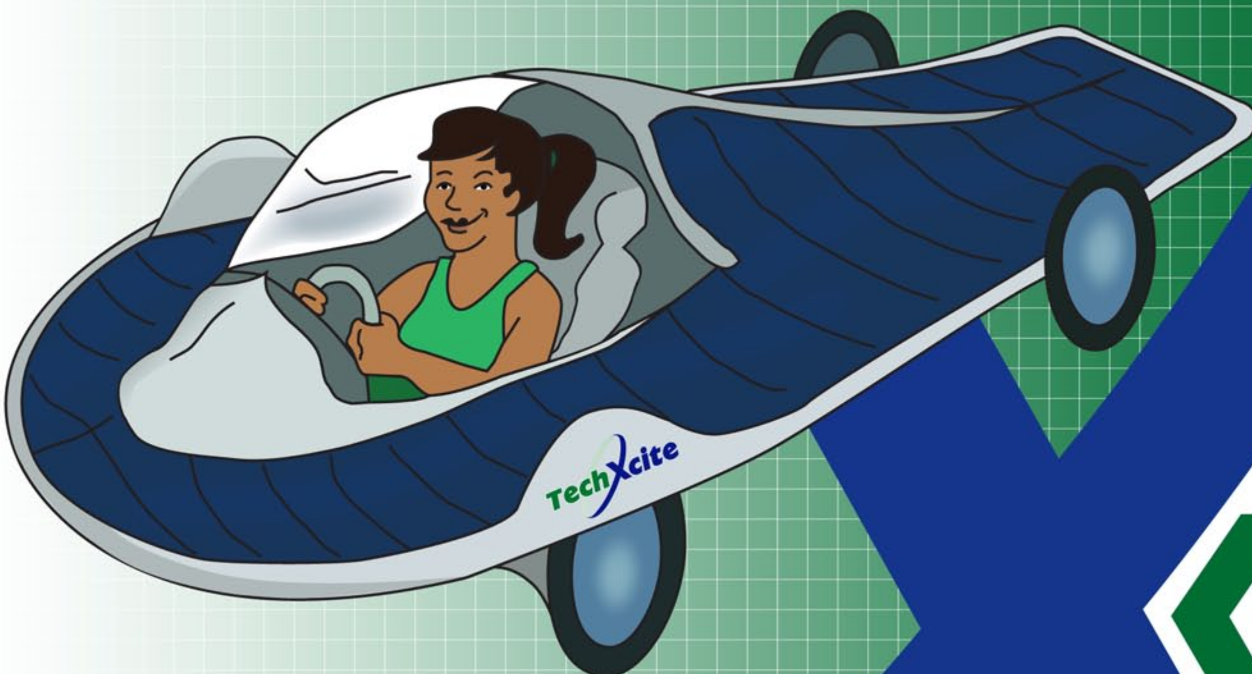

Racing with the Sun

TechXcite Discover Engineering

Facilitator's Guide

Module Overview

In this TechXcite: Discover Engineering module, youth harness the power of the sun by learning about and designing their own solar cars. 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.

This curriculum is intended for use with youth in middle grades in informal settings, such as after-school programs and summer camps. However, it has also been successfully implemented in formal school contexts, homeschool content, and with youth in elementary and high school.

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

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TechXcite: Discover Engineering

TechXcite is an informal engineering program partnering 4-H Youth Development/Family and Consumer Sciences at North Carolina State University, National 4-H Council and the Engineering K-PhD Program at Duke University's Pratt School of Engineering. It was initially funded by a five-year grant from the National Science Foundation.

In 2000, Drs. Ybarra and Klenk created an informal after-school engineering program at Rogers-Herr Middle School in Durham called Techtronics, which spread to additional schools across North Carolina and other states. The TechXcite: Discover Engineering curriculum builds on the Techtronics foundation by implementing hands-on, exploratory, engineering learning modules in 4-H Afterschool programs nationwide. Other after-school programs and even formal in-school and home-school programs have chosen 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 learned in school. TechXcite's mission is to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

TechXcite is the product of a collaboration of twelve 4-H leaders at land grant universities, two leaders at National 4-H Council and a team at Duke University.

