Solar Energy:

Racing with the Sun

TechXcite: Discover Engineering

Pratt School of Engineering
Duke University

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Module Overview

This TechXcite: Discover Engineering module introduces youth to solar-power technology by letting them design a solar car. They will first explore how solar panels generate electricity by measuring the maximum voltage the panels can create in different lighting situations. They will then work in pairs to design and build a solar car with optimum performance, then race it.

Activity 1: Youth explore how a solar panel converts sunlight into electricity.
Activity 2: Youth explore multiple solar panels in series.
Activity 3: Youth design and build an electric car that has a motor connected to a solar panel.
Activity 4: Youth race their solar cars and explore factors that affect the performance of their solar cars.

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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 Guide 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

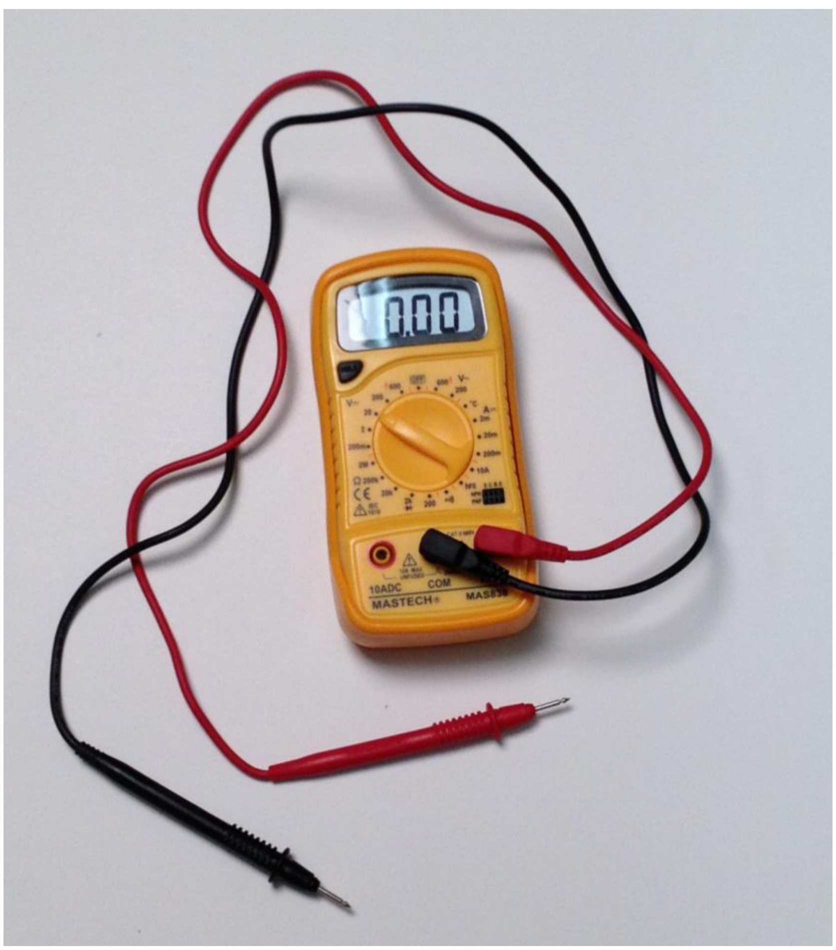
This section tells you how to assess whether or not students understood the material presented to them in the activity. These assessments are generally based on students' answers to questions asked during the Activity Closure section.

Tools Used in the Module — Digital Multimeter

A multimeter measures voltage, current and resistance. In these activities, you will be using the multimeter to measure voltage. You may want to demonstrate the multimeter to students before beginning the activity.

Adjust the dial on the multimeter to DC (direct current) voltage. The dial should point to a setting in the “V---” range. The symbol “V~” is used to specify AC (alternating current) voltage and will not be not used in these activities. The multimeter shows a range of settings. If you are measuring a voltage that exceeds the selected range, the multimeter will display an overlimit and you must adjust the dial to a higher range setting.

This photograph shows the dial adjusted 20VDC. In this position, it will measure up to 20 volts. The red lead is touching the positive source, and the black lead is touching the negative source. If you reverse these leads (red to negative and black to positive), the multimeter will display the same voltage, but the value will be negative.



Activity 1: What Does a Solar Panel Do?

Time Required: 45 minutes
Group Size: 2
Materials List

Each group needs:
- Solar panel (from SolGear solar car kit)
- Digital multimeter
- Motor (from SolGear solar car kit)
- 1 AA battery

Each class needs:
- Masking tape
- Scissors
- Clear tape

Youth Handouts:
- “What Does a Solar Panel Do?”

http://www.dreamstime.com/royalty-free-stock-photo-solar-road-sign-image21466325

Instructor Preparation:
- Find a place to take the class outdoors to test their panels.
- Inspect the solar panels in the kits for cracks if they have been used before. A solar panel can still be used if there are cracks in it, but its efficiency will be reduced. Because there are no extra panels in the kit, it is worth trying to use it. If the panel is broken and does not work at all, carefully discard it.

Learning Objectives
After this activity, students should be able to:
- Explain that a solar panel converts light energy into electricity.
- Explain that a solar panel functions like a battery when sunlight hits it because it can directly power electrical devices.

Vocabulary

Word	Definition
Current	Flow of electricity.
Multimeter	A device that measures voltage, current and resistance.
Solar cell	Device that converts sunlight into electrical energy.
Voltage	Electrical energy that causes current to flow.

