Solar Energy:

Cooking with the Sun

TechXcite: Discover Engineering

Pratt School of Engineering
Duke University

Table of Contents

Module Overview

This TechXcite: Discover Engineering module introduces youth to the direct use of solar thermal energy through the design of a solar oven. Youth will do some initial experiments to explore heat transfer through radiation and conduction. Next, they will learn how to locate the sun in the sky by finding the solar angle at a particular time during the day. Finally, they will use this knowledge to design and build a solar oven.

Activity 1: Explore what factors affect the amount of heat absorbed or reflected by the objects.
Activity 2: Locate the sun using solar angle.
Activity 3: Learn about insulation and build a device to determine if a material is a good insulator.
Activity 4: Build a solar oven and use the oven to cook food.

Authors: Paul Klenk, Ph.D., Gary Ybarra, Ph.D., and David Kahler, Ph.D.

Editor: Carla Burgess

TechXcite Program

TechXcite is a partnership between the Pratt School of Engineering at Duke University, the National 4-H Council/4-H Afterschool and North Carolina 4-H.

The program is directed by Drs. Gary Ybarra (PI) and Paul Klenk (Co-PI). Beginning in 2001, they co-created the successful Techtronics afterschool engineering program at Rogers-Herr Middle School and Lowes Grove Middle School in Durham, N.C. The TechXcite: Discover Engineering curriculum is building on this work by creating engineering learning modules in seven theme areas for use in afterschool programs nationwide. Together they have created an engaging, substantive, experiential and inquiry-based curriculum in engineering, technology and applied science for 4-H-supported middle school youth in afterschool programs across the nation. We hope to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

If your program is interested in adopting any of the TechXcite: Discover Engineering learning modules, please contact us at techxcite@duke.edu.

Online Support

The TechXcite Web site (techxcite.pratt.duke.edu) contains additional material to help you implement this module. There are videos to guide you through facilitating the activities with students. You can download copies of the Instructor's Guide and Youth Handouts. You'll also find a list of sources for any materials you'll need. Finally, there are links to additional resources.

E-Mail and Phone Support

If you have questions about any of the material in this curriculum, please do not hesitate to ask. The Duke team is available to support you if you have questions about implementing the modules. Please contact our staff at techxcite@duke.edu. You can also call us anytime by calling the phone number listed on the Contact Us page on our website - http://techxcite.pratt.duke.edu/contact/index.php.

Using this Guide

The first portion of this handbook is the Instructor's Guide for all of the activities in the module. It includes this introductory section and also the Instructor's Guides for each activity. This introduction contains general information about the TechXcite curriculum, what to expect in each activity's Instructor's Guide and background on tools you will be using.

The Instructor's Guide for each activity follows the same format. Below is what you can expect to find in each section. At the beginning, you will find basic information about the module. This includes:

- Time Required
- Materials
- Group Size – This is the suggested number of students per group.
- Youth Handouts – These will need to be copied.
- Instructor Preparation – This includes what you need to do before the activity and approximately how much time it will take you.
- Learning Objectives
- Vocabulary

Introduction, Procedure and Activity Closure

Three sections form the body of the activity: Introduction, Procedure and Activity Closure. The Introduction and Activity Closure sections are scripted. You may read these sections verbatim to students. Instructions that are not to be read to students, as well as answers to questions, are in brackets/italics. The Procedure section is not scripted. It contains step-by-step instructions for facilitating the activity with a group of students.

Cleanup

This section appears in activities in which cleaning up in a particular way will help reassemble the kit or prepare for the next activity. Following these instructions will keep the kit in proper order.

Assessment

This section tells you how to assess whether or not students understood the material presented to them in the activity. These assessments are generally based on students' answers to questions asked during the Activity Closure section.

