After this activity, students should be able to:

- Identify examples of heat transfer through conduction.
- Explain the purpose of insulation.
- Plot data on a grid.

Introduction:

The flow of heat occurs through three mechanisms conduction, convection, and radiation. Our solar ovens have the goal of collecting heat from the sun and keeping it in the oven. In the last activity, we discussed the collection of heat from the sun by radiation. Today, we will look at keeping heat in the oven utilizing insulation. Insulation reduces the loss of heat through the walls of the solar oven. Heat loss through the wall is called conduction.

Conduction is a heat transfer mechanism that occurs when two objects that have different temperatures are in direct contact with each other. Examples of this include touching a hot or cold object such as the handle of a soup spoon. In this case, the spoon is in soup that is hot. The soup spoon conducts heat from the soup to its handle. Heat is also conducted between the handle and the hand when the person touches the spoon.

Insulation is material that reduces the flow of heat through conduction. Insulation is used in ovens, in refrigerators, in your house, and anywhere else we want to reduce the flow of heat. A coffee cup must be a good insulator so that you can hold a cup of hot coffee without burning your hand. Today, we will test a number of insulators to learn about their properties in determining which would be best to utilize in our solar ovens.

Vocabulary

Word	Definition
Conduction	Heat flow due to the contact of two objects or within a solid object.
Thermal Conductivity	The property of a material that determines how well it conducts/transmits heat (Examples: metal generally has a high thermal conductivity, plastic generally has a low thermal conductivity)
Insulator/insulation	A material that does not conduct heat very well and has a low thermal conductivity (Examples: a good jacket, fiberglass insulation, a sleeping bag, anything with air trapped in it)

Procedure

Before the Activity: 25 Minutes

1. Cut the corrugated cardboard roll into a 37” length for each group. This should cut well with scissors.
2. Cut the foam core boards into two pieces (each 1 foot square) for each group. These will form the top and bottom of the insulation testing device.
3. Make sure you have a location to plug in the electric teapot and fill it with water.

During the Activity:

In this activity, the class will be working together. Each group will be testing a different insulating material or pair of insulating materials if you have time. Air, newspaper, and rubber foam should all be tested. Beyond that, be creative and let the students decide if there are any other readily available materials that they would like to test in their testing devices for possible use in the solar ovens.

Demonstrate to the class how to use the thermocouple to take a temperature measurement. Turn the dial on the multimeter to temperature. Then, plug the black connector on the thermocouple into black hole labeled Com and the red connector into the red hole that has most of the multimeter measurements listed next to it including temperature.

Ask students to follow the procedure on their handout. You can then walk around and answer questions while the students are working.

Processing and Activity Closure:

On a board, ask each group to send a representative to plot their curve on the same set of axes and then label their curve with the material they were testing. This will allow the class to evaluate the insulation of each material. After all of the curves are plotted on the board, ask the students, "Which material(s) held the heat in the mason jars best?”

You can tell the students that during the next session, they will begin building their solar ovens. Boxes and newspaper for this activity are not provided in the kit for the solar oven activity. Ask the students to collect one box each and some newspaper from home for their solar ovens. In addition, it is a good idea for you to pick up some boxes and newspaper just in case the students forget. You can find boxes in the recycling bins of many stores. Newspaper is often left behind where newspapers are freely distributed. It may also be found in recycling bins.

Embedded Assessment
Collect and copy pages 18-20 from each group. The question on page 18 will assess what students have learned about insulation. The table and charge on pages 16-17 will assess student knowledge of creating a plot from data.

