solar 4R schools™

Mini Solar Houses

Lesson 1: Investigating Orientation, Voltage, and Current

AUTHOR: Bev Satterwhite

DESCRIPTION: This lesson focuses on understanding how the angle and orientation affect the amount of energy that is generated through use of a solar cell. Paper azimuth finders, Keva Planks, and multimeters will be used in order for students to draw conclusions about the optimal placement of a solar cell. This lesson will prepare students for the construction of a roof for their solar home based on these angles.

GRADE LEVEL(S): 4, 5, 6

SUBJECT AREA(S): Electricity, solar energy, current, voltage, photovoltaics, seasonality

ACTIVITY LENGTH: ~90 minutes

LEARNING GOAL(S):
1. Students will understand how to use an Azimuth finder to determine the direction and altitude that solar modules will face.
2. Students will learn how to describe why a solar module is pitched at a particular angle.
3. Students will understand how to measure the voltage and current for an electrical energy source.

NEXT GENERATION SCIENCE STANDARDS:
- 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
- 4-ESS3-1. Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.

COMMON CORE STATE STANDARDS:
- CCSS.MATH.CONTENT 4.MD.C.5 Recognize angles as geometric shapes that are formed wherever two rays share a common endpoint, and understand concepts of angle measurement:
- CCSS.MATH.CONTENT.4.MD.C.5.A An angle is measured with reference to a circle with its center at the common endpoint of the rays, by considering the fraction of the circular arc between the points where the two rays intersect the circle. An angle that turns through 1/360 of a circle is called a "one-degree angle," and can be used to measure angles.

- CCSS.MATH.CONTENT.4.MD.C.6 Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

Materials List*

- compass (1 per group of two)
- Azimuth Finder - found in the book Teaching Solar by Rahus Institute (1 per group of two). This resource can additionally be found by searching for Rimstar's "DIY elevation/azimuth tool" (http://rimstar.org/renewnrg/elevation_azimuth_shadow_site_survey_tool.htm)
- Keva planks - see image (12 per group of two) - if you don't have Keva planks, tongue depressors, popsicle sticks or paint stir sticks would also work
- protractor (1 per group of two)
- multimeter (1 per group of two)
- "Worksheet Lesson 1: Investigating Orientation, Voltage, and Current" (1 per student)
- 2 volt, 1.5 volt, and .5 volt solar cells (1 each per group of two)
- flashlights (optional, 1 per group of two)
- batteries (optional, 1 per group of two)

*Please note group sizes depend on materials available and teacher discretion.

Other Supplies

- tape
- journals
- bamboo skewers, brass fasteners for making the Azimuth finder

Vocabulary

- altitude
- azimuth
- multimeter
- voltage
- current
- angle
- degrees
- optimal
- horizon
- true north
- energy source
- energy transfer
- light energy
- electricity
- photovoltaic

Lesson Details

Planning and Prep

1. Copy onto cardstock enough **Azimuth** Finders for each pair of students in your room. Prepare the **Azimuth** Finder using a bamboo skewer and tape. Test each one for stability.

2. Put 12 Keva planks in bags for each group of two, as well as a **multimeter**, the three sizes of solar modules and a protractor.
3. Make one copy of the “ Worksheet Lesson 1: Investigating Orientation, Voltage and Current” for each student to add to his science journal.

Student Background

Students participating in this lesson should be familiar with the following:

- **Energy transfer**
- The sun provides energy for our life on earth
- How solar energy is similar/different than the electricity in our homes
- **Solar energy** (Potential preliminary lessons could include “Our Place in Space: Tracking the Earth’s Path Around the Sun” by Jamie Repasky or “Introducing Solar Energy Lesson 1: Hypothesizing Why Solar Beads Change Color” by Leah Gorman on Solar 4R Schools’ Educator Library: http://www.solar4rschools.org/teach/teacher-activity-center.
- Measuring angles and using a protractor.
- How a **photovoltaic** cell works (refer to the Solar 4R Schools Educator Library http://www.solar4rschools.org/teach/teacher-activity-center for the lesson “How a Solar Cell Works: Photon Simulation,” by Erin Sturtz.

Educator Background

Educators leading this lesson should be familiar with the following:

The Azimuth Finder from Teaching Solar: A Teacher’s Guide to Integrating Solar Energy into the Classroom (http://solarschoolhouse.org/introducing-teaching-solar/) allows students to understand the position from the sun in two ways:

- The **altitude** of an object is the distance that the object appears to be above the **horizon**. The **angle** is measured up from the closest point on the **horizon**. In this case, the object is the sun.
- The **azimuth** of an object is the angular distance along the **horizon** to the location of the object. By convention, **azimuth** is measured from north towards the east along the **horizon**. For this activity, we assume the world is flat in order to measure the **degrees** away from **true north** by going towards the east. Your protractor should be laid with the line intersecting north and south, then laid in the east hemisphere to measure the degrees from North (0 degrees). See Figure 1 and Figure 2 below.