Activity 1: Absorbing Heat from the Sun

Time Required: 20 minutes
Group Size: Entire class

Materials List

To share with the entire class:

- Infrared thermometer
- Standard thermometer
- Black spray paint
- 2 silver pans

Youth Handouts:

- None

Instructor Preparation (20 minutes)

- The day before the activity, paint one of the pans black.
- Place the pans outside in the sun a few hours before class. You can do this activity if it's partly cloudy, but it works best on a sunny day. These should be placed on grass or another good insulator. Concrete will quickly conduct heat away from the pans and may not work as well.
- Activities 1 and 2 are good companion activities and may be done on the same day.

Learning Objectives

After this activity, students should be able to:

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

Vocabulary

Word	Definition
Radiation	Energy transferred through the movement of electromagnetic waves; heat transfer not requiring a medium.
Solar oven	A device that uses solar radiation to cook food.
Solar radiation	Radiant energy emitted by the sun.

Introduction

Finding ways to use energy more efficiently will be an important part of engineering in the 21st century. Thermal energy from the sun is used in solar ovens, passive solar architecture, and to generate electricity in some applications.

Over the next few weeks, you will be designing and building a solar oven that can hold as much heat as possible. You may not know it, but you've probably experienced how a solar oven works. What happens when a car sits in the sun on a hot summer day with its windows rolled up? [*The interior heats up.*] Can the car's interior get hotter than the outside air temperature? [*Yes.*] The sun's rays go through the windows and strike the surfaces inside 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 radiation will be absorbed and some will be reflected. The absorbed radiative energy is converted to heat in the surfaces inside the car. This is called heat transfer through radiation. The solar ovens you build will gather heat in the same way as the car in the sun.

Today we will conduct a simple experiment to discover how the sun heats objects and what factors affect the amount of heat they absorb or reflect.

Procedure

1. Take students outside and show them the two pans. Ask: "Which pan do you think will be hotter?" Let students offer a few explanations why one will absorb more solar radiation than the other. Then have them vote on which explanation they think is accurate.
2. Explain that the hottest pan is the one that has absorbed more solar radiation. Tell them it would be difficult to measure the temperature of a surface using a standard thermometer. If it were touched to the pan, part of the thermometer would still be exposed to the air. The reading would be somewhere in between the air temperature and the temperature of the surface, so it would be inaccurate. You can demonstrate this with one of the standard thermometers in the kit. For an accurate reading, we use a special infrared thermometer that reads the surface temperature by measuring the heat reflected in the form of radiation.
3. Demonstrate how to use the infrared thermometer. To measure the surface temperature of one of the pans, point the thermometer toward the pan, holding it a few inches away, and press the button on the thermometer. The controls on the thermometers may vary.
4. Tell students to measure the temperature at several locations on each pan. The black pan should have a significantly higher temperature than the silver pan.

Activity Closure

Let's try to answer a few questions based on the experiment:

1. Which pan was hotter, the black or the silver one? [*The black pan should have been hotter.*] Was this what you expected?
2. When you go outside on a hot day, would you feel cooler wearing a white shirt or a black shirt, assuming both were made of the same fabric? [*You would tend to feel cooler in a white shirt. In general, a black object absorbs more heat through radiation than the same object in white.*]
3. If you want your solar oven to collect as much heat from the sun as possible, what color should you paint the interior? [*At least some of it should be painted black.*] As we discuss the solar oven further, you will discover which parts of it are best painted black.

When you look at an object, you usually identify it by the color reflected back to your eyes. When you see white, you perceive a combination of all colors. The white object actually reflects most of the light shining on it. Black is the absence of color. A black object absorbs most of the light shining on it. That is why the black pan was hotter. That light also has heat energy.

Assessment

Take note of how student answer the question about a white t-shirt or black t-shirt during the activity closure. This is a good assessment of their understanding of this material.

Activity 2: Where is the Sun?