Online Support

The TechXcite website (techxcite.org) contains additional material to facilitate implementation of this module. There are videos, Facilitator's Guides, Youth Handouts, and kit inventories with vendors and pricing for each item required. 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 Facilitator's Guide and Youth Handouts from our website. There are links to additional resources for information about the module topics and ideas for further activities and exploration.

Training Videos

Each module comes with a set of training videos found on its curriculum page (techxcite.org/curriculum). These videos serve as a companion to the Facilitator's Guide. An introductory video provides an overview of the material and concepts. The corresponding video for each activity then covers basic setup, Facilitating the Activity, and helpful tips for facilitating that activity. It's recommended that instructors watch all of the videos before starting the module.

Using this Guide

The Facilitator'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 be given basic information about the activity. This includes:

- Time Required
- Group Size – Suggested number of students per group.
- Materials List
- Youth Handouts – These will need to be copied.
- Getting Ready – What you need to do before the activity and approximately how much time it will take you.
- Learner Outcomes
- Vocabulary

Introduction and Activity Closure

The Introduction and Activity Closure 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.

Facilitating the Activity

This section contains step-by-step instructions for facilitating the activity. Students have their own procedure in the Youth Handouts.

Exploration Questions

Provides possible answers to the Exploration Questions found at the end of each activity in the Youth Handouts. After the students have a chance to answer the questions individually, instructors should hold a class discussion. The main purpose of this section is to encourage critical thinking and to promote the exchange of ideas.

Activity 1: What Does a Solar Panel Do?

Time Required: 45 minutes **Group Size:** 2

Materials List

Each group needs:

- Solar panel (From SolGear kit)
- Digital multimeter
- Motor (From SolGear kit)
- AA battery
- 2 Alligator clip leads

Youth Handouts:

- "What Does a Solar Panel Do?"

Getting Ready (5 minutes)

- 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.

Learner Outcomes

- 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
Voltage	The force or "pressure" 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	A device that converts sunlight into electrical energy. A group of several solar cells connected together is a solar panel.

Activity 1: What Does a Solar Panel Do?

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 lights, and solar panels on the roofs of houses.*]

A **solar cell** converts light energy into electrical energy. But not all of the sun'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.

Facilitating the Activity

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 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 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.

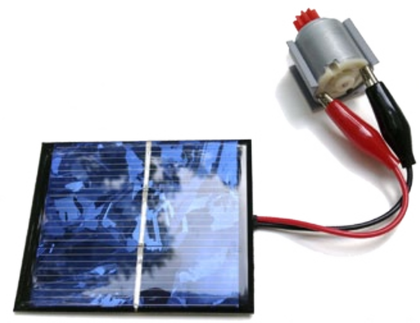
7. Next the participants will connect the leads on the multimeter to the solar panel. Ask them to measure and record the voltage across the panel in three different lighting conditions: darkness (inside a desk, for example), bright indoor lighting, and sunlight. Participants will likely learn that without any light, the panel will not create any voltage.
8. 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 new.*]

Activity 1: What Does a Solar Panel Do?