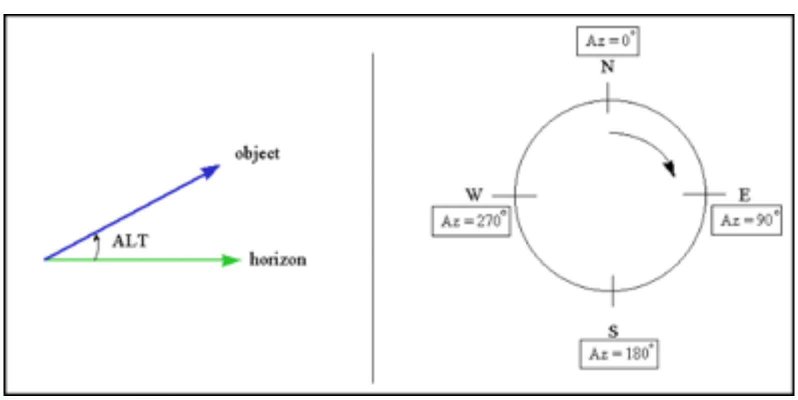
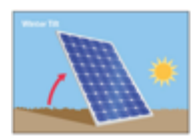


Figure 1 (left): altitude . Figure 2 (right) azimuth

- **Multimeter** notes: When using a **multimeter**, you have two options for what you want to measure: voltage or current. If you are yourself unfamiliar with electrical concepts, it might be easier to measure voltage. However, for this experiment, measuring current will show a much greater change in output values. If you are willing to devote more time to the activity, students could measure both values, or teams of students could be tasked with measuring either voltage or current. For additional help with multimeters, see Multimeter Cheat sheet - http://www.solar4rschools.org/teach/teacher-activity-center/using-multimeter-analyze-solar-circuit-measuring-current-and-voltage.
  - **Current:** When you measure current without a load in the circuit (anything you are trying to power), then you are creating a short circuit! Make sure that neither you nor your students try to measure the current through a battery by itself! Solar panels are current-limited. You can short-circuit the small solar modules in this activity without any problems. For this experiment, the dial should be set at 10 A (indicating that you expect a current between 0.2 A and 10 A). The red probe should be plugged into the “10A DC” port on the multimeter. If you are practicing measuring current without a good light source, you may need to turn your dial down to the 200 mA (0.2 A) setting and switch the red lead to the volts-ohms-milliamps port.
  - **Voltage:** Make sure you are measuring in **voltage** - direct current (⎓) - and that the leads match black-to-black (negative to negative) and red-to-red (positive to positive). For this experiment, the dial needs to be set at 20 V (indicating that you expect a voltage between 2V and 20V) when measuring the volts a solar module is producing. While a sunny day is not necessary to measure a voltage across the solar module, it is important for the data collection portion of this activity.
- Solar cells output different **current** and **voltages** at each angle depending on the time of year as the position of the Sun in the sky changes. This may be an investigation to do at least three times a year in order for students to see how the **altitude** and **azimuth** changes throughout the year and how this affects **solar energy** reaching the earth and electricity generated from a solar module (Google “Human Sundial Activity” for related activities). For example, during the summer a solar module’s **optimal angle** in Portland, Oregon is 32 degrees, while in winter it is 70 degrees (using the altitude as seen in Figure 1). Keeping data throughout the year will also help students confirm why we experience different seasons.



- A great book to help understand all of this is Teaching Solar: A Teacher’s Guide to Integrating Solar Energy into the Classroom (http://solarschoolhouse.org/introducing-teaching-solar/)

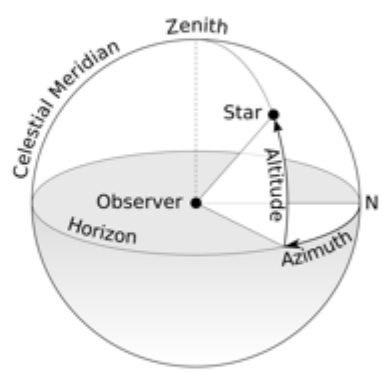


Figure 3. Position of the Sun

Lesson sequence

(5 minutes) ~ When beginning a new sequence of learning, it is important to start with finding out what students know about

sun and shadows. Ask students which direction you would need to face to feel the sun on your face, does the sun change locations throughout the day (this is a strong misconception as it is the earth that is moving, not the sun), and how would this affect the use of solar cells. Having already completed the recommended lesson listed under Student Background on solar cells from Solar4Schools.org, students will have an understanding of how **photovoltaic** cells work.

(10 minutes) ~ Then introduce students to the idea of **altitude** and **Azimuth** using a diagram that demonstrates how both help us to determine the position of the sun (see Figure 3).

(5 - 10 minutes) ~ Use the **Azimuth** Finder to demonstrate how to position it using a compass to find **true north.** The compass should be placed on the base of the **Azimuth** Finder to help students understand how to move the base until it is positioned correctly.