Solar disc passing behind a pylon by Stefan Wernli
[CC-BY-SA-2.5], via Wikimedia Commons

Time Required: 30 minutes
Group Size: 3

Materials List

To share with the entire class:

- Level
- Wooden skewer
- Compass

Youth Handouts:

- None

Instructor Preparation (10 minutes)

- Find a location where students can place their skewers vertically into the ground. An ideal location is next to a level or fairly level sidewalk on which the shadow of the stick can fall. Use the level to locate a portion of sidewalk that is almost flat.

Learning Objectives

After this activity, students should be able to:

- Use a shadow to describe the position of the sun in the sky and how it moves.
- Explain that a solar oven should be moved throughout the day so that it always faces the sun.

Vocabulary

Word	Definition
Solar angle	The angle of the sun as measured from the horizon.

Introduction

Today you will be learning how to measure the direction and angle of the sun. Based on this information, you can decide where to place your solar ovens to maximize the energy they receive.

What is the purpose of a solar oven? [*To use energy from the sun to heat food*.] Would you position a solar oven in the same direction in the morning as you would in the afternoon? [*No, because the sun rises toward the east and sets toward the west.*] A solar oven or solar panel that moves with the sun can capture more energy than a solar panel that is stationary. When we test our solar ovens, we will need to determine the direction of the sun at the current time of day to know which way to point the ovens.

How would you describe the location of the sun right now?

[*Students might have a number of responses. They might point at it. They might say it is in a certain direction. They might compare its current location in the sky to various reference points.*]

Solar engineers use two measurements to locate the sun in the sky. The first is the direction of the sun and the second is the solar angle, which describes how high the sun is in the sky in reference to the horizon.

Procedure

1. Place students in groups of 3 or 4.
2. Use the level to find a flat place on the ground.
3. Stick the wooden skewer into the ground vertically (it must not lean). It should cast a shadow onto flat ground. This works best when the skewer is stuck into the ground next to a level piece of concrete and the shadow is cast onto the concrete. It is important for the shadow to be straight.

4. Ask students to come up with a method of approximating the solar angle and the direction of the sun using the stick and a compass. Students may have to share compasses.
5. Give students a few minutes to come up with a method of determining these two values to determine the direction of the sun.
6. Ask them to explain their ideas.

Activity Closure

Those are some good ideas. From the shadow of the stick, we can determine the sun's direction and angle. The direction of the shadow may be measured with a compass. The shadow is exactly *opposite* the direction of the sun. Because the sun is so big, it's difficult to measure the direction of the sun by pointing the compass directly at it. For a precise answer, we can measure the shadow and then read the compass. To determine the solar angle, we can use the length of the shadow. The longer the shadow, the lower the sun is in the sky. The shorter the shadow, the higher the sun is in the sky.

These principles were used a long time ago to keep track of time with a device called a sundial. You can use measurements taken on the shadow to determine the exact time of day if you know your location on Earth.

Assessment

Will you have to move your solar oven if it is outside for 6 hours? [*Yes. As the sun moves across the sky during the day, the solar oven will have to face different directions to catch the maximum amount of sunlight.*]

You can also tell them that depending on the way the reflectors are designed, the design may require more or less adjustment. They can explore this when building their solar ovens.

Sundial by Liz West [CC-BY-2.0], via Flickr

Activity 3: Create a TechXcite Thermos

Insulation around the cabin windows of the Boeing 747-8I by Olivier Cleynen [CC-BY-SA-3.0], via Wikimedia Commons

Time Required: 60 minutes
Group Size: 3

Materials List

Each group needs:

- Standard thermometer
- 12-ounce soda can

To share with the entire class:

- Scissors
- Duct tape
- Aluminum foil
- Small funnel
- Hot water
- Not included in kit: Newspaper
- Not included in kit: Cardboard
- Not included in kit: An assortment of useful junk, such as scraps of fabric (various sizes), socks from the lost and found, packing peanuts, pieces of foam, construction paper (both light and dark colors), bubble wrap, quilt batting, old overhead transparencies, rubber tubing, drinking straws, aluminum foil, large zipper-close plastic bags and any other materials you can think of that could be used as insulating or conducting material or to absorb or reflect radiation.

