Solar Energy:
Racing with the Sun

TechXcite: Discover Engineering

Pratt School of Engineering
Duke University

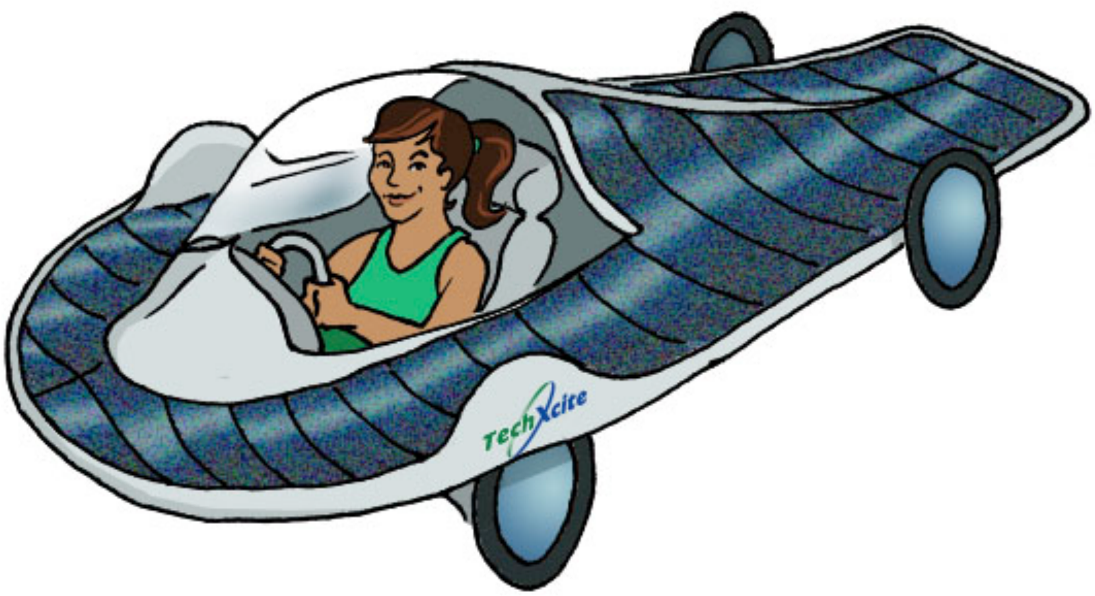


Table of Contents

Module Overview

This TechXcite: Discover Engineering module introduces youth to 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 generate in different lighting situations. Then, they will work in pairs to design, build, and race a solar car with optimum performance.

Activity 1: Explore how a solar panel converts sunlight into electricity
Activity 2: Explore solar panels in series
Activity 3: Design and build electric car with a motor connected to a solar panel
Activity 4: Race solar cars and explore factors that affect their performance

Authors: Paul Klenk, Ph.D., Gary Ybarra, Ph.D., Rebecca Simmons, Ph.D., Rahmin Sarabi and Roni Prucz

Editor: Rodger Dalton, Carla Burgess

TechXcite: Discover Engineering Program

TechXcite is a partnership between Duke University's Pratt School of Engineering and the National 4-H Council / 4-H Afterschool.

The program is directed by Dr. Gary Ybarra (PI). In 2000, Dr. Ybarra created ***Techtronics***, an informal after-school engineering program at Rogers-Herr Middle School in Durham that eventually spread to additional schools across North Carolina and other states. The ***TechXcite: Discover Engineering*** curriculum builds on this work by creating learning modules in seven theme areas for use in 4-H Afterschool programs nationwide. Other after-school programs and even formal in-school programs may choose to use the TechXcite curriculum. TechXcite is an engaging, substantive, experiential and inquiry-based curriculum centered on engineering, while using technology, applied science and mathematics youth have learned in school. It provides an excellent foundation for any career pursuit.

TechXcite's mission is 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 implementation of this module. There are videos to guide instructors who facilitate the activities with youth. Although the curriculum is written with a focus on middle school youth, it has been successfully implemented at both the elementary and high school levels. Anyone can download copies of the Instructor's Guide and Youth Handouts from our website. A list of sources for all materials needed is provided. Finally, there are links to additional resources for information about the module topics and ideas for further activities.

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 using 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 that will be used in each of the activities.

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 participants 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 participants. Instructions that are not to be read to participants, 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 participants.

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 participants understood the material presented to them in the activity. These assessments are generally based on participants’ answers to questions asked during the Activity Closure section.