Using a flashlight, demonstrate how to move the bamboo skewer until the shadow is a perfect circle. Explain that this tells us where the **Azimuth** is. While finding the **altitude** would be helpful, the **Azimuth** will assist students in initially deciding where to place the solar cell for this investigation.

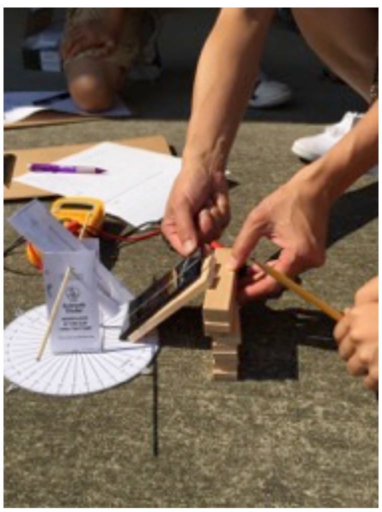


Figure 4. Using the Azimuth Finder and Keva planks

Allow students time (approximately 5 minutes) to play with the **Azimuth** Finder and the flashlight in groups of two. You may want to turn the lights off for this activity. Then have students gather and report what they noticed as they were using the flashlight at different **angles**. While this will help students when you move the lesson outside, it is also optional in the course of this lesson. Please refer to Teaching Solar for detailed directions on how to use the Azimuth Finder.

(5 minutes) ~ Hand out the lesson 1 worksheet ("Lesson 1: Investigating Orientation, Voltage, and Current") or begin work in the journals. Begin with the guiding question, "Which **angle** will **optimize** the **voltage** produced by a solar cell?" Allow students time to discuss this in a Think-Pair-Share. Then have students record their hypothesis.

(10 minutes) ~ Demonstrate in a whole group how to use a **multimeter**. Explain that they will measure the **current** across a circuit that is generated from the **energy source. (Note:** if you decide to measure voltage only, make sure to modify your terminology and worksheet!) If recording voltage, demonstrate the process using a battery (don't measure the short circuit current of a battery!), and then explain the procedure the students will follow today and the data that will need to be collected. (If you have enough batteries, allow students time to try measuring the voltage from a battery with the multimeter.) Clearly demonstrate how to lay the solar cell on two Keva planks as this will become the ramp that will lift the solar cell to different angles. Also show students how to lift the ramp up by sliding another Keva plank under the ramp to raise it. Then use the protractor to measure the top **angle**, and the ground **angle** **(**please see Figure 3**)**.

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(20 - 30 minutes) ~ Allow students time to carry out the investigation, using the worksheet to guide the process. Troubleshoot with students as necessary.

(10 minutes) ~ When students have compiled their data, have them write a conclusion that relates to the question using Claim-Evidence-Reasoning to help structure the responses. If you wanted to do this as a whole class, you could create a line plot to display data and look for inconsistencies, or other data that arises. Both the conclusions and the line plot could be used as assessment for this lesson. Discuss any problems that occurred with the mechanics of using a multimeter. Prepare students for thinking about how they can build a simple circuit in the next lesson.

At the end of the class time, ask students to share conclusions and generate questions that would still need to be explored. For example, students may wonder if the **angle** is different in the winter than in the summer. This would allow students to repeat the process independently at other times during the year and consider ways to make solar cells more efficient for homeowners.

Assessment

Rubric used for scoring Claim-Evidence-Reasoning

	2	1	0
CLAIM	Makes a complete and accurate claim that answers the guiding question to the investigation.	Makes a claim that is partially incomplete or contains slight misconceptions.	Does not make a claim.
EVIDENCE	Provides two or more accurate sources of evidence, using labels when necessary, and addresses variables.	Provides one or two sources of evidence.	Does not provide evidence or only provides evidence that does not support the claim.
REASONING	Demonstrates comparative data that connects to and supports the claim. Uses scientific vocabulary and principles.	Evidence is not comparative although it supports or connects to the claim. Some scientific vocabulary and principles are used, but there may be some misconceptions.	Does not connect or use evidence to support the claim.

Lesson Extensions

- Tracking the sun - using a transparent dome, track the azimuth of the sun at different times during the day and year (see “Earth’s Path Around the Sun” by Jamie Repasky in Solar 4R Schools Educator Library http://www.solar4rschools.org/teach/teacher-activity-center).
- See lesson “How Tilt Affects Solar Cell Output (PV Output Lesson 3” by Todd Freiboth. This can be used if the sun is not out. “How Light Intensity Affects Solar Cell Output (PV Output Lesson 2)” that may be useful if you want to delve deeper. These lessons can be found in the Solar 4R Schools Educator Library http://www.solar4rschools.org/teach/teacher-activity-center.
- Using UV sensitive beads (available from Steve Spangler Science), carry out various experiments to understand the power of the sun. See “Introducing Solar Energy Lesson 1: Hypothesizing Why Solar Beads Change Color” by Leah Gorman on Solar 4R Schools’ Educator Library http://www.solar4rschools.org/teach/teacher-activity-center.
- Make a classroom quilt with UV sensitive paper. Gather various objects that are special to students and have them arrange them on the paper. Arrange papers together into a “quilt” and have students guess the items brought in by classmates for their part of the quilt.
- Try making a surface that would reflect solar energy towards the solar cells. Lining a board with aluminum foil and focusing the angle to reflect on the solar cell or creating a wide funnel are some ideas to try.