Authors (Contributors): David Kahler, Paul Klenk, Gary Ybarra

Experiment – Testing Types of Insulation Student Handout

Name: ______________________________________

Date: __________________________

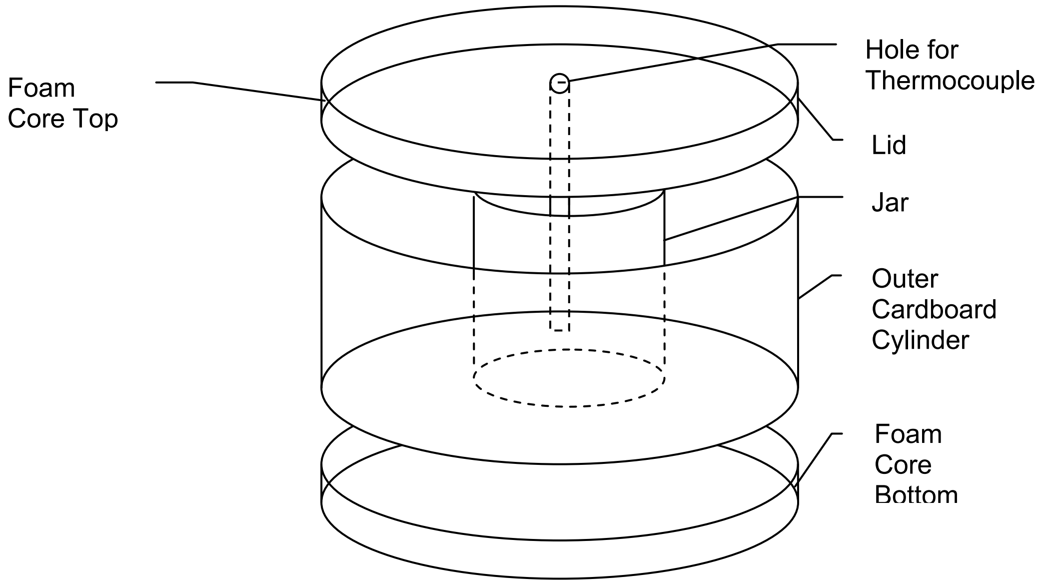
Materials List:

- Hot plate or small water heater
- Glass jar (1 quart)
- Two pieces of Foam Core Board (cut to approximately 1' x 1')
- Multimeter with thermocouple
- Outer corrugated cardboard piece (12" x 37")
- One or more sample insulating materials

Preparing your insulation testing device

1) Your testing device will be what you use to test the insulation of your assigned material(s). To begin, create the outer cylinder of the testing device from the (12" x 37" piece of corrugated cardboard. Bend the length into a cylinder and tape it with 1" of overlap. This will create a cylinder that is 12" tall, has a 36" circumference, and about 11.5" diameter. The glass jar has a diameter of approximately 3.5" so it will be surrounded by approximately 4" of insulation.

2) Cover the jar with aluminum foil and place a hole in the aluminum foil for the thermocouple to go through. This is to ensure that heat escapes only via conduction.



3) Assemble the testing device as shown in the diagram. The square foam core pieces go in the place of the discs at the top and bottom of the diagram. If there is no hole in one of the foam core pieces, you can make one with something small like a paperclip, pencil, or scissors. The smaller the better because the thermocouple is very small.

Testing

Heat water to a boil in the class's electric tea pot.

1. Switch the multimeter to the temperature setting. Then, plug the thermocouple into the multimeter.
2. Measure the temperature in the room: _________
3. Carefully pour the boiling water into the jar until it is approximately half full.
4. Carefully place the lid on your testing device with the thermocouple suspended in the water in the jar not touching the sides.
5. As soon as you close the lid, and every 30 seconds after, write down the temperature from the thermocouple on the attached data sheet.
6. Each group will be testing a different insulation sample and the class will be recording the results of all of the samples. Test the insulation sample for at least 15 minutes.

Record your data on the class data sheet. You can then use graph paper or the grid provided to plot your data. If there is time, your group can test a second sample, record the data, and plot it on the datasheet.

Data analysis

What do you think is the best insulator you tested? Why?

Time	Sample #1	Sample #2
0		
0:30		
1:00		
1:30		
2:00		
2:30		
3:00		
3:30		
4:00		
4:30		
5:00		
5:30		
6:00		
6:30		
7:00		
7:30		
8:00		
8:30		
9:00		
9:30		
10:00		
10:30		
11:00		
11:30		
12:00		
12:30		
13:00		
13:30		
14:00		
14:30		
15:00		

Graphing Your Data

Activity 4: Building a Solar Oven

Time Required: 90 minutes
(Testing with food will need to be done on a different day.)