Tools Used in the Module — Digital Multimeter

A multimeter takes electrical measurements such as voltage, current and resistance. In these activities, you will be using the multimeter to measure voltage. You may want to demonstrate the multimeter before beginning the activities by using it to measure the voltage produced by a battery. You should also carefully distinguish connector, lead**,** terminal and probe. If you disconnect one of the leads from the multimeter, you can point to one end, which is the **connector**, sweep the whole length of the wire and call that the **lead**, and finally showing them the other end that is held in the hand with the metal spike sticking out. That part of the lead is called the **probe**.

Voltage Measurement Demonstration

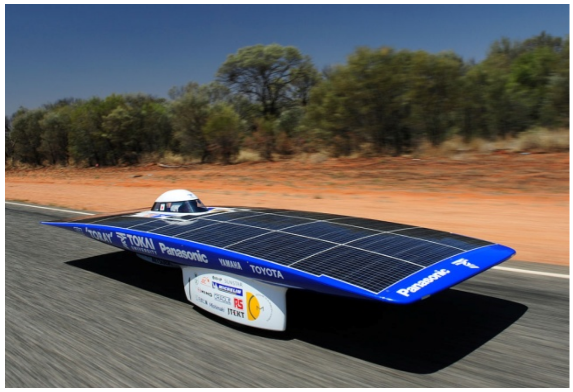
To measure the battery voltage, first rotate the dial on the multimeter to the 20 VDC setting as shown in the picture below. DC means constant voltage and is represented symbolically by a dashed line above a solid line "V---". The tilde symbol in "V~" is used to specify AC (alternating) voltage and will not be used in these activities.

Using a AA or similar battery, connect the red positive (+) meter probe to the positive terminal of the battery (the end with the bump on it) and the black negative (-) probe of the meter to the negative terminal of the battery (flat end). The meter should read around 1.5 V to 1.6 V for a fresh AA battery and will read less voltage as the battery drains down.

The meter shows a range of settings for DC Voltage such as "2", "20", "200", etc. If you are measuring a voltage that exceeds the selected range, the multimeter will display an overlimit indication and you must adjust the dial to a higher range setting. You can see this happen with the battery test by turning the knob two clicks counter clockwise to the "200m" setting which has 200 mV (0.20 Volts) as the maximum. When you touch the probes to the AA battery now, the meter will indicate overlimit / out of range.

As a final demo, change back to the 20 VDC setting and swap the meter leads so that the red meter lead has its probe in contact with the negative terminal of the battery and the black meter lead has its probe in contact with the positive terminal of the battery (this is backwards, but it won't hurt anything). Now the meter will read the same amount of voltage as it did before, however it will have a negative sign in front to indicate that the probes are "backwards" and are therefore measuring a negative voltage.

Activity 1: What Does a Solar Panel Do?



Winner of 2011 World Solar Challenge in Australia by Kohei Sagawa and Hideki Kimura, [CC-BY-SA-3.0], via Wikimedia Commons

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
- 2 alligator clip leads

Youth Handouts:

- "What Does a Solar Panel Do?"

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's worth trying to use it. If the panel is broken and does not work at all, carefully discard it.

Learning Objectives
After this activity, participants 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
Electric Current	How much electricity is flowing through the wire. Measured in amperes or "amps" for short.
Voltage	The force / electric pressure that is pushing the electricity through the circuit. Measured in volts.
Electric Circuit	The closed path from the positive side to the negative side of the battery or solar cell. Electricity will only flow through a closed path.
Terminal	A piece of metal used to make an electrical connection.
Solar Cell	Device that converts sunlight into electrical energy.
Solar Panel	A group of several solar cells connected together.

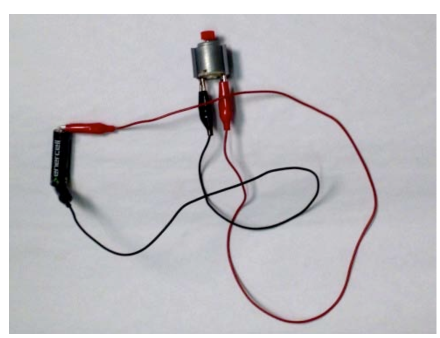
Introduction

During the next few sessions, we will investigate how to generate electricity using the sun and then use what we learn to build a 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 participants to brainstorm and respond. If you have a board, write down participants' answers. Possible answers include calculators, solar-powered sidewalk night-lights, and solar panels on the roofs of houses.*]