Lesson 2: Part 1 Solar Circuits

AUTHOR: Bev Satterwhite

DESCRIPTION: This lesson is designed for students to learn about circuitry and how solar cells compare to batteries. Part 1 Solar Circuits is the first of three activities in this lesson. Now that students have an idea of how to position the cells to get the optimal current and/or voltage, they will begin the day with an idea of how to connect the solar cells to another voltage source or a load. Having both batteries and solar cells as part of this lesson will help to strengthen the idea of energy transfer and the similarities/differences between energy sources. Once students have mastered the simple circuit with a switch, they will be prepared for part 2 of this lesson when they learn about wiring series circuit and parallel circuits.

GRADE LEVEL(S): 4, 5, 6

SUBJECT AREA(S): Electricity Fundamentals, Circuitry, Solar Energy, Energy Transformations, Energy Storage, Photovoltaics

ACTIVITY LENGTH: 1 day, approximately 60 minutes

LEARNING GOAL(S):
1. Students will learn how to build a circuit that will light a light bulb with a switch and without a switch.
2. Students will understand that the electricity flows through a circuit from an energy source to a load.
3. Students will understand the difference between open and closed circuits.
4. Students will understand the similarities and differences between solar cells and batteries as an energy source.

NEXT GENERATION SCIENCE STANDARDS:

- 4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
- 4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Materials List

- AA batteries, preferably rechargeable for use later (2 per group)
- AA battery holder (1 per group) (optional)
- Alligator test leads (4 per group), or insulated copper wire (4 strands)
- 3 mm LED lights (2 per group)

- Grain of wheat bulbs (2 per group)
- Kidwind sound and light board (1 per group) available at vernier.com
- Simple switch (1 per group)
- 2 V, 1.5 V, and .5 V solar cells (2 of each for each group)
- DC motor (1 per group)

Other Supplies

- Journals

Vocabulary

- energy
- electromagnetic energy
- light energy
- heat energy
- circuit
- energy source
- load
- switch
- current
- energy flow

Lesson Details

Planning and Prep

Prepare materials for easy distribution ahead of time. Copy the worksheet "Lesson 2: Solar Cell Circuits" for each student. This is an inquiry lesson for students to apply background knowledge of circuitry to the usage of different **sources**, **loads**, and a **switch**. (A foldable could be used in place of the worksheet based on the compare/contrast foldable by Dinah Zike.)

Student Background

Students participating in this lesson should be familiar with the following:

- How to find the azimuth from **Mini Solar Houses Lesson 1: Investigating Orientation, Voltage, and Current**
- Basic understanding of electricity
- Basic understanding of why materials repel and attract as relating to electricity, charge, and magnetism

Educator Background

Educators leading this lesson should be familiar with the following:

- The components of a simple **circuit** and how a photovoltaic system works.
- How the current flows in a simple **circuit** with a battery and with a solar cell.
- "Introducing Solar Energy" lessons 1-5 by Leah Gorman in the Solar 4R Schools Educator Library http://www.solar4rschools.org/teach/teacher-activity-center. There are specific lessons on simple, series and parallel circuits that compliment the outcome of this lesson.
- How to diagram a simple **circuit** (see Figure 5 below)

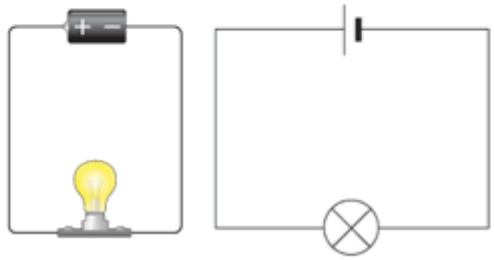

Figure 5. Diagramming a simple circuit.

Lesson Sequence

(5 minutes) ~ Begin with the guiding question, “How can I light a light bulb?” This is an inquiry style lesson with opportunities for students to get comfortable with **circuits** and to strengthen their understanding of the flow of **energy**.

(5 minutes) ~ Give each group of student one battery, 2 alligator test leads, and 1 light.

(5 minutes) ~ Once students have successfully lit their bulbs, demonstrate how to draw a simple circuit, taking time to discuss the difference between positive and negative sides of a battery. Students share their thinking about how the simple **circuit** works. It may be helpful for students to lay paper underneath their circuit and explain, with illustrations, what is taking place along the pathway their circuit creates.