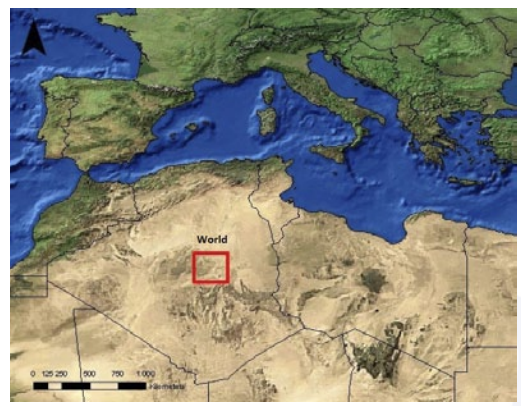
9. Instruct the participants to connect the motor to the solar panel, as shown in the picture to the right. Make sure they demonstrate an understanding that the solar panel works like a battery and powers the motor. Prompt them as they experiment:

    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



Sunlight is great source of energy. On a bright day the sun's rays give off about 1000 watts of energy per square meter of the earth's surface. According to a recent study, if we could harness this energy, a 254-by-254 kilometer area could theoretically absorb enough rays to power the entire world! This may sound like a lot of area, but with the Sahara Desert alone covering about 9.4 million square kilometers, the land required is actually *less than 1%* of this mostly-empty and unused land.

Unfortunately, this would require solar panels with 100% efficiency. Current solar panel designs are about 20-30% efficient, but with continuous research and testing, they're getting better every day.

Exploration Questions

1. What factors affected the voltage output from your solar panel?

    - [*Type of light source (sunlight, light bulb, etc)*
    - *Intensity or brightness of the light*
    - *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 advantages of solar energy?

    - [*Solar energy is free*
    - *Unlike fossil fuels, solar energy does not have a limited supply*
    - *Saves ecosystems because it doesn't rely on mining*
    - *In many states, solar energy can be fed back to the utilities, eliminating a the need for storage and reducing electric bills*
    - *Systems require very little maintenance and have a long life-span*
    - *Does not cause pollution*
    - *Can be used in remote areas where it's too expensive to extend the electricity power grid*
    - *Modern systems are easier to install, less expensive, and more efficient than they used to be*]

Activity 1: What Does a Solar Panel Do?

3. What are some disadvantages of solar energy?
    - [*Relatively large upfront cost (anywhere from $15,000-$35,000)*
    - *Can only be harnessed during the daytime, when it's sunny*
    - *Solar power stations require large areas of land*
    - *Since solar energy cannot be acquired 24/7, batteries—which are large, heavy, and expensive—are often necessary*]

References

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

http://mic.com/articles/91313/here-s-how-much-renewable-energy-it-would-take-to-power-the-entire-world

Activity 2: Multiple Solar Panels

Time Required: 45 minutes **Group Size:** 4

Materials List

Each group needs:

- 2 Solar panels (From SolGear kit)
- Digital multimeter
- Motor (From SolGear kit)
- 2 AA batteries
- 4 Alligator clip leads

Youth Handouts:

- "Multiple Solar Panels"

Getting Ready (5 minutes)

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

Learner Outcomes

- Explain that the voltage of solar panels connected in series is the sum of the individual panel voltages.

Vocabulary

Word	Definition
Current	The flow of electricity through a wire. Measured in amperes or "amps".
Series circuit	Components connected along a single path so that the same electric current flows through each component. In this configuration, the voltages will add together but the current stays the same.
Parallel circuit	Components connected such that the voltage stays the same across each component but their currents 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.

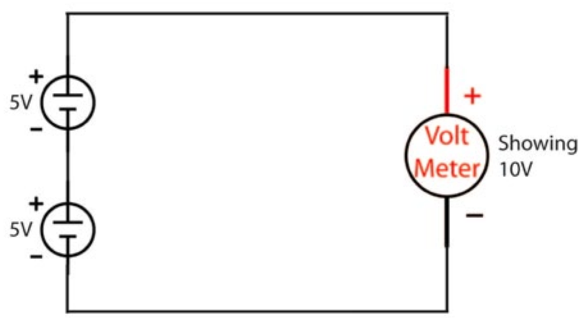
Facilitating the Activity

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.