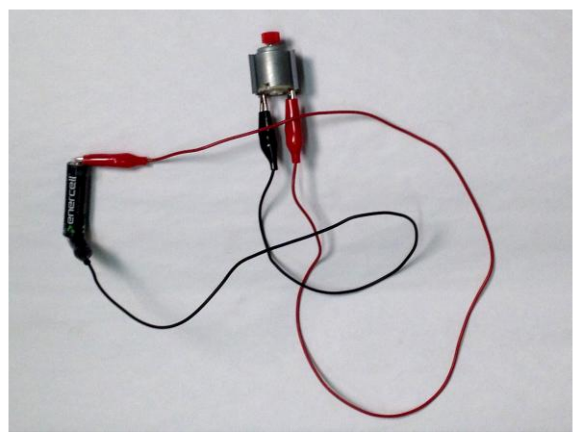
Introduction

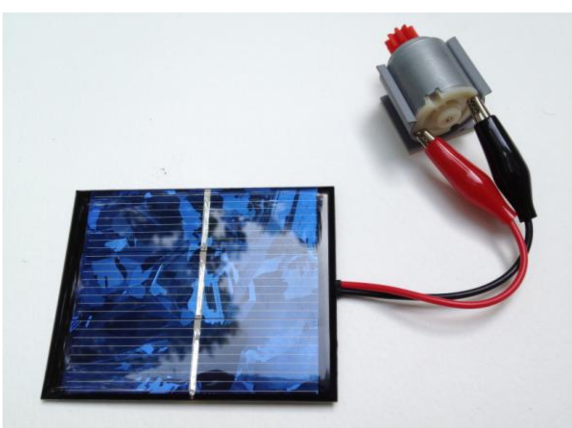
During the next few sessions, we will investigate how to generate electricity using the sun and will use what we learn to build a solar car. Today we will be exploring solar panels to prepare us for building the solar car. Have any of you ever seen a solar panel before? What everyday electrical items have you seen that are powered by solar panels? [*Allow students to brainstorm and respond. If you have a board, write down* *students' answers. Possible answers include calculators, solar-powered driveway/sidewalk lights, traffic signs/lights and road construction signs.*]

A solar cell converts sunlight into electrical energy. A solar panel is an array of individual cells. In each cell, energy from sunlight is transferred to electricity (moving electrons). Not all of the sunlight's energy is converted to electricity. Some sunlight is reflected, and some is turned into heat. The solar panels that you'll be using in these activities produce about 0.75 watts of power in full sunlight. By comparison, a typical incandescent light bulb you might use at home requires about 60 watts.

Procedure

1. Place students in pairs. These pairs will work together throughout the project.
2. Distribute materials and handouts. Tell students that the solar panel is fragile and to be careful with it.
3. Instruct students to adjust the dial on the multimeters to measure voltage by changing the dial to a setting in the "20V---" range. Then ask them to connect the leads on the multimeter to the solar panel. Ask them to measure the voltage across the panel in three different lighting conditions: in darkness (inside a desk, for example), bright indoor lighting and sunlight. Students will likely learn that without any light energy, the panel will not create any voltage.
4. Ask students to measure the voltage across the battery. Have them connect their motor to an AA battery to confirm that the motor runs. They may use electrical tape to connect the motor wires to the battery. Ask: How does the voltage from the batteries compare to the voltage from the solar panel? [*The solar panel produces a little more than 1.5 volts. The battery also produces a little more than 1.5 volts if it is new.*]





5. Instruct students to disconnect their motor from the battery and connect it to the solar panel. Make sure students demonstrate an understanding that the solar panel works like a battery and powers the motor. Prompt them as they experiment:
   a. Does the solar panel work like the battery?
   b. Under what light conditions (indoor light, outdoors, cloudy, sunny, etc.) does the solar panel work with the motor?

Activity Closure
Let's talk about what we've observed and learned today. [*Ask students these questions and allow them time to respond.*]

1. What did you find out when measuring the voltage produced by the panels in different lighting conditions? [*When more light shines on the panels, the panels produce more voltage.*]
2. What conclusions can you draw from this information? [*The motor will run better when more light shines on the panels because when the panels produce more voltage, they can provide more electrical energy to the motor.*]
3. How did the solar panel compare to the battery in terms of powering the motor?

Assessment

Ask students the following questions:

What factors affected the voltage output from your solar panel(s)?
[*Some examples: the type of light source, e.g., sunlight, light bulb; the type of connection, e.g., series, parallel; the area of the solar panel that is exposed to light.*]

What are some situations in which solar power is used as an alternate energy source?
[*Some examples: a solar car (similar to what will be built in the next activity), solar lights (lights that line a driveway or walkway), solar traffic signs (signs that caution you to drive slower in a school zone).*]

What does a solar panel do?
[*A solar panel converts light into electricity.*]

Additional Instructor Resources

http://science.howstuffworks.com/solar-cell.htm

Activity 2: Multiple Solar Panels

Time Required: 45 minutes
Group Size: 4
Materials List

Each group needs:
- 2 solar panels (from SolGear solar car kit)
- Digital multimeter
- Motor (from SolGear solar car kit)
- 2 AA batteries

Youth Handouts:
- "Multiple Solar Panels"

Instructor Preparation:
- Find a place to take students outdoors to test their panels.

Learning Objectives
After this activity, students should be able to:
- Explain that the voltage of solar panels connected in series is the sum of the individual panel voltages.