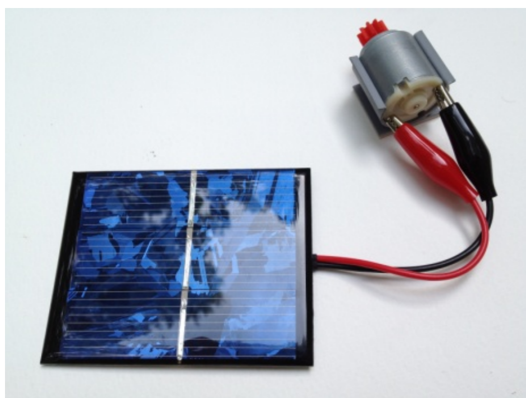
A solar cell converts light energy into electrical energy. But not all of the sunlight's energy is converted into electricity; some sunlight is reflected and some is turned into heat. The solar panels that you'll be using in these activities generate about 0.75 watts of power in full sunlight. By comparison, a typical light bulb you might use at home requires about 60 watts of electric power.

Procedure

1. Place the participants in pairs.
2. Distribute materials and handouts. Remind participants to be careful with the solar panel because it's fragile.
3. Instruct participants to adjust the multimeters to measure DC voltage by rotating the dial to a setting of the "20V---" range. (NOT 20V~)
4. Ask participants to measure and record the voltage across the AA battery by touching the probes of the multimeter to each terminal on the end of the battery. A fully charged new battery should generate more than 1.5 volts.
5. Have them measure the battery again (YH procedure step 3) with the probes switched to observe that the meter shows a negative value for the voltage when the polarity is reversed.



6. Use the alligator clip leads to connect the motor terminals to the battery terminals. If the battery voltage, measured in step 4, is greater than 1.5 volts the motor should run. If the battery voltage is high enough but the motor still does not run, it may be broken.
7. Next the participants will connect the leads on the multimeter to the solar panel. Ask them to measure and record the voltage across the panel in three different lighting conditions: darkness (inside a desk, for example), bright indoor lighting, and sunlight. Participants will likely learn that without any light, the panel will not create any voltage. 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.*]
8. Ask the participants to connect the motor to the solar panel, as shown in the picture below. Make sure they 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 participants 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? [*Depending on the lighting conditions the solar panels perform as well as a fresh battery.*]

Assessment

Ask participants the following questions:

1. What factors affected the voltage output from your solar panel(s)? [*Type of light source (sunlight, light bulb, etc); angle of the solar panel with respect to the light source (changes the amount of light hitting the surface area of the solar panel)*]
2. What are some situations in which solar power is used as an alternate energy source? [*Examples: calculators, solar-powered cars (similar to what will be built in the next activity), solar lights (night lights that line a driveway or walkway)*]
3. What does a solar panel do? [*Converts light energy into electrical energy*]

Additional Instructor Resources

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

Activity 2: Multiple Solar Panels

NCSU Solar House in Raleigh by Akhil Jariwala,
[CC-BY-SA-3.0], via Wikimedia Commons

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
- 4 alligator clip leads

Youth Handouts:
- "Multiple Solar Panels"

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

Learning Objectives
After this activity, participants 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 circuit	Components connected along a single path so that the same electric current flows through each component. The voltages will add together but the current stays the same.
Parallel circuit	Components connected such that the voltage is the same across each component but their currents will merge together. The voltage stays the same but the currents from each component will add together.