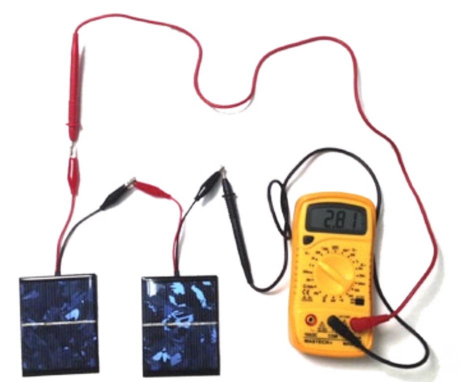
Activity 2: Multiple Solar Panels

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 in both series and parallel configurations. They should notice that the voltages of each panel add together when connected in series, but not when connected in parallel.

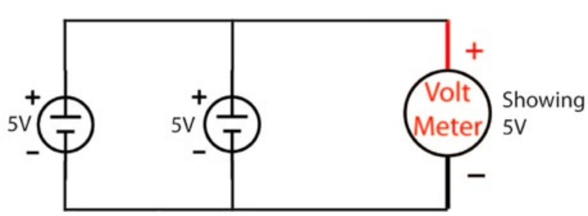
   Series Circuit: To connect the panels in series, first clip together the red positive lead of one solar panel and the black negative lead of the other solar panel. Then connect the red probe of the multimeter to the unused red solar panel lead and the black meter probe to the unused black solar panel lead. Your setup should look like the photo 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 Circuit: 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. When connected in parallel, the voltage will stay the same and instead the **current** will increase.



PARALLEL CONNECTION
Currents Add, Voltage the Same

Activity 2: Multiple Solar Panels

6. Connect the motor to multiple solar panels in series. What's 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 also see that the motor runs faster when two batteries are placed in series.

Activity Closure

Generally, a group of electrically connected solar cells is known as a solar panel, and a group of electrically connected solar panels is known as a solar array. Arrays can range from just a couple panels in a small home setup to a couple *million* panels in a solar power plant.

In 2014, the largest solar power facility in the world was completed in Arizona between Yuma and Phoenix. The plant is comprised of more than 5 million solar panels, spanning an area the size of two Central Parks, and generates more than 280 megawatts of power.

Exploration Questions

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?

   [T*he 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.*

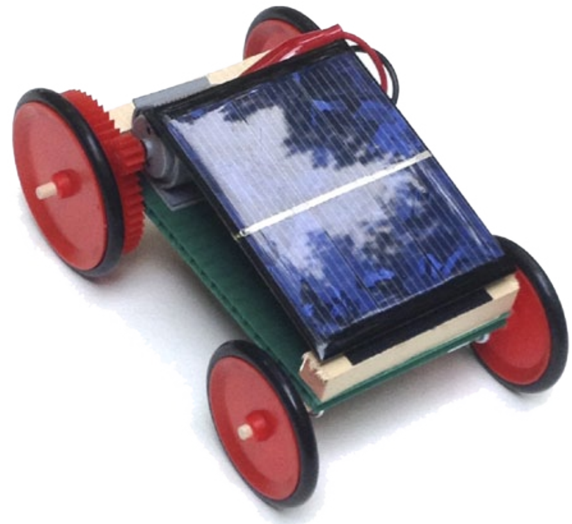
   b. *Two solar panels connected in parallel might cause the motor to run faster in low light. In full sunlight, the motor will run at about the same speed as a single panel since the voltage produced is about the same.*

   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*.]

Activity 3: Building a Solar Car

Time Required: 90 minutes **Group Size:** 2



Materials List

Each group needs:

SolGear solar car kit:
- 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

Each class needs:

- Masking tape
- Double-sided mounting tape (Optional)

Youth Handouts:

- "Building a Solar Car"
- SolGear Instructions

Getting Ready (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.
- Watch "How to make a Solar Car" video (http://vimeo.com/57695262).

Learner Outcomes

- 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).

Activity 3: Building a Solar Car

Introduction

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 another.

What are some of the parts you’ll need to build your car?