Vocabulary

Word	Definition
Series	Connecting a circuit such that each component is attached to only two other components in a row. Voltages of batteries or solar panels in series are combined.
Parallel	Connecting batteries such that the positive terminals are connected together. The voltage of batteries or panels in parallel remains the same.

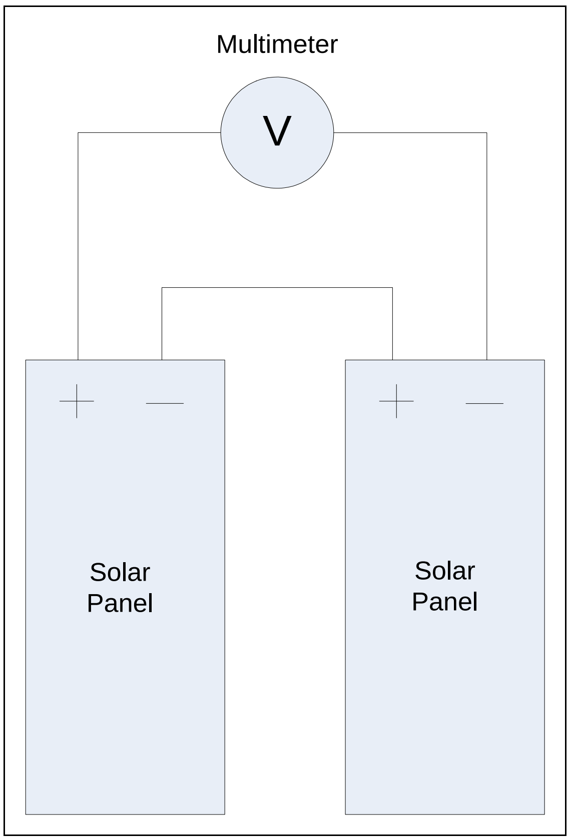
Introduction

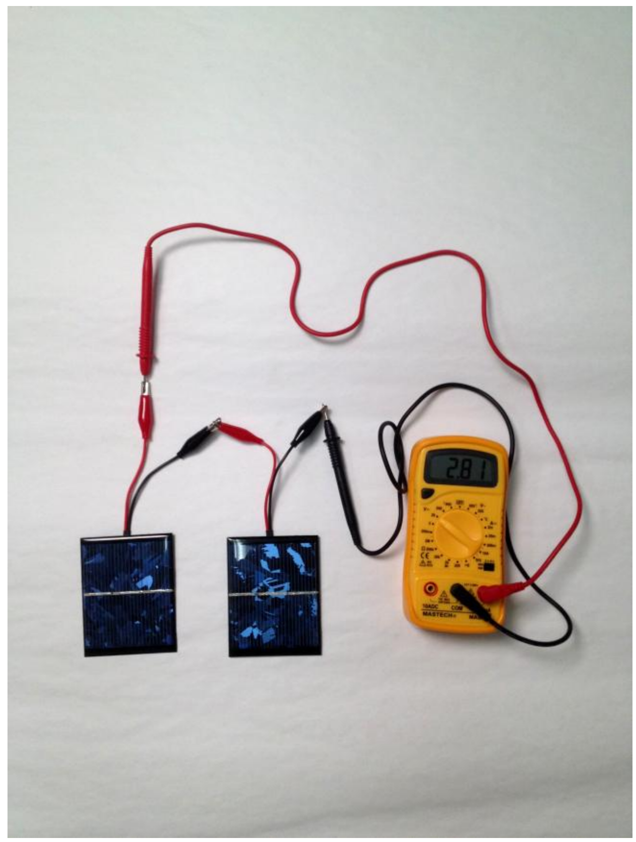
In the previous activity, you connected a solar panel to a motor and used a multimeter to measure its voltage in various lighting conditions. You also connected it to a battery. As you found out, when a solar panel is in the sun, it may be used like a battery.

Procedure
1. Ask each pair of students to team up with another pair of students.
2. Distribute materials. Tell students that the solar panel is fragile and to be careful handling it.
3. Instruct students to adjust the dial on the multimeters to measure voltage by changing it to a setting in the "20V---" range.

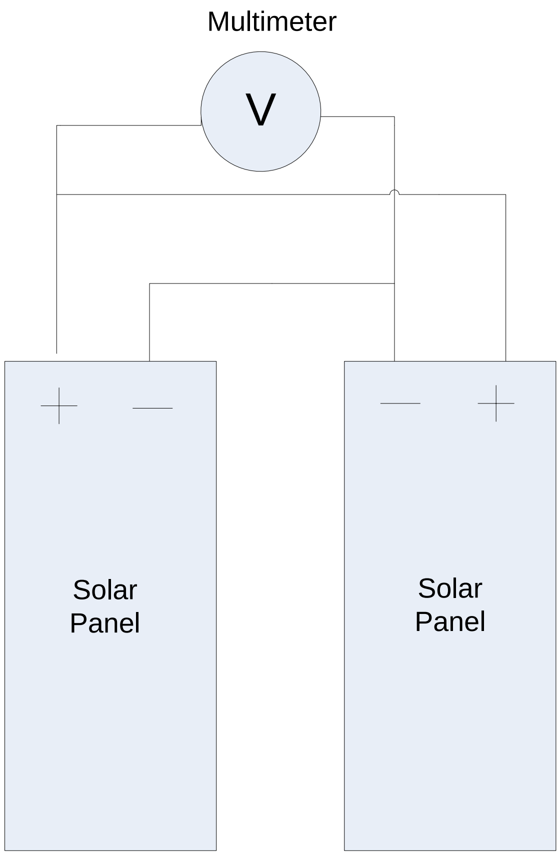
4. Ask students what they think will happen if two solar panels are connected. Ask students to think about how they might connect the two panels to increase the voltage. They will discover that they must connect the panels as shown here. You can tell them electrical engineers refer to this as a connection in series.