Materials List

Group Size: 3

Each group needs:

- 2 Boxes – about one cubic foot – one which fits inside the other
- Additional cardboard to make panels – could just be one additional box
- Aluminum foil
- An oven bag
- Multimeter with thermocouple

To share with the entire class:

- Black spray paint
- Black construction paper
- Black duct tape
- Insulating materials (rubber foam, Styrofoam, newspaper, etc.)

Youth Worksheets

- Building a Solar Oven Worksheet

Learning Objectives
After this activity, students should be able to:

- Explain that insulation prevents heat loss through conduction.
- Explain that making portions of the inside of the oven black absorbs heat in order to raise the temperature of the oven.
- Explain the flow of energy from the sun to their solar oven and to the object they cook.

Introduction:

During the last few activities, we have measured some values that will help you in designing your solar ovens:

1. You learned that dark colored objects absorb more solar radiation than light colored objects.
2. You explored various types of insulation that can be used to keep heat in your ovens.
3. You learned how to measure the solar azimuth and the solar angle to determine the sun's position in the sky during your class periods. This is important because the sun's rays will be providing heat for your solar ovens.

Now, it's time to begin designing your solar ovens. Let's think back to the first activity involving solar radiation and discuss again the example of getting into a hot car. As we discussed, the car temperature is often warmer than the temperature outside and how warm the car becomes is dependent on the color of the interior. You can use this concept to build a solar oven.

The following describes the behavior of the car and of the solar oven. The interior surfaces are heated by solar radiation. Then through conduction the interior surfaces heat their surrounding. The air will then circulate through the interior of the car or oven and transport heat from the heated surface to the rest of the space. This movement of heat through moving air is called convection. Finally, heat can escape through the walls of the oven or car via conduction. For this reason, there is a maximum temperature the car or oven will reach.

As described in that example, engineers recognize three types of heat transfer:

1) Radiation: Would the car be hotter inside if it had a black interior or a white interior? [Answer: The car would be hotter if it had a black interior. That is because heat transfer via the absorption of solar radiation would be increased.]
2) Conduction: Would the car be hotter if it was made of a single thin sheet of cardboard or 6 inches of foam insulating material used on houses? [Answer: The car would be hotter if it were made of foam insulating material. That is because heat transfer via conduction would be reduced.]
3) Convection: We have not talked about convection much, but it is the third type of heat transfer. Convection is the movement of heat through moving hot air from one place to another. It can also be moving cool air. A fan is designed to increase heat transfer by convection from your body to make you feel cooler. Which would be hotter: a car in the sun on the side of a windy mountain or a car in the sun where there is no wind? [Answer: The car out of the wind would be hotter. That is because there would be less heat transfer away from the car due to convection from the wind blowing. For this reason, it would be better to locate a solar oven where there is less wind.]

You will play the role of an engineer when you are designing and building your solar oven. The design problem is provided to you on your handouts. Your goal is to utilize what you have learned and the materials provided to you to build a solar oven that can attain the highest temperature within half an hour, and can hold a small container that is

Procedure

Before the Activity: 10 Minutes

Boxes and newspaper for this activity are not provided in the kit. Ask the students to collect one box each and some newspaper from home for their solar ovens. In addition, it is a good idea for you to pick up some boxes and newspaper just in case the students forget. You can find boxes in the recycling bins of many stores. Newspaper is often left behind where newspapers are freely distributed. It may also be found in recycling bins.

This activity will generally take 2-3 class sessions. It can be good to encourage students to bring in additional materials from home. This lets students really think about what they want their oven to look like. It also gives them an opportunity to think more about the project outside of class. Be sure they are not bringing in expensive materials they had to buy that might give one group an advantage. As an example, students should not go to a home improvement store to buy insulation. You could either say that materials a group obtains outside of the ones provided must not cost more than $5-10 total, or you could even say that materials obtained must be freely available. This is up to the individual instructor.