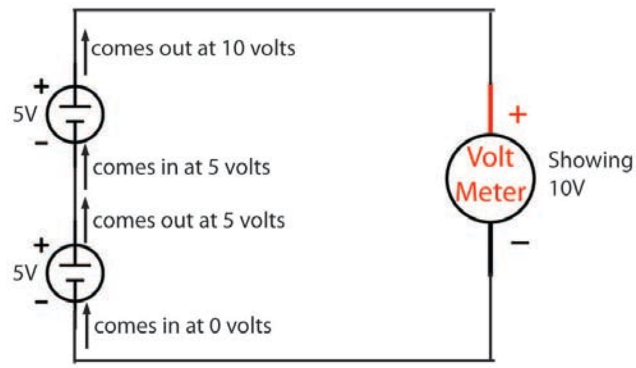
Introduction

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

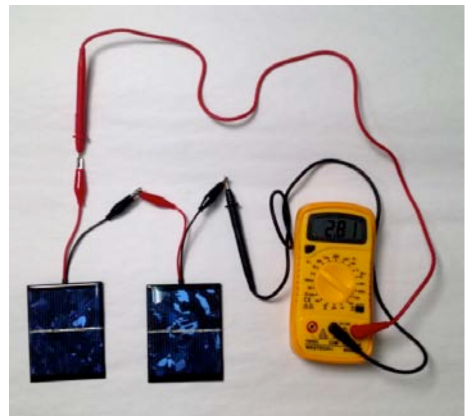
Procedure

1. Ask each pair of participants from the previous activity to team up with another pair of participants to create groups of 4.
2. Redistribute materials if necessary and again remind participants to be careful with the solar panels.
3. Instruct participants to adjust the dial on the multimeters to measure voltage by changing it to a setting in the "20V---" range.
4. Ask participants to predict what will happen if two solar panels are connected together. Without giving them any further information, allow them to experiment on their own to explore the different ways in which two solar panels can be connected while also attempting to measure the voltage produced using the multimeter (don't worry, they can't hurt anything).
5. After students have experimented some on their own, have them connect their solar panels correctly as shown on the following page in both series and parallel configurations. They should notice that the voltages of each panel add together when connected correctly in series.

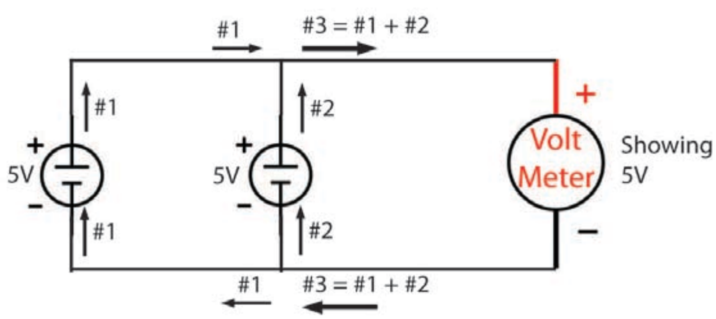
Series Connection: To connect the panels in series, first clip together the red positive lead of one solar panel and the black negative lead of the other solar panel. Then connect the red probe of the multimeter to the unused red solar panel lead and the black meter probe to the unused black solar panel lead. Your setup should look like the photograph below. When connected in series, the voltage produced is approximately double the amount of voltage produced by a single panel.



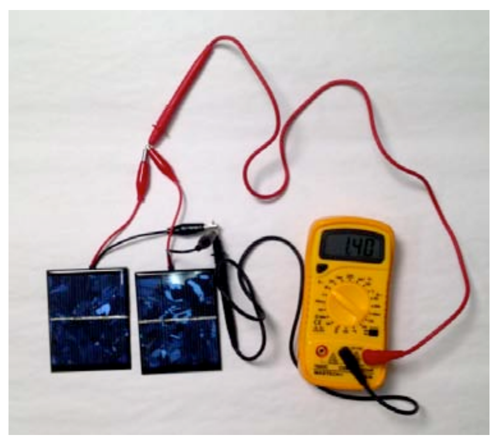
SERIES CONNECTION
Voltages Add, Current the Same



Parallel Connection: To connect the panels in parallel, first clip both of the red positive lead wires from each solar panel to the positive probe on the multimeter. Then clip both of the black panel leads to the negative probe on the multimeter. In this circuit, the voltage will stay the same and instead the current will increase.



PARALLEL CONNECTION
Currents Add, Voltage the Same



6. Connect the motor to multiple solar panels in series. What is different compared to connecting only a single solar panel to the motor? [*It runs at a faster speed.]*
7. Participants may also try connecting multiple batteries to the motor in the place of solar panels. They should see the motor run faster when two batteries are placed in series.

Activity Closure

Let's talk about what we learned today.

1. 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 added together.*]
2. 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. It will also be different for solar panels, depending on the amount of light.*
    a. *Two solar panels connected in series will cause the motor to run faster if they are both in the same light as the single panel.*
    b. *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 as a single panel since the voltage produced is about the same.*
    c. *Two batteries in series will make the motor run faster than one battery because of the higher voltage.*
    d. *Two batteries in parallel will run the motor at the same speed as one battery because the voltage is the same.*

Assessment

Ask participants the following questions:

1. What factors affected the voltage output from your solar panel(s)? [*Examples: type of light source (e.g. sunlight, light bulb); type of circuit connection series or parallel; angle of the solar panel tilting away from the light*.]
2. Draw how you 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 participants outdoors to test their cars. If it's not sunny, participants can build their cars without testing them.

Learning Objectives
After this activity, participants 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, weight of the car, and how much light shines on the solar panel.