[*Write their ideas on the board, if possible. If participants overlook any key component help them discover what they’re missing*: *chassis/body*, *motor, wheels, solar panel, wires, gears, axles.*]

As you’ve discovered, your car will have these key components: a **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.*]

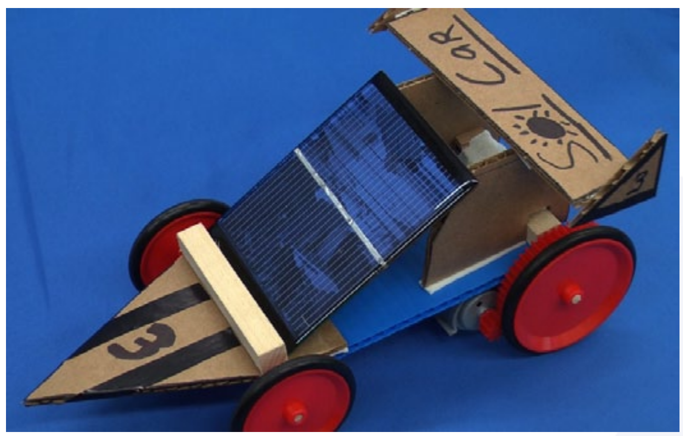
How might mounting a solar panel on the car at a tilt create problems? [*There are many valid answers, but it is key for participants to recognize that if the panel is fixed and pointed at the sun, it might not function as well if the car changes direction.*]

Facilitating the Activity

1. Pair up participants 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 directions on the SolGear instructions 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. Momentum (car already in motion), inertia (car starting from standstill), gravity, and drag (friction of wheels rotating on axle) may also play a role.*]

Activity 3: Building a Solar 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 3: Building a Solar Car

Activity Closure

What would be some advantages or disadvantages of owning a solar car?

[*Give participants time to brainstorm.*]

One of the most obvious benefits of solar-powered cars is the fuel. People who own solar cars do not need to purchase fuel or plug into an electrical socket, meaning they have no regular expenses aside from maintenance and repairs. Another major benefit is the lack of environment-threatening emissions. Exhaust from vehicles burning fossil fuels is proven to negatively affect the environment and contribute greatly to global warming.

But there are quite a few disadvantages too. Solar cars do not have the same power and speed that regular cars with combustion engines have. They're also not as safe because the limited power means all extra weight must be stripped out to increase its efficiency. Another drawback is their dependance on the weather. If it's dark or cloudy outside for days on end you may have a problem storing enough power to get where you need to go. And even if it's not cloudy, travelling long distances still may be an issue.

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].

Exploration Questions

1. Describe your design process. What factors did you consider when constructing your solar car?

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

   Possible answers include wheel placement and spacing, solar panel placement and angle, efficiency, motor placement, and chassis weight.]

2. How should we evaluate the performance of the cars? What conditions must we consider when testing them?

   [*Possible answers include racing them against one another or timing them over a known distance.*

   Is the sunlight constant? Is there a slope?]

Activity 4: Mini Solar Challenge

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; Not included in kit)

Each class needs:

- 2 Stopwatches
- Tape measure
- Chalk

Youth Handouts:

- "Mini Solar Challenge"

Getting Ready (15 minutes)

- A clear, sunny day is best for racing, but as long as the sky is not completely overcast, the 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.

Learner Outcomes

- 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?

Activity 4: Mini Solar Challenge

Facilitating the Activity

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. [*For example, participants may want to reposition the angle of their solar panel or find ways to reduce friction between the wheels and axles.*]

Activity 4: Mini Solar Challenge

Activity Closure

Designing vehicles that are 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.

Exploration Questions

1. What are some advantages of a solar-powered car compared to a car with an internal combustion engine?
    - [*Quieter*
    - *Savings on fuel*
    - *Less pollution*]
2. What are some obstacles we would need to overcome to make solar cars more practical? Brainstorm some possible solutions to these problems.
    - [*Operating the car at night or when it's cloudy*
    - *Harnessing enough power to run larger vehicles*
    - *Ability to store power without large, heavy batteries*
    - *Expensive solar panels*]
3. How did you conduct your race? How might you change the racing procedure?
4. Did your solar car move as fast as you thought it would? What changes would you make to increase its performance?