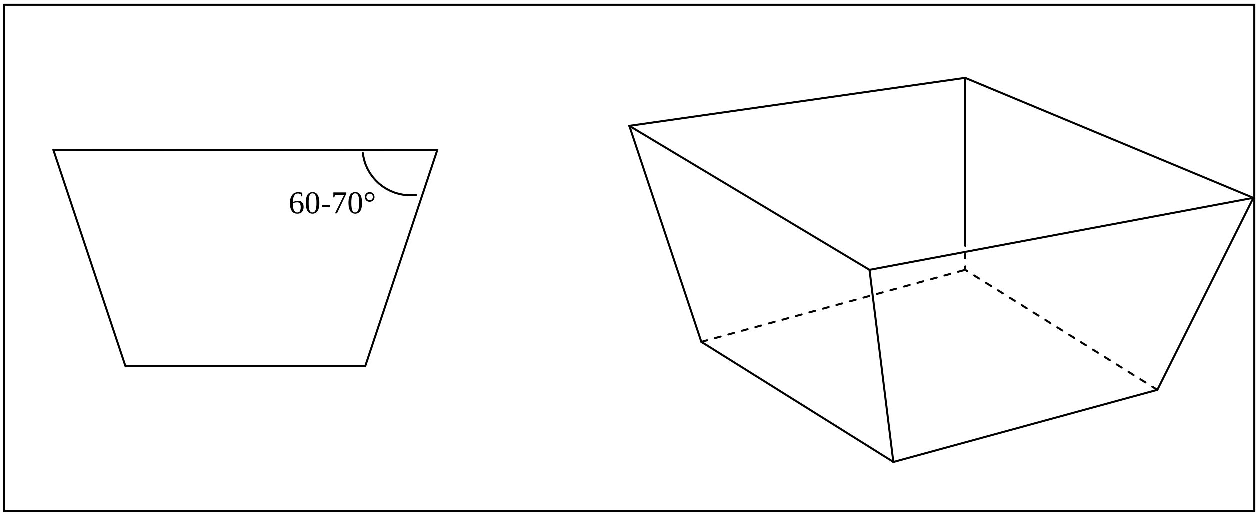
During the Activity:

The solar oven engineering design project is outlined in the student handouts.

The construction of the ovens should be guided by the materials chosen. Students should be encouraged to use different materials where available to experiment with what works better. The two nested boxes provide the external and internal walls of the oven while the oven bag serves as the transparent window. Insulation is placed between the boxes. Newspaper can serve as a very good form of insulation. Portions of the interior box, or wall of the oven, may be painted black to increase heat it will absorb by solar radiation. Black containers for cooking will help with this as well. It is also useful to reflect sunlight directly towards the areas where cooking is occurring.

Students are provided with the opportunity to reflect additional sunlight towards the interior of the oven using aluminum foil as a reflector. These will typically require some kind of backing probably made from cardboard cut from one of the boxes. The students must determine their own reflector configuration and how many panels they would like to use. In this way, they must think about where the sun is coming from and how to orient their boxes.

Some students will use a single reflector to reflect sunlight into the oven. Others might try more complex arrangements. One of the most efficient arrangements, if the students can figure out how to mount the collectors in place, is to put four collectors on top of the oven as shown below. The panels could be trapezoidal with angles in the range of 60-70°. The solar oven may need to be propped in order to point at the sun. The ovens will need to be moved while cooking so that the sun is always directed into the oven.



The most important thing the students can do to create solar ovens that will work well is to make sure there are no places where air can flow out of the interior of the oven. If the hot air can just flow out of an open space in the oven, the insulation will not be able to keep the heat in.

Processing and Activity Closure:

While the goal of the activity is to build and use a solar oven, the objective of the lesson should focus on what makes each oven different. Students should discuss as a class what is different about each oven. It is useful to list the specific parameters of each box; for instance, did one group not paint the inner walls black? Did one group not use aluminum foil or a collector at all? To test the ovens, each group should set up the oven outside on a sunny day and measure the air temperature inside the oven and plot that temperature as time progresses, as they did in Activity 2. Measurements may be taken every 10 minutes for a total of 30-40 minutes after which time the increase in temperature should begin to slow down, assuming the oven is empty.

The class data should be compiled so that students can observe the different heating curves that the other groups obtained and what different variables caused those changes.