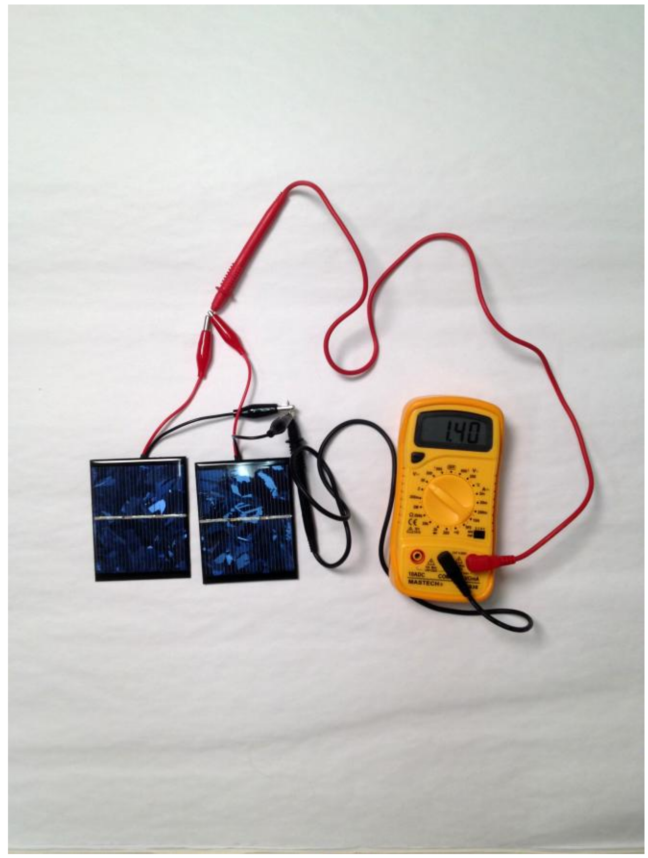
   Series Connection: To connect the panels in series, students should use one alligator clip to connect the positive connector tab on one of the solar panels to the negative connector tab on the other solar panel. The multimeter leads should then be connected to each of the free connector tabs on the two panels. Students will find that when the two solar panels are connected in series, the voltage produced is double the voltage produced by a single panel. The configuration shown here will increase the voltage.





Parallel Connection: If the voltage is not doubling, the panels are probably connected in parallel as shown below. To connect the panels in parallel, students can join the red positive wires from each panel. Then they can connect the black, negative wires from each panel to each other. Finally, they can connect those two separately to the motor or multimeter. The voltage will stay the same, but there will be additional current available at that voltage to drive the motor.





5. Now try connecting the motor to multiple solar panels in series as you did in the last activity.
6. You may also try connecting multiple batteries to the motor.

Activity Closure
Let's talk about what we learned today.

How did the number of solar panels connected in series affect voltage? [*When the solar panels were connected in series, the voltage of the two panels was combined.*]

How did the motor react when it was connected to multiple solar panels? Multiple batteries?
[The most likely answers are below. The reaction will be different in series and in parallel (see diagrams). It will also be different for solar panels, depending on the amount of light.

1. *Two batteries in series will make the motor run faster than one battery because of the higher voltage.*
2. *Two batteries in parallel will run the motor exactly the same as one battery because the voltage is the same.*
3. *Two solar panels connected in series will cause the motor to move faster if they are both in the same light as the single panel. The higher voltage would cause the motor to spin faster if there is enough light, just like the batteries. If the second panel is in the dark, the motor would run slower.*
4. *Two solar panels connected in parallel might cause the motor to run faster in low light. In full sunlight, the motor will run at about the same speed, just like the batteries. In low light, the motor may run faster with two panels than one panel.]*

Assessment

Ask students what factors affected the voltage output from your solar panel(s)? [*Some examples: the type of light source, e.g., sunlight, light bulb; the type of connection, e.g., series, parallel; the area of the solar panel that is exposed to light.*]

Ask students to draw how they might connect two solar panels to a motor in series.

Activity 3: Building a Solar Car

Time Required: 90 minutes
Group Size: 2
Materials List

Each group needs:

- SolGear solar car kit, including:
  - Solar panel
  - Motor
  - Plastic motor mount
  - 4 wheels
  - 4 rubber tires
  - 4 eyelets
  - Small gear
  - Large gear
  - 2 wooden dowels
  - Plastic tubing
  - 2 square wooden sticks
  - SolGear Instructions

Each class needs:

- Masking tape

Youth Handouts:

- "Building a Solar Car"

Instructor Preparation (10 minutes)

- Find a place to take students outdoors to test their cars. If it is not sunny, students can build their cars without testing them.

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

- Design and build an electric car that has a motor connected to a solar panel.
- Identify factors that affect the performance of a solar car, including friction, position of the axles and weight of the car.

Vocabulary

Word	Definition
Axle	Shaft on which a wheel can rotate.
Chassis	Component of a car that supports the body, wheels and motor. (pronounced CHASS-ee)

Introduction
What would be some advantages or disadvantages of owning a solar car? [*Give students time to brainstorm.*] Though you don't see many solar cars on highways, they may one day become more practical for regular use. A Swiss inventor has built a solar-powered taxi that he drives all over the world to demonstrate what a sun-powered car

can accomplish [*http://www.solartaxi.com/*]. College students race solar cars over hundreds of miles in national and international competitions each year. The two main competitions are the American Solar Challenge [*http://americansolarchallenge.org/*] and the World Solar Challenge [*http://www.wsc.org.au/*].