(10 minutes) ~ Allow further time for exploration with the various items listed in the materials to see if all items will work. While each group can use two batteries, encourage students to work first with one battery. It is likely that the LEDs will not light, so you may want to save these for the end of the lesson in order to gather critical thinking questions for exploration in the next lesson about series and parallel circuits. Waiting until later in the lesson to give students battery holders would also allow students to problem solve and ask questions.

(20 minutes) ~ After students become comfortable with the battery, review how to find the azimuth and then move outside to continue exploring **circuits** with solar cells. Use the guiding question, “How are batteries and solar cells similar and different?” to help students understand that this is more than exploration time and the goal is not only to complete various **circuits** but also to prepare them to think about various **energy sources**. Have students start with the sound and light board as it will allow students to notice how the song speeds up in direct rays, and slow down as it is covered in shadow. Encourage students to change the angle of the solar cell and note the differences. After they have been successful with that, move to the motor, and end with the LED. Encourage students to add the switch in the circuit, and ensure that students are not trying to put the batteries and solar modules together in the circuit. This will help them as they plan how to power different loads in their mini-houses in upcoming lessons.

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(5 minutes) ~ In your debrief of the day's learning, pose the question, "How are the battery and solar cells alike and different?" Spend time discussing how shadows and direct rays affected the sound and light board, and review the importance positioning the solar cell at the correct angle and orientation to the sun.

(10 minutes) At the end of the lesson, students fill out a Venn diagram comparing batteries and solar cells using the worksheet "Lesson 2 Compare/Contrast" or by using a foldable. Gather questions students may have or what they have noticed about circuits and add this to a classroom anchor chart to guide learning in future lessons. This will be a starting point for the next lesson in the sequence.

Lesson 2: Part 2 Solar Circuits

AUTHOR: Bev Satterwhite

DESCRIPTION: This lesson is the second of three days learning about circuitry and how solar cells compare to batteries. Students will have experienced a simple circuit with a switch, and now they will learn about wiring series circuits and parallel circuits. This will prepare them to identify potential problems for the upcoming design challenge when they create a mini-house that will power both a light and a fan.

GRADE LEVEL(S): 4, 5, 6

SUBJECT AREA(S): Electricity Fundamentals, Circuits, Photovoltaics

ACTIVITY LENGTH: 1 day, approximately 60 minutes

LEARNING GOAL(S):
1. Students will understand how electricity flows through a circuit (from energy sources to loads) with more than one source and more than one load.
2. Students will understand how to build series and parallel circuit and the characteristics of each.
3. Students will learn to power both a light and a fan.

NEXT GENERATION SCIENCE STANDARDS:
- 4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
- 4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Materials List

- alligator test leads (8 per group), or insulated copper wire (4 strands)

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- 3 mm LED lights (2 per group)
- grain of wheat bulbs (2 per group)
- solar music module (1 per group) available at solarschoolhouse.org or Vernier Sound and Light Board (vernier.com)
- DC motor (1 per group)
- simple switch (1 per group), optional
- 2 V, 1.5 V, and .5 V solar cells (2 of each for each group)

Other Supplies

- Journals

Vocabulary

- light energy
- heat energy
- energy source
- load
- current
- parallel circuits
- series circuits
- energy transfer
- voltage

Lesson Details

Planning and Prep

Having worked with all materials in the lesson before this one, most preparation is already complete. Add 4 more test leads to each group's set of materials. Copy a class set of student worksheet "Lesson 2: Part 2 Simple Solar Circuits."

Student Background

Students participating in this lesson should be familiar with the following:

- energy flow in a circuit
- components of a simple circuit
- voltage (from Lesson 1: Investigating Orientation, Voltage, and Current)

Educator Background

Educators leading this lesson should be familiar with the following:

- How a simple circuit can have more than one source and/or more than one load
- How to wire series, parallel and series-parallel circuits. (Please see Figure 5 and Figure 6).
- "Introducing Solar Energy" lessons by Leah Gorman in the Solar 4R Schools Educator Library http://www.solar4rschools.org/teach/teacher-activity-center. There are specific lessons on simple, series and parallel circuits that compliment the outcome of this lesson.