Youth Handouts:

- "Create a TechXcite Thermos"

Instructor Preparation (10 minutes)

- Make sure you can get hot water from a faucet or somewhere nearby.
- Gather newspaper, cardboard and other assorted materials that students can use to create their insulating devices.

Learning Objectives

After this activity, students should be able to:

- Explain the purpose of insulation.

Vocabulary

Word	Definition
Conduction	The movement of heat through solid objects.
Insulation	A material that has low thermal conductivity and slows the movement of heat (for example, a warm jacket, fiberglass insulation, a sleeping bag, anything with air trapped in it).
Thermal conductivity	The property of a material that determines how well it conducts, or transmits, heat (metal generally has high thermal conductivity; plastic generally has low thermal conductivity).

Introduction

Heat flows by three methods: radiation, conduction, and convection (which we will discuss next time). In the first activity, we investigated how objects are heated by solar radiation and what determines how much heat they absorb or reflect. Your solar oven will need to absorb and retain as much heat as possible. Today we will explore how to store heat by using insulation. Insulation will reduce the loss of heat through the walls of your solar ovens. Heat loss through the wall is called conduction.

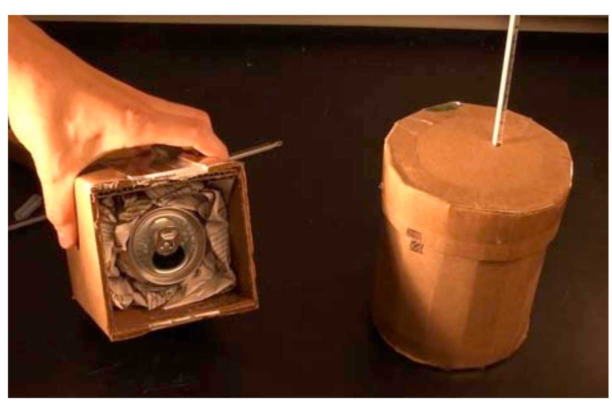
Conduction is a method of heat transfer that happens when two objects of different temperatures are in direct contact. Think of a metal spoon in a pot of hot soup. Heat is conducted between the soup and the spoon. If you touch the handle of the spoon, you'll notice that heat is also conducted between the handle and your fingers.

Insulation is any type of material that reduces the flow of heat. For example, using a well-insulated coffee cup lets you hold a cup of hot coffee without burning your hand. We use insulation in ovens, refrigerators, windows, and walls—anywhere we want to reduce the transfer of heat.

Your engineering challenge today is to design the most effective insulation and keep the heat in an aluminum can.

Procedure

Part 1: Designing the TechXcite Thermos

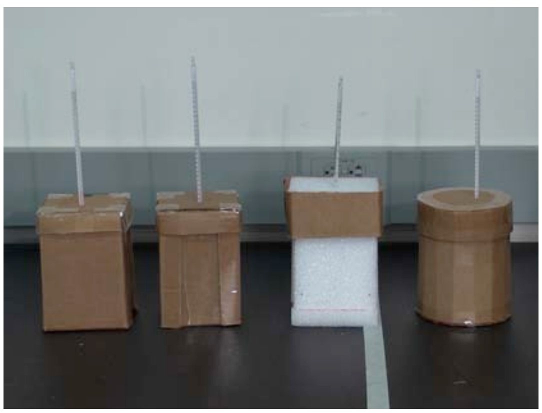


1. Start by providing a table full of the useful junk materials (see Materials List), scissors, and tape.
2. Let students examine the materials and then allow them 20 minutes, working in small groups, to plan and construct a TechXcite thermos

to keep liquid warm or cold. We will be testing with warm liquid. It's best to use an empty can during planning and construction, but make sure it's removable so it can be replaced with a filled can in Part 2.