In the last activity, you explored how solar panels generate electricity. Now it's time for you to design and build your model solar car. Once your solar cars are built, you will race them against one another.

What are some of the parts you'll need to build your solar car? [*Write their ideas on the board, if possible. If students overlook any of the following, help them discover what the car is missing*:]

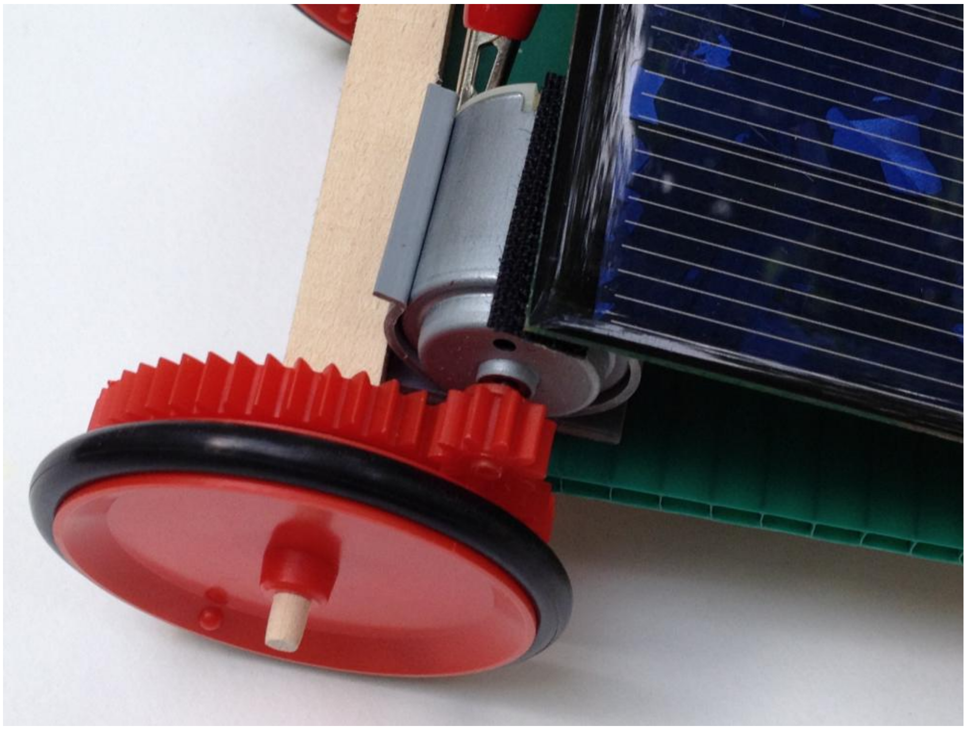
- *Chassis/body*
- *Motor*
- *Wheels*
- *Solar panel*
- *Gears*
- *Axles*

As you've discovered, your car will have these key components: the chassis, a solar panel, two axles, four wheels, a motor and gears. The chassis is the frame of the car. It supports the weight of the motor and solar panel. The chassis must be sturdy. It should not break when the motor, panel and wheels are connected to it. When designing the chassis, you'll need to plan the placement and alignment of the wheels carefully. Also, you should think about the placement of your solar panel. You might consider adding a mechanism to tilt your solar panel, but if you do this you must consider the effect that extra material will have on your car's performance. Why might you want to tilt your solar panel? [*To point the panel more directly at the sun to collect more energy.*]

How might mounting a solar panel on the car at a tilt create problems? [*There are many valid answers, but it is key for students to recognize that if the panel is fixed and pointed at the sun, it might not function as well if the car changes direction.*]

Procedure

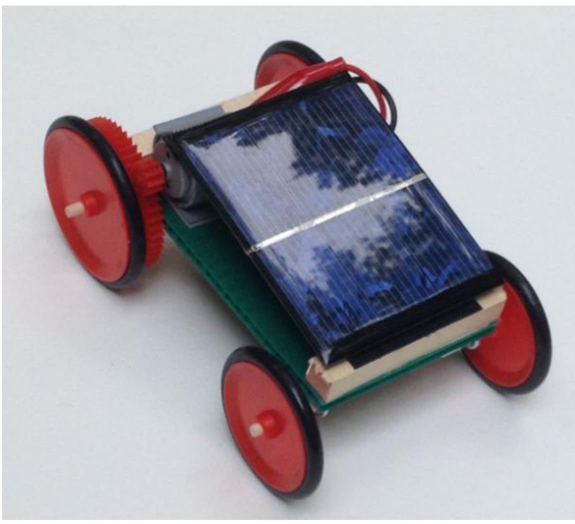
1. Tell students to pair up with their partners from the previous activity.
2. Give handouts and materials to each pair.
3. Tell them that the solar panel is fragile and to handle it carefully.
4. Tell students that they will use a small gear for the motor and a large gear for the axle. Ask students why they think this configuration might be important. [*Going from a small gear to a large gear increases the torque, or mechanical advantage, from the motor to the axle. This provides good acceleration in the same way that starting in a low gear on a bicycle increases speed. Without this mechanical advantage, the car would start very slowly or not at all. It would be like trying to start riding a bicycle in a high gear.*] Note: If you have enough time, providing a lesson on gears would be appropriate. It is difficult to change the gear arrangements once a gear ratio has been selected with these cars. For that reason, this is not the ideal activity for students to experiment with gear ratios.