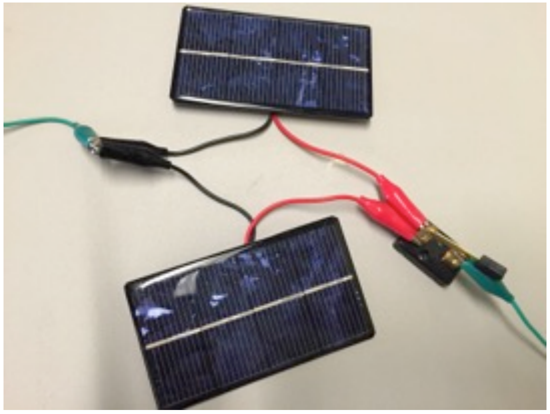

Figure 6. Solar parallel circuit

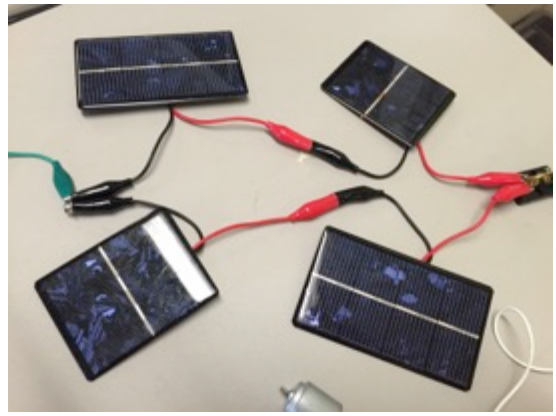

Figure 7. Solar series-parallel circuit

Lesson Sequence

(5 minutes) ~ Introduce today's inquiry question. "How can we power two items with solar modules?" Based on experiences from the lesson prior to this, students may have an idea of things they tried the day before that they can offer to the group to consider. The students may also have struggled to light the LED, as it requires a higher voltage than the sound setting on the sound and light board. Keep in mind different colors and types of LEDs will have different voltage requirements. Be sure to look up those of each (they should be in the 1.8-3.8 V range). Red LEDs generally have the lowest voltage requirements and are therefore generally the easiest to get to work. Today the goal is to have each group light an LED and a motor in the same circuit in preparation for designing the mini-house in the design challenge.

(5 minutes) ~ Review how solar cells and batteries are similar/different, allowing students to explain how they function similarly in a circuit. Refer to the circuit diagram shared with the class yesterday and draw predictions students share.

(20 minutes) ~ Then have students work through the inquiry process with the worksheet "Part 2: Simple Solar Circuits." (This can also be done in students' journals.) It will be important to allow students extended outdoor time to explore and problem solve. Meet with students to check for misconceptions and struggles, keeping an observational checklist based on the one found in the assessment section.

(10 minutes) ~ Once most groups have identified a **series circuit**, pull students together to demonstrate and diagram the different ways the students found that worked. Point out that the problem with a series circuit is that when one component isn't working, the single pathway in the circuit is broken and no longer connected. Introduce parallel circuits. Connecting the solar modules can be challenging in a parallel circuit, and I have included pictures to help you. It is important to attach the solar modules to the load, switch or other pathway "parallel" to each other, with the colors (polarity) matching (see Figure 6).

(10 minutes) ~ Ask students to consider using a parallel circuit as they continue exploring. It is critical to have them verbally explain that a series circuit will power their LED, and a parallel circuit most likely will not. Guide students through scientific discourse and which will push them towards creating parallel-series circuits to have the necessary voltage for the LED. It is likely that students will need the circuit shown Figure 7 to power both the LED and fan.

(10 minutes) ~ At the end of the lesson, diagram the different **parallel circuits** students found. Explain the difference between a **parallel circuit** and a **series circuit**. Have students point to evidence that exemplifies these differences, e.g. "different loads could only be powered with a certain type of circuit, meaning ________ requires more voltage/current." Clearly demonstrate the ways that both the LED and fan were powered. Students then write a conclusion in their journals using the Claim-Evidence-Reasoning format.

Assessment

The conclusion can be graded using the Claim-Evidence-Reasoning Rubric from the Lesson 1: Investigating Orientation, Voltage, and Current.

The observational checklist below will also help you plan for small groups or mini-lessons that may be needed before the design challenge.

Names of Students	Circuit with a switch and without a switch	Completes series circuit	Completes a parallel circuit	Powers LED and fan

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Lesson 2: Part 3 Solar Circuits

AUTHOR: Bev Satterwhite

DESCRIPTION: This lesson is part 3 of three days spent learning about circuitry and how solar cells compare to batteries. One of the struggles students will have is guarding against shorts in the system and other complications disabling their components. It is imperative that students learn how to find which component is creating a fault. There are several key places to guard against, including where the solar modules connect to the alligator lead and to the switch. Students will also need to know how to test each component for conductivity. This lesson is primarily demonstration before students work in teams to find the fault in a circuit.

GRADE LEVEL(S): 4, 5, 6

SUBJECT AREA(S): Electricity and Circuitry, Solar Energy

ACTIVITY LENGTH: 1 day, approximately 60 minutes

LEARNING GOAL(S):
1. Students will learn how to find a fault in a circuit.
2. Students will understand that the electricity flows through a circuit from an energy source to a load.
3. Students will understand the difference between open and closed circuits.
4. Students will identify the causes and solutions to various complications that arise in the construction of circuits.