Questions during the class data analysis offer more opportunities for the students to make connections and draw conclusions about the construction decisions made in the construction of the ovens. As the students observe all of the solar ovens in action, ask the students some of the following questions to help them think about what they just accomplished:

- Which solar ovens worked really well?
- Why do you think a particular solar oven worked well?
- How can a particular solar oven that did not work as well be improved?

After these ovens have been tested once to determine how hot they will get, it is time to test them with food (they may be tested with food during the next session). As the maximum temperature of the ovens may not be high enough to cook all food, it is recommended that you find something that is thin and is ok for the students to eat even if it does not fully cook. Pre-made cookie dough works well. You can back cookies in the oven on small pieces of aluminum foil. Do not place the cookies directly on spray painted aluminum foil. Place a layer of aluminum foil that has not been spray painted as a barrier for the food.

Embedded Assessment
Collect and copy page 29-30 from each group. The questions on both of these pages will assess student understanding of conduction, radiation, and how solar ovens utilize these two science concepts to heat a solar oven.

Authors (Contributors):

Engineering Design Activity – Building a Solar Oven Student Handout

Name: ___________________________________

Date: _____________________

In this exercise, you will play the role of an engineer while you are designing and building a solar oven. Keep in mind what you have learned about heat transfer and the movement of the sun in the sky in the previous activities.

Materials

Your group will receive:

- 2 Boxes – about one cubic foot – one which fits inside the other
- Additional cardboard to make panels – could just be one additional box
- Aluminum foil
- An oven bag
- Multimeter with thermocouple

The following materials are available to share with the class:

- Black spray paint
- Black construction paper
- Black duct tape
- Insulating materials (rubber foam, Styrofoam, newspaper, etc.)

Engineering Design Problem:
The design problem is to utilize what you have learned and the materials provided to build a solar oven that can attain as high a temperature as possible.

Engineering Design Specifications and Constraints:

- The interior of the oven must be large enough to hold whatever container you plan on using for cooking. In this case, you will want to be able to cook at least a few cookies on a piece of aluminum foil, or heat up water in a small teacup to make tea. To meet these requirements, the base of the interior of your oven must be at least 6"x6" and the height of it must be at least 4". Depending on the boxes you have, you are welcome to make your oven much bigger than this.
- You must be able to open and close your oven somehow. An oven bag is provided to create a transparent window. You must find a means of attaching this to your oven in order to create a lid. This way, food may be put in the oven or removed from the oven.
- Another reason you must be able to open and close your oven is to mount the thermocouple wire inside the oven. Once your oven is finished, mount the end of the thermocouple wire inside your oven with tape approximately one inch above the bottom and so that the tip is approximately one inch from the wall.

Design Tips

Insulation: Reducing heat loss through conduction

Utilizing two boxes, an inner and an outer box will provide a place for insulation to reduce heat transfer out of the oven. In between the inner and outer wall, you can place insulating materials the oven. Your instructor will have some materials available for you to choose from to insulate your oven. In general, the amount of insulation – how tight you pack it into that region – will change how well your oven retains heat. Use the results of your experiments from Activity 3 as a guide. You may not be able to use large amounts of the best insulation so think about how best to utilize it.

Interior Color: Increasing heat gain from solar radiation

When constructing your oven, you should try to maximize the amount of radiative energy, or sunlight, into the oven. Recalling the analogy of the car, the color of the interior of your car does affect the amount of energy transferred from radiative energy (sunlight) to heat. You may wish to experiment with painting portions of the interior black. Black containers for cooking will absorb more heat than other colored containers. It is also useful to reflect sunlight directly towards the areas where cooking is occurring.

Reflectors: Increasing the amount of solar radiation entering the oven

The maximum amount of solar radiation that your oven can currently collect is the amount that strikes the opening of your oven. One way to gather more radiative energy is to use reflectors to catch more light. You can use up to four cardboard reflectors. You must determine where you think the reflectors will be most useful in collecting the suns rays.