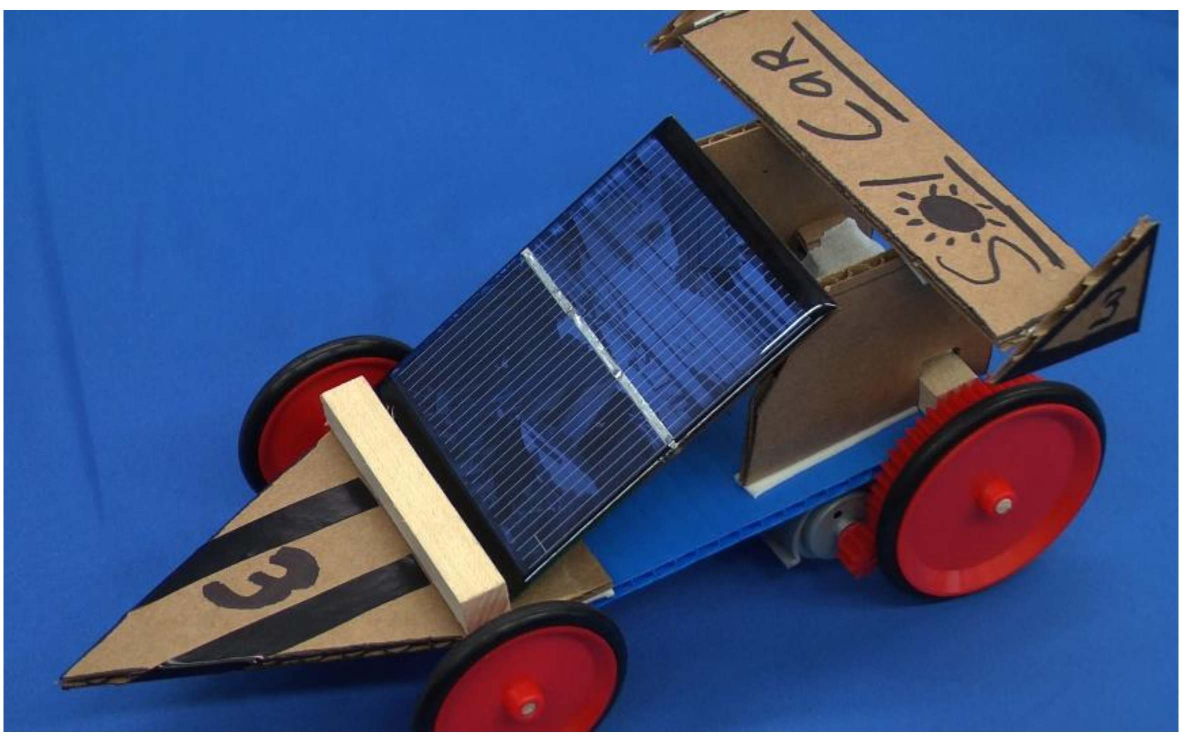


5. Tell students to begin working on their cars, following the instructions on the handout. This is an open-ended activity. Each pair might work at a different pace.
6. Walk around and help students while they design and build the chassis and connect the motor, gears and wheels. While they are working on their cars, encourage them to think about the following:
    a. What affects the solar panel efficiency? [*You have discussed how cracks and dirt on the panel reduce efficiency, but students should also demonstrate that they understand that performance is affected by both the angle of the solar panel to the sun and the available sunlight. Ask them how their car might perform indoors where the only light source is overhead light bulbs; how it might perform in the shade; and how it might perform at different times of day. Finally, if there is dirt on the panel, that will reduce efficiency.*]
    b. What aspects of the chassis design will affect the performance of the solar car? [*Students should understand that the weight of the vehicle, friction, the stability of the chassis and the wheel placement/alignment affect performance. They may also recognize that momentum (car already in motion), inertia (car starting from standstill), gravity and drag (friction of wheels rotating on axle) affect the performance of the car.*]
7. When construction is finished, ask the pairs to verify that their solar car works properly. If the car isn't running properly, help them troubleshoot possible solutions. If a car is not running properly and students cannot figure out why, suggest the following:
    a. If the motor is running backward, try reversing the wires.
    b. Make sure the small gear is on the motor and the big gear is on the axle.

   c. If the wheels are sliding from side to side, try using pieces of the plastic tubing as spacers.
   d. If the car turns significantly, rather than going straight, check the axles to make sure they are parallel to each other.

8. Once their solar cars are completed and functional, let students decorate them however they wish.
9. Collect and store the cars.





Activity Closure

[*Select two or three pairs that seem to have particularly good solar cars to come forward and explain their design process and solutions.*]

Take turns describing your design process, specifically your chassis construction, solar panel placement, and how and where you attached the different components to the chassis. Is there anything you might have done differently? [*Allow several students time to share stories.*]

The rest of you will have an opportunity to describe your solar car design and performance later in the project.

In the next activity, you will be racing your solar cars and evaluating their performance. Let's think about how you might evaluate the performance of the cars and generate a list of ideas.

Assessment

See how students have answered this question on their worksheets: What design factors did you consider when building your solar car and what factors will affect the performance of your solar car when you race it? [*Possible answers include wheel placement and spacing, solar panel placement and angle, efficiency, motor placement and chassis weight.*]

Activity 4: Mini Solar Challenge

Time Required: 45 minutes
Group Size: 2
Materials List

Each group needs:
- Solar car (built in Activity 3)
- Opaque material (file folder, book, etc.)