NEXT GENERATION SCIENCE STANDARDS:
- 4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
- 4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Materials List
- alligator test leads (4 per group), or insulated copper wire (4 strands)
- 3 mm LED lights (2 per group)
- incandescent Grain of wheat (or other small) bulbs (1-3 V rating) (2 per group)
- Kidwind sound and light board (1 per group) available at vernier.com
- simple switch (1 per group)
- 2 V, 1.5 V, and .5 V solar cells (2 of each for each group)
- DC Motor (1 per group)

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- 250-500 Watt shop light (note: some of the new LED shop lights will not work because they do not provide enough light)

Other Supplies

- Journals

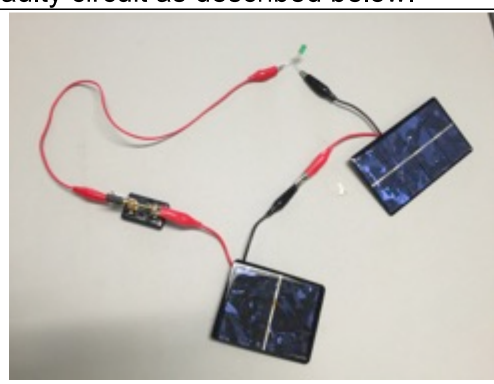
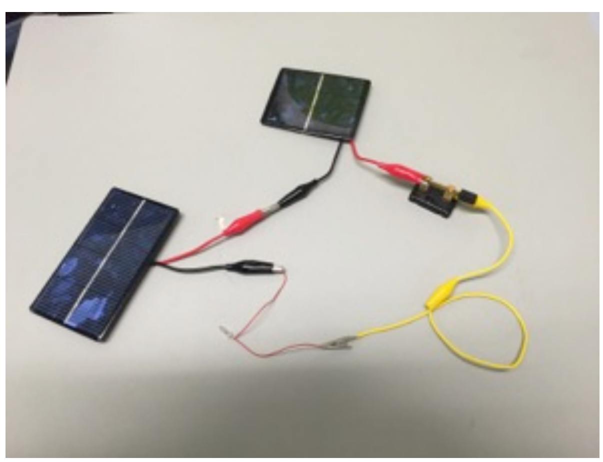
Vocabulary

- energy
- light energy
- heat energy
- circuit
- energy source
- load
- switch
- current
- energy flow
- short
- component

Lesson Details

Planning and Prep

Set up 6 stations, each with a faulty circuit as described below.

Station 1: the LED is placed in the wrong direction (in these circuits, current flows in one direction. LEDs are diodes, which means they have a polarity and current can only flow in one direction)	
Station 2: an alligator lead is damaged (the chomper clip is dislodged and isn't always contacting the wire)	

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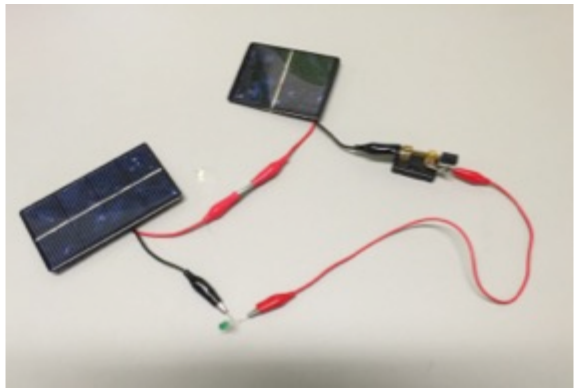
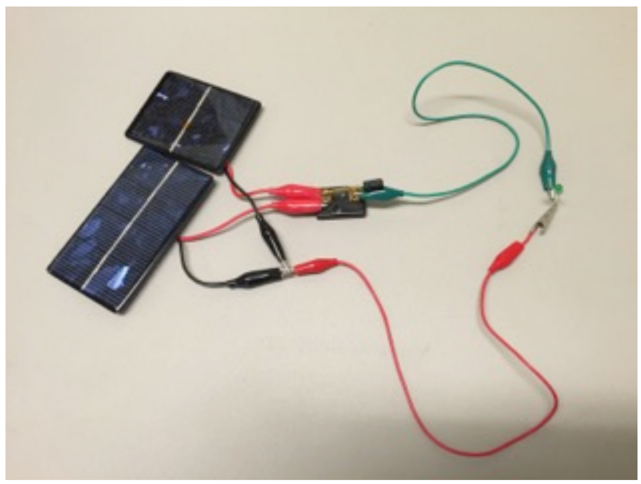
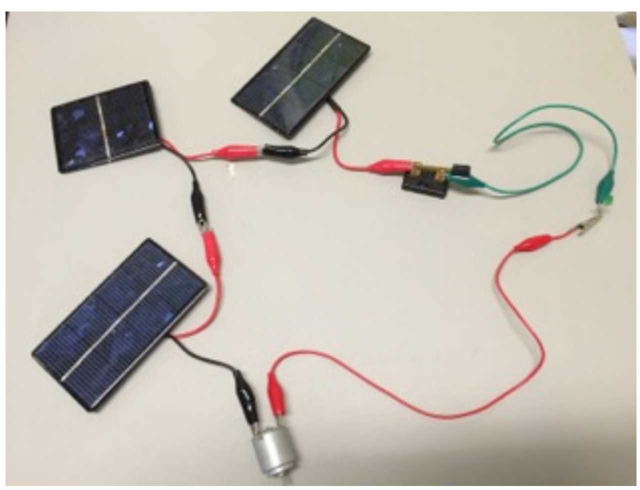
Station 3: the positive ends of the solar modules are touching	
Station 4: the voltage requirements of the LED were not met (note: "fixing" this circuit and understanding why it isn't working are two separate tasks – if students know the voltage requirements of the LED and then measure the voltage across the LED in this circuit they may realize the true problem)	
Station 5: the motor is running the LED is not (LED leads are touching)	