You may want to impose some limitations on the types of materials used. For example, it is a good idea to forbid human-made containers or devices such as insulated lunch boxes, thermoses, flashlights or classroom radiators. The idea is for students to start from scratch rather than use existing technology. Flames should not be allowed. The original water must stay in the can for the duration of the experiment.

3. While students are designing and constructing, prepare the soda cans by filling a sink or large basin with water that is about 35°- 45°C. Hot water from the faucet will generally work. You will need two cans per group, plus two extra. Fill each can completely with the warm water. By the time students are ready to use the cans, the water will have cooled a few degrees and will be at a good temperature for the activity.



Part 2: Keeping cans warm

4. When everyone is ready, hand out the water-filled cans and thermometers. Each group should receive one thermometer for each can, if possible. If two groups must share a thermometer, be sure they wait 2 minutes after switching between cans before reading the thermometer. You can keep track of time for the group.
5. The groups must take a measurement every 5 minutes. Tell students they need an organized way to keep track of their time and temperature data.
6. In addition to the groups' cans, fill two or three extra cans with the 35°C water and leave them sitting in a central location. These will serve as the control. The temperatures in these cans should be checked at the same 5-minute intervals. This can be your responsibility, or you can assign the task to a student.

Tips:

- After 5 or 10 minutes, some students may find that the device they have devised to keep their can warm is not performing well. They may want to change their tactics immediately, and this is OK. Real engineering solutions are seldom perfected on the first attempt, and mid-course corrections are commonplace.
- Check to make sure students are reading their thermometers accurately, especially if their device seems to be performing exceptionally well.
- As students test their arrangements, ask questions to help them begin analyzing their data, such as:
  - How much has the water temperature changed so far?
  - How does the temperature in your can compare to the temperature in the control cans? Does that mean that your strategy is working (to keep your can warm)?

Activity Closure

Each group will prepare a brief presentation to give to the class. Your group must present your graphs and summarize the performance of your device. You are to calculate the temperature changes that you observed during the 30 minutes and compare these to the temperature changes in the control cans during that time. As part of your presentation, you should also show your device and explain how you tried to reduce heat transfer via conduction and radiation.

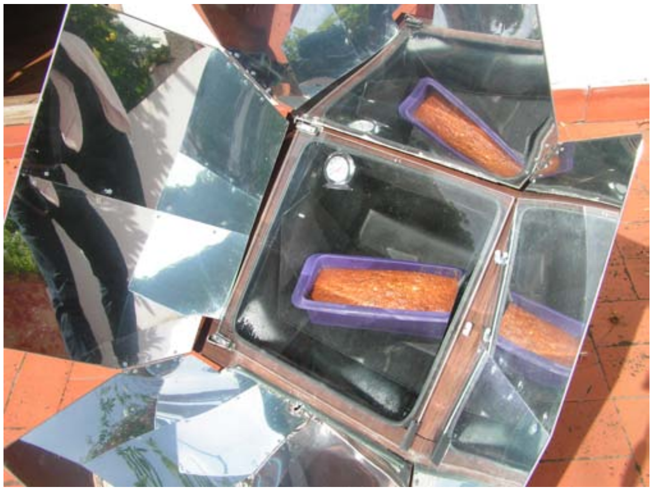
[Students may have difficulty articulating the roles of conduction and radiation in their devices, so be prepared to help them understand these roles in their devices. Insulation materials such as newspaper reduce heat transfer via conduction. Aluminum foil in the device would reflect heat back in and would reduce heat transfer via radiation. Aluminum foil is not a good insulator so it would not prevent heat transfer via conduction.]

For next week, please bring a newspaper and one or two cardboard boxes. You will be using these materials to build solar ovens.

Assessment

You can assess students' ability to understand and apply the ideas of conduction and radiation by evaluating the effectiveness of their devices or strategies. If the water in any group's "warm can" did not stay several degrees warmer than the water in the control cans, students involved might benefit from further discussion of the concepts and how they can be applied to practical problems. Ask students to give examples of materials that work well to reduce heat loss through conduction.