Each class needs:
- Two stopwatches
- Tape measure
- Chalk

Youth Handouts:
- "Mini Solar Challenge"

By Hideki Kimura (Own work) [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

Instructor Preparation (15 minutes)

- A clear, sunny day is best for racing, but as long as the sky is not completely overcast, your solar panel will still generate electricity to power the motor. On cloudy days, you may find that the motor spins the wheels when the car is held in the air, but not when it is set on the ground. In this case, locate a testing area with a hard, fairly flat surface, such as a sidewalk, basketball court or empty parking lot.
- Gather some file folders, books, magazines or dark pieces of paper (one item per car). Students will need opaque material to block sun from their solar panels until it is time for their cars to move.

Learning Objectives

After this activity, students should be able to:
- Design and build an electric car that has a motor connected to a solar panel.
- Identify factors that affect the performance of a solar car, including friction, position of the axles and weight of the car.
- Design an experiment to test the performance of a solar car.

Introduction

In the previous activity, I told you about the collegiate American Solar Challenge and World Solar Challenge. Now it's time to race your cars in your own contest: the Mini Solar Challenge.

Test-engineers play an important role in ensuring that devices are ready for production and sale. They must first establish test procedures that will analyze whether the product is safe, durable and performs within desired specifications. Then they must conduct the tests and present the results along with any recommendations for changes.

Last time, we brainstormed ways we might test our solar cars. What procedures do you recall? Can you think of any others? [*Possible answers: Race them against one another. Time them over a known distance.*]

What conditions must we consider when testing the cars? [*Possible answers: Is the sunlight constant? Is there a slope?*]

Procedure

1. Tell students to pair up with their partners from the previous activity.
2. Distribute handouts.
3. Instruct students to examine their solar cars to make sure they are ready to be raced. Some cars may require last-minute adjustments. Have students verify that: (•) The solar panel has not been cracked or damaged. (•) All components (solar panel, motor, wheels and axles) are securely attached to the chassis. (•) Wheels and axles don't slide from side to side. (•) The motor and solar panel are connected.
4. Let students decide how they want to conduct the race. Solutions might include: (•) Each car runs the course independently, with everyone's times compared at the end of the race. (•) Two cars race together. (•) All cars race at the same time.
5. Take students to the testing area.
6. Tell students to mark the starting line and finish line with chalk. [*Let them decide the length. If necessary, you could suggest between 20 and 40 feet.*] Instruct them to measure the distance between the starting line and finish line and record the distance on their handout.
7. Tell class to select two students to time the races. The class might choose to have the same two students time each race to ensure consistent results.
8. To get ready for the race, one student in each pair is to position the car at the starting line, covering the solar panel with an opaque material to keep it from moving too soon. The other student is to stand at the finish line to catch the car.
9. Tell students that no one is to touch any car until it reaches the finish line.
10. Remind the racers at the starting line to make sure their solar panels are secure and pointing toward the sun. Tell them they will be starting their cars by removing the cover from the solar panel.
11. Instruct the timers to give the official start signal.
12. Ask students to record their start/finish times on their worksheet.

13. After each car has raced, give students a few minutes to make changes to their cars to make them go faster. [*For example, students may reposition the angle of their solar panel or find ways to reduce friction between the wheels and axles.*]

Activity Closure
Designing cars that are more environmentally friendly but also practical is an important modern engineering challenge. Though cars powered entirely by solar panels have limitations in large-scale application, solar technology could be integrated or combined with other alternative car technologies, e.g., an electric car powered with solar-charged batteries.

Let's revisit some questions we've discussed earlier. What are some of the advantages of a solar-powered car compared to a car with an internal combustion engine? [*Quieter, renewable source of energy, does not need gas, etc.*] What obstacles would need to be overcome to make a solar car more practical? [*Possible answers: How to operate the car at night or when it is cloudy; how to harness enough power to run larger vehicles.*] Let's brainstorm some possible solutions to these problems.

Assessment

Ask students to explain what makes their cars run.

Activity 1: What Does a Solar Panel Do?

Name: ___________________________________

Date: __________________________

Materials List

- Solar panel (from SolGear solar car kit)
- Digital multimeter
- Motor (from SolGear solar car kit)
- 1 AA battery
- 2 wires with alligator clips

Rules

- Do not lose any of the parts. Other classes will be using them.
- Be careful with your solar panel. Do not drop or bang it on something. Your solar car will not be able to go as fast if the solar panel is damaged.

Procedure

1. You will use a **multimeter** to measure **voltage**. The red lead is positive (+) and the black lead is negative (-). Adjust the dial until the indicator points to 20VDC (direct current). DC indicates a constant voltage, and 20V is the maximum voltage you can measure. In this position, it will measure up to 20 volts.

2. Measure the voltage across your solar panel by connecting the red lead (+) to the red wire from the solar panel and the black lead (-) to the black wire. If the reading has a negative value, switch the leads. When the readout is positive, the red lead has been properly connected to the positive terminal, and the black lead has been properly connected to the negative terminal.

3. Measure the voltage across the solar panel under three different lighting conditions: (a) darkness, (b) bright indoor lighting, and (c) sunlight. Record your measurements in the table.
4. Measure the voltage across a battery. How does the voltage across a battery compare to the voltage across the solar panel? Connect the motor to the battery using wires with alligator clips to make sure it is functioning. Just touch the wires to the battery.
5. Disconnect the motor from the battery and connect it to the solar panel.