Tools Used in this Module

Digital Multimeter

A multimeter is an electronic device that measures voltage, current, and resistance. The red probe is positive (+) and the black probe is negative (-). The selection knob should always be in the "off" position when the meter is not being used.

Each type of measurement has a range of possible settings, such as 2, 20, 200, etc. If your measurement exceeds the selected range, the multimeter will display a "1" which indicates overload or out-of-range. If this happens, simply adjust the selection knob to the next highest setting. If the displayed value has a negative sign in front of it, the probes are just "backwards". This won't hurt the meter.

Voltage

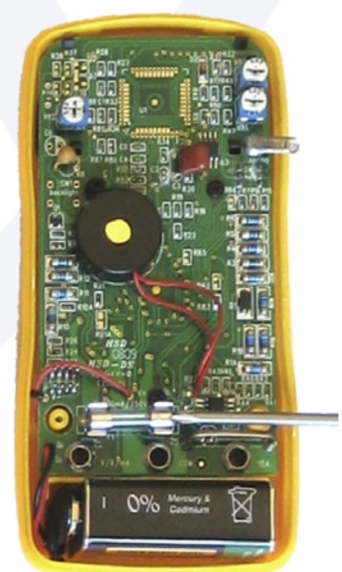
Voltage is measured in volts (V). You'll notice there are two different voltage settings on the multimeter: V--- for DC voltage and V~ for AC voltage. We will only be measuring DC voltage in these activities. DC means constant voltage, like a battery. AC means alternating voltage, like a wall outlet at home.

To measure a battery's voltage, turn the selection knob to a value slightly higher than the expected voltage. For example, to measure a 1.5 V battery, the meter should be set to the "2" position or higher in the V--- range. Touch the red probe to the positive (+) end of the battery and the black probe to the negative (-) end. If the battery is still good, the display value should be between 1.4 V and 1.6 V.

Current

Current is measured in amperes (A). WARNING: The meter is at risk of being damaged when measuring current. Never connect a meter directly to a battery when set to measure current or you will blow the fuse inside the meter. However, you can safely measure a small solar cell's current with a direct connection to the meter. Current flowing through the meter going into the red probe and out of the black probe will yield a positive reading on the display. The measurement will be negative if the current flows into the black probe and out of the red probe.

Replacing a Fuse or Battery



If the meter is used improperly, you may blow a fuse. To replace the fuse, remove the screws from the back and open the case. The fuse will look like a small glass cylinder with metal end caps. A picture of the opened meter is shown to the right with a screwdriver pointing at the fuse. Pop out the old fuse and replace it with a new 200 mA, 250 V fuse.

If the meter is left turned on, the battery will drain down. To replace the battery, remove the screws from the back and open the case. Pull the battery out, unclip the battery snap, connect a new 9 V battery, and reinsert it into the meter case.

Glossary

Axle
Shaft on which a wheel can rotate.

Chassis
The frame on which the body of a vehicle is built (pronounced CHASS-ee).

Current
The flow of electricity through a wire. Measured in amperes or "amps".

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.

Parallel circuit
Components connected such that the voltage stays the same across each component but their currents add together.

Series circuit
Components connected along a single path so that the same electric current flows through each component. In this configuration, the voltages will add together but the current stays the same.

Solar cell
A device that converts sunlight into electrical energy. A group of several solar cells connected together is a solar panel.

Terminal
A piece of metal used to make an electrical connection.

Voltage
The force or "pressure" pushing the electricity through the circuit. Measured in volts.

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Acknowledgements

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This Module was created with support from the National Science Foundation grant 0638970.

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