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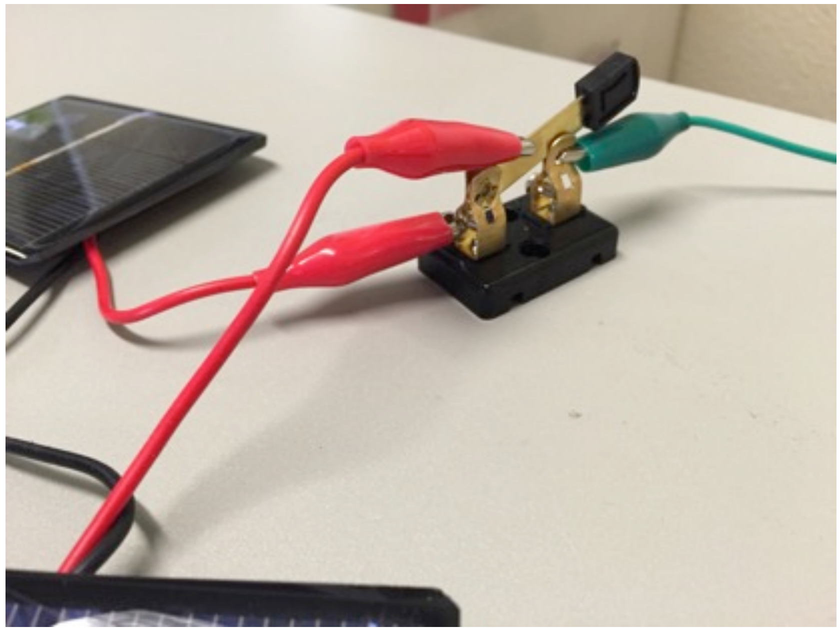
Station 6: the attachments to the switch are placed incorrectly (the bottom lead is not fully attached)	

Setting up these stations will save time as you begin the design challenge. It will also create student expert groups that can step in when you are busy troubleshooting with different groups.

Student Background

Students participating in this lesson should be familiar with the following:

- How to find the azimuth from **Mini Solar Houses Lesson 1: Investigating Orientation and Voltag**e
- Basic understanding of electricity
- Basic understanding of repel and attract as it relates to electricity and magnetism
- Part 1 and Part 2 of Solar Circuits

Educator Background

Educators leading this lesson should be familiar with the following:

- The components of a simple **circuit** and how a photovoltaic system works.
- How the current flows in a simple **circuit** with a battery and with a solar cell.
- “Introducing Solar Energy” lessons by Leah Gorman in the Solar 4R Schools Educator Library http://www.solar4rschools.org/teach/teacher-activity-center. There are specific lessons on simple, series and parallel circuits that compliment the outcome of this lesson.
- How to test each component of a circuit - use a simple circuit with a solar module, sound and light board and an alligator lead. You may need to use a 3 V coin battery to test an LED.

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Lesson Sequence

(5 minutes) ~ Begin with the guiding question, “How can I find a fault in a circuit?” Explain to students that when a circuit has a fault, the energy cannot continue to flow through the system. In other words, there is an open circuit without a switch.

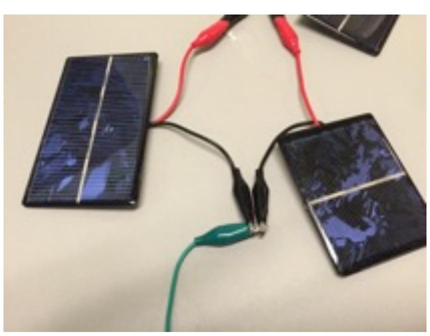
(10 minutes) ~ Review how to complete a simple circuit using a solar module and a Vernier sound and light board. Doing this in the classroom with a shop lamp may make this process easier. Explain to students that the fewer the components, the easier it is to find the fault in a system. Using a coin battery and an LED at this time would be appropriate. Show how you can put an LED around a 3 V coin battery to determine negative and positive poles. Then flip the LED to demonstrate how it won’t light. Point out the importance of connecting positive to negative to positive to negative in a series for your solar modules (“voltage sources”).

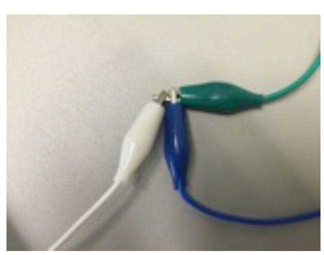
(10