	Voltage
Single solar panel: Darkness	
Single solar panel: Indoor light	
Single solar panel: Sunlight	

Exploration Questions:
What factors affected the voltage output from your solar panel(s)?

List some applications in which solar energy can be used as an alternative energy source.

Explain what a solar panel does.

Activity 2: Multiple Solar Panels

Name: ___________________________________

Date: __________________________

Materials List (Combine 2 groups from Activity 1)

- 2 solar panels (from SolGear solar car kit)
- Digital multimeter
- Motor (from SolGear solar car kit)
- 2 AA batteries

Rules

- Do not lose any of the parts. Other classes will be using them.
- Be careful with your solar panel. Do not drop or bang it on something. Your solar car will not be able to go as fast if the solar panel is damaged.

Procedure

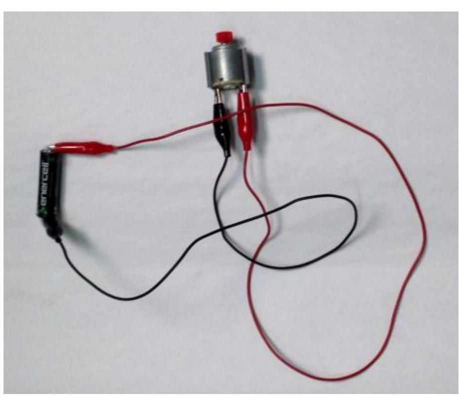
1. Team up with another pair of students so you can share materials and explore what happens when you connect multiple solar panels together.
2. We will use a multimeter to measure voltage. The red lead is positive (+) and the black lead is negative (-). Adjust the dial until the indicator points to 20VDC (direct current). DC indicates a constant voltage, and 20V is the maximum voltage you can measure. In this position, it will measure up to 20 volts.

3. What do you think will happen if two solar panels are connected together? Try connecting the panels together and measuring their voltage with the multimeter. There are different ways of connecting them. Try to connect the panels in a way that increases their voltage.

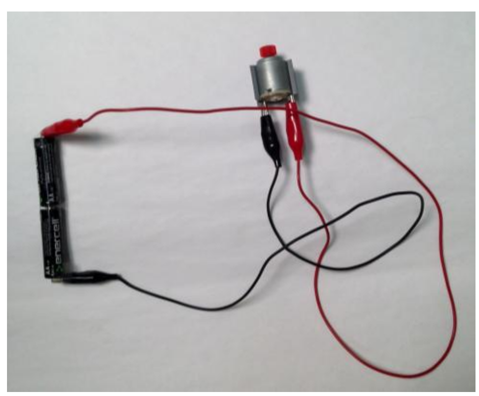
4. Draw below how you connected the panels together and write the voltage you measured in sunlight. How does this compare to the voltage of a single panel that you measured in the last activity?

    a. Measured Voltage: _____

5. When you connect the panels together and increase the voltage higher than the voltage of the original connection, this is called connecting in **series**. Connect the batteries in series, as you did with the solar panels, and test the motor. Now measure the voltage across both batteries. How does the voltage across one battery compare to the voltage across the solar panel? How does it compare using two batteries? Use tape to secure the motor wires to the batteries.



Motor connected to battery



Motor connected to two batteries in series

Activity 3: Building a Solar Car

Name: ______________________________________

Date: ________________________

Engineering Design Problem

Your design challenge is to build a car that will move as fast as possible over a flat surface using only power from the sun. Your SolGear instructions provide a starting point for designing the car.

Materials List

- SolGear solar car kit, including:
  - Solar panel
  - Motor
  - Plastic motor mount
  - 4 wheels
  - 4 rubber tires
  - 4 eyelets
  - Small gear
  - Large gear
  - 2 wooden dowels
  - Plastic tubing
  - 2 square wooden sticks
  - SolGear Instructions
- Masking tape

Rules

- Do not lose any of the parts. Other classes will be using them.
- Be careful with your solar panel. Do not drop or bang it on something. Your solar car will not be able to go as fast if the solar panel is damaged.

Exploration Questions:

What design considerations did you make when constructing your solar car?

What factors do you think will affect the racing performance of your solar car?

How fast do you think your solar car will go? How might you test its speed?

Activity 4: Mini Solar Challenge

Name: ________________________________

Date: ________________________

In this activity, you are going to test your solar car. You will be examining different factors that affect the racing performance of your solar car.

Materials List

- Solar car (built in Activity 2)
- Sun blocker (file folder, book, etc.)

Rules

- Do not lose any of the parts. Other classes will be using them.
- Be careful with your solar panel. Do not drop or bang it on something. Your solar car will not be able to go as fast if the solar panel is damaged.

Procedure

1. Examine your solar car to make sure it is ready to be raced.
2. As a class, decide how you want to conduct the race.
3. You and your partner will play different roles in the race. One of you will hold the car at the starting line while covering the solar panel with something to block the light (to keep it from taking off too soon). The other will wait at the finish line to catch the car.
4. The person at the starting line should remove the sun blocker when the starting signal is given.
5. Record the length of the racecourse (distance from starting line to finish line) and enter your race time in the table.
6. After the race is completed, make any necessary changes to your solar car that would help it go faster.

Length of racecourse (distance measured from starting line to finish line)	
Race time of your solar car	
Race time of fastest solar car	

Exploration Questions:

How did you conduct your race? How might you change the racing procedure?

What factors affected the performance of your car? Was its performance different than you expected? If so, explain.

Did your solar car move as fast as you thought it would? What changes would you make to your solar car to make it perform better and race faster?