Vocabulary

Word	Definition
Axle	Shaft on which a wheel can rotate.
Chassis	The frame on which the body of a vehicle is built (pronounced CHASS-ee).

Introduction

What would be some advantages or disadvantages of owning a solar car? [*Give participants time to brainstorm.*] Though you do not 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 solar power can accomplish [*www.solartaxi.com*]. College participants also race solar cars over hundreds of miles in national and international competitions each year. The two main competitions are the American Solar Challenge [*americansolarchallenge.org*] and the World Solar Challenge [*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 each other.

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

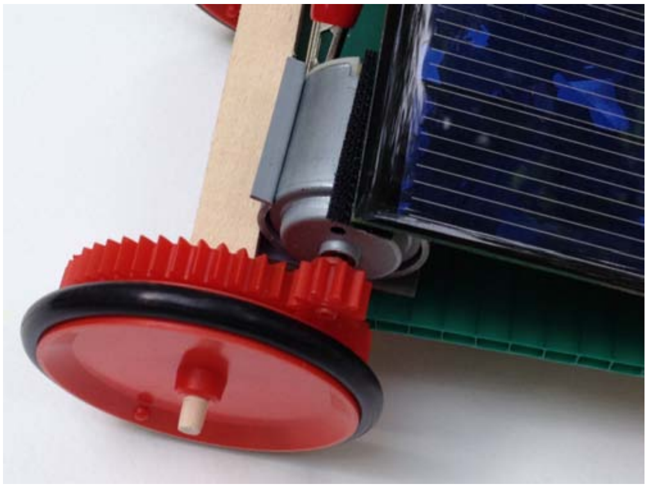
- *Chassis/body*
- *Motor*
- *Wheels*
- *Solar panel*
- *Wires*
- *Gears*
- *Axles*

As you've discovered, your car will have these key components: the chassis, a solar panel, wires, two axles, four wheels, a motor and gears. The chassis is the frame of the car and must be sturdy enough to support the weight of the motor, solar panel and wheels. 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 towards the sun, 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 participants to recognize that if the panel is fixed and pointed at the sun, it might not function as well if the car changes direction.*]

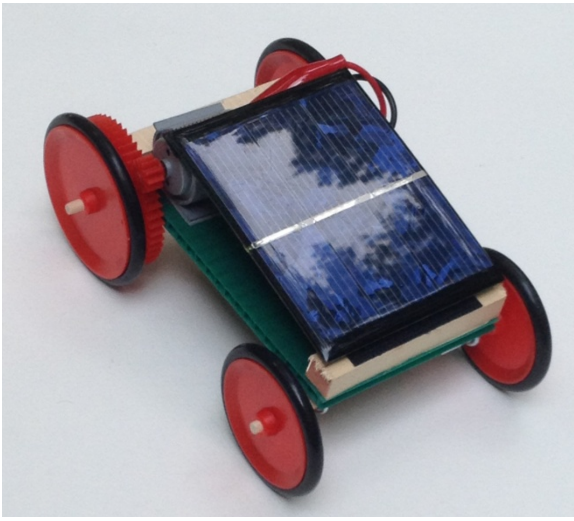
Procedure

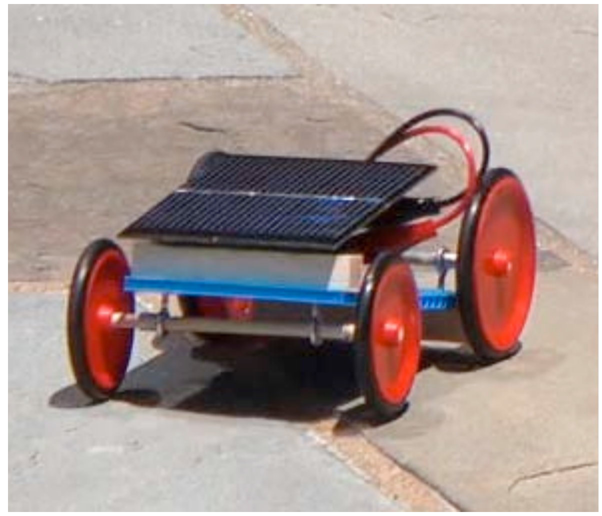
1. Tell participants to pair up with their partners from the first activity.
2. Give handouts and materials to each pair. Remind them that the solar panel is fragile and to handle it carefully.
3. Remind participants to use the small gear for the motor and the large gear for the axle as shown in the photo below. These are just like the gears on a bicycle. They make it easier for the motor to turn the axle shaft.