Activity 4: Building a Solar Oven



Baking a cake in a solar oven by Atlas de la Cuisine Solaire
[Public Domain], via Wikimedia Commons

Time Required: 90 minutes (This activity will likely take two or three sessions. You may test with food on a separate day.)
Group Size: 3

Materials List

Each group needs:

- Not included in kit: Two cardboard boxes (about 1 cubic foot) that nest inside each other
- Not included in kit: Cardboard scraps to make solar panels
- Aluminum foil
- Oven bag
- Thermometer

To share with the entire class:

- Black spray paint
- Black construction paper
- Black duct tape
- Not included in kit: Newspaper and other types of insulating materials

Youth Handouts:

- “Building a Solar Oven”

Instructor Preparation (10 minutes)

- Your kit does not include boxes or newspaper. At the close of the previous activity, you asked students to bring a box and some newspaper for this activity. It is a good idea to have some extra boxes and newspaper available in case any students forget.

- You might want to ask students to bring in additional materials from home. It will prompt them to think more about the project outside of class and contemplate what their ovens could look like. Instruct them not to buy or bring expensive materials. For example, students should not buy insulation from a home improvement store. You could specify that any supplemental materials must cost no more than $10, or you could say they must be available for free.

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 helps it absorb more heat and stay hotter.
- Explain how energy flows from the sun to their oven and to the food inside.

Vocabulary

Word	Definition
Convection	The movement of heat by circulation through liquids and gases.

Introduction

During the last few activities, you learned many concepts that will help you design your solar ovens:

1. You discovered that dark-colored objects absorb more solar radiation than light-colored objects.
2. You explored various types of insulation that can help your oven retain heat.
3. You learned how to measure the solar angle to determine the sun's position in the sky using a shadow. This will help you decide where to best position your solar oven.

Let's think back to the first activity and the example of the car heated through solar radiation. Your solar oven will mimic what happens in the car. Solar radiation heats the interior surfaces. Through conduction, the interior surfaces then heat the air next to them. The air then transfers this heat to the rest of the car. This movement of heat through air circulation is called convection. Because heat escapes through the exterior walls via conduction, there is a maximum temperature the car or oven will reach.

Let's review the three types of heat transfer:

1. Radiation: Which would make a car hotter inside: if it had a black interior or a white interior? [*The car would be hotter if it had a black interior because heat transfer via the absorption of solar radiation would be increased.*]
2. Conduction: Which would make a car hotter: if it's walls were made of a thin sheet of cardboard or made with the 6-inch-thick foam used to insulate houses? [*A car made of foam insulating material would be hotter because heat transfer via conduction would be reduced.*]

3. Convection: We have not talked much about convection, the third type of heat transfer. Convection moves hot air from one place to another. A fan cools you by increasing heat transfer from your body by convection. 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? [*The car out of the wind would be hotter because there would be less heat transfer away from the car due to convection. For this reason, it would be best to locate a solar oven where there is less exposure to wind.*]

You will play the role of engineer as you design and build your solar oven. The design problem is listed on your handout. You must use what you have learned and the materials provided to you to build a solar oven that can attain the highest temperature possible using only energy from the sun. It must be sized to hold a small cooking container.