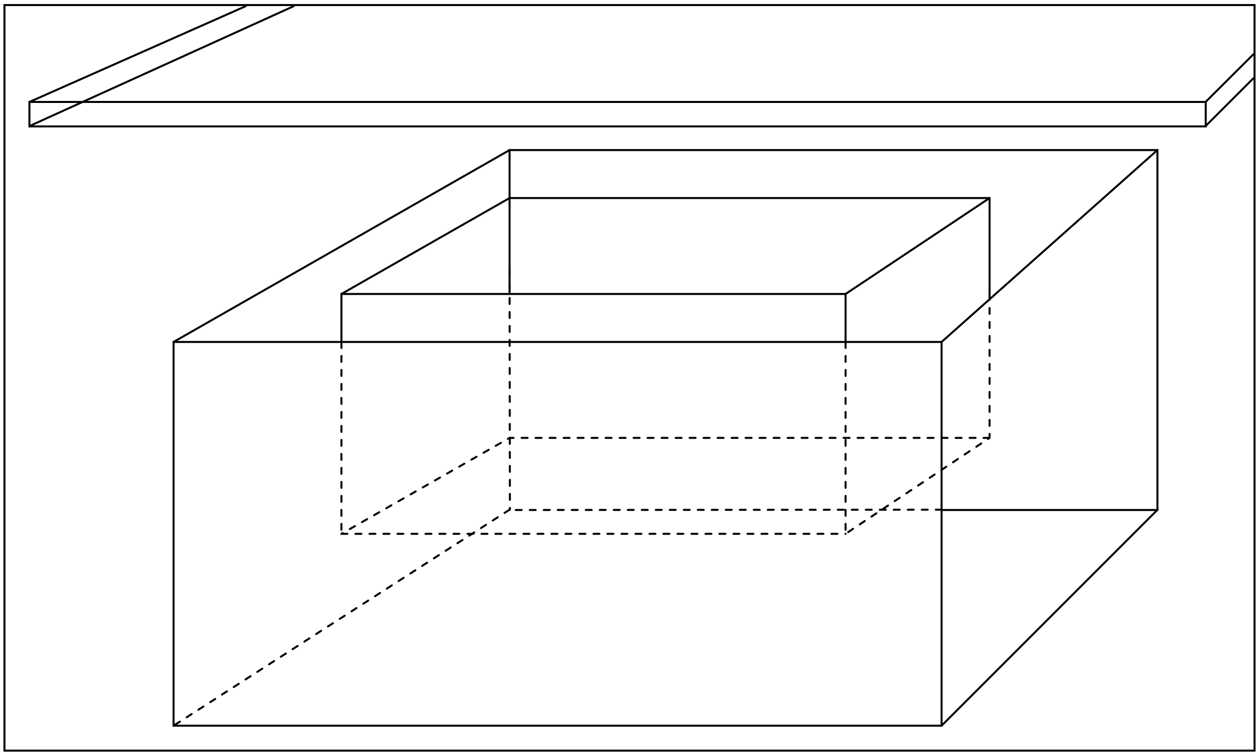
Oven Lid

The last component of your oven is the lid. The lid will be placed on top of your oven, underneath your collector. Remembering the car that heats up, think about what happens when you open the door – hot air comes flowing out. As opposed to your car, we actually want all of the hot air to stay in, so do your best to seal the oven when the lid is in the closed position. Remember, there must be a method to open and close the oven to put food in and take it out.

Blocks can be used to prop the oven up so that it is pointing at the sun. The ovens will need to be moved while cooking so that the sun is always directed into the oven.

Analysis:

To test the ovens, set up the oven outside on a sunny day and measure the air temperature inside the oven. Measure the temperature every 10 minutes and graph your results. After the first 30 minutes, you can take measurements less often. The class data should be compiled so that all students can observe the different heating curves that the other groups obtained and what different variables caused those changes.



This drawing shows the box within a box of the solar oven without reflectors.

Questions:

Was it cloudy, partly cloudy, or sunny when you tested your solar oven?	
What was the outside temperature during your test?	
What time of day did you perform your test?	
What temperature did your solar oven reach 30 minutes after it had been sitting in the sun?	

Draw a diagram of your solar oven below. Please label where there is heat transfer due to radiation, and label where there is heat transfer due to conduction.

Explain how a solar oven works.

What aspects of your solar oven design worked well?

How could your solar oven be improved?