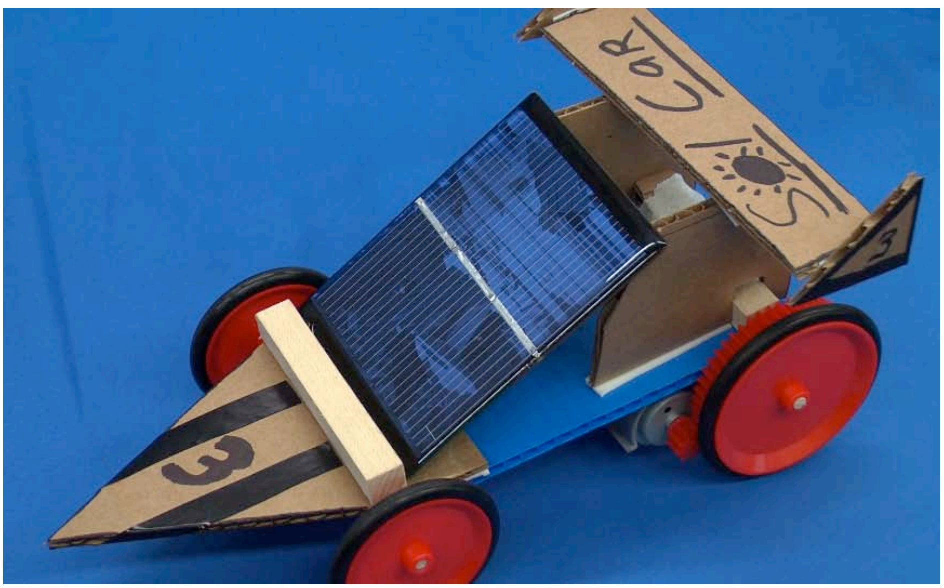


4. Tell participants to begin working on their cars, following the instructions on the handout. This is an open-ended activity. Each pair might work at a different pace.
5. Walk around and help participants while they design and build the chassis and connect the motor, gears, and wheels. While they are 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 participants should also demonstrate they understand 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?*]
   b. What aspects of the chassis design will affect the performance of the solar car? [*Participants should understand that the weight of the vehicle, friction, stability of the chassis, and wheel placement/alignment affect performance. They may also recognize 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.*]
6. 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 participants 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, make sure the axles are parallel to each other.

7. Once their solar cars are completed and functional, let participants decorate them however they wish.
8. 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 participants 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 participants 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

Start scene of 2007 Dream Cup Solar Car Race Suzuka
by Hideki Kimura, [CC-BY-3.0], via Wikimedia Commons

Time Required: 45 minutes
Group Size: 2

Materials List

Each group needs:

- Solar car (built in Activity 3)
- Sun blocker (opaque material such as a file folder, book, etc.)

Each class needs:

- Two stopwatches
- Tape measure
- Chalk

Youth Handouts:

- "Mini Solar Challenge"

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). Participants 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, participants 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, you learned 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.

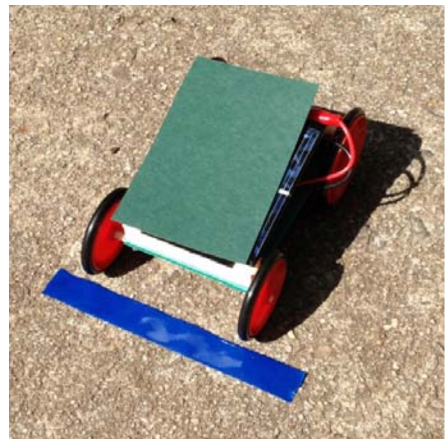
Last time, we brainstormed ways we might test our solar cars. What procedures do you recall? Can you think of any others? [*Possible answers: Race them against one another or time them over a known distance.*]

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

Procedure

1. Tell participants to pair up with their partners from the previous activity.
2. Distribute handouts.
3. Instruct participants to examine their solar cars to make sure they are ready to be raced. Some cars may require last-minute adjustments. Have participants verify:
   - 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
   - Motor and solar panel are connected
4. Let participants 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 participants to the testing area.
6. Tell participants 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 the class to select two individuals to time the races. They might choose to have the same two individuals time each race to ensure consistent results.
8. To get ready for the race, one participant 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 participant is to stand at the finish line to catch the car.
9. Tell participants 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 participants to record their start/finish times on their worksheet.
13. After each car has raced, give participants a few minutes to make changes to their cars to make them go faster. [*For example, participants 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.

1. 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.*]
2. 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 participants to explain how their cars work.