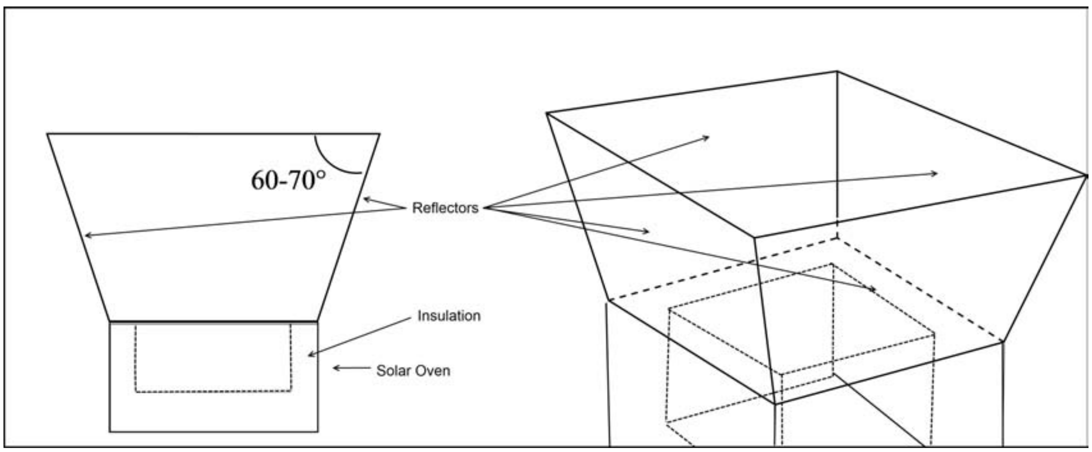
Procedure

1. Before students begin, go over the engineering design problem, constraints, and design tips.
2. Tell students to follow the steps on the handout. Walk around to answer any questions.
3. Once the ovens are completed, have students set them up for testing (outside on a sunny day).
4. Instruct each group to measure the air temperature inside the oven and plot the temperature as time progresses, just as they did in Activity 3. They are to take measurements every 10 minutes for 30 – 40 minutes, after which the increase in temperature should begin to slow down.
5. While students are observing the solar ovens in action, ask some of these questions to help them evaluate their accomplishments: Which solar ovens are working really well? Why do you think a particular solar oven is working well? How might you improve a solar oven that is not working well?
6. Students should compile their data so that they can observe everyone's heating curves and what variables may have caused differences. Ask questions that will prompt students to draw conclusions about their construction decisions.
7. After the ovens have been tested for their heating potential, have students test them using food (you may wait until a later date). The maximum temperature of the ovens might not be hot enough to cook all kinds of food. Cookie dough is a good choice because it is thin and is safe to eat if undercooked. You can bake cookies on small pieces of aluminum foil. Do not place any food directly on spray-painted aluminum foil. Use a clean sheet of foil as a barrier between any painted surfaces.

While students are working:

Encourage students to experiment with different materials, if available. The two nested boxes will provide the external and internal walls of the oven, while the oven bag will be the transparent window. They should place insulation between the boxes. Newspaper is one possible choice for insulation. They may paint portions of the interior box (walls of the oven) black to increase the amount of solar radiation absorbed. Black construction paper may also serve the same purpose. Using black containers for cooking, if available, would also help absorb heat, but most of our cooking will be done on aluminum foil.

It is helpful to reflect sunlight directly toward the cooking area. Reflectors will typically require some kind of backing, such as cardboard pieces. Students must decide on their own reflector configuration and the number of panels they want to use. Some students might use a single reflector to reflect sunlight into the oven, while others might try more complex arrangements. One of the most efficient arrangements, if students can figure out how to mount the reflectors, is to put four reflectors on top of the oven as shown below. The panels could be trapezoidal, with angles in the range of 60°to 70°.



Students will need to prop the ovens so that they point at the sun. They should think about what can be used to prop them. They will also need to move the ovens during cooking so that the sun is always directed into the oven.

The factor most critical to success is that there be no places through which air can flow out of the interior. If hot air can flow from any interior space, the insulation cannot retain the heat.

Activity Closure

Your design challenge was to build and use a solar oven. Your ovens weren't exactly alike. What differences or similarities did you notice between your oven and the ones that other groups made? [*Allow the class time to examine all the ovens and discuss as a class the similarities and differences. They might 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?*]

Assessment

Ask students to describe which parts of their oven are designed to increase the heat input from the sun. Then, ask them which parts are designed to reduce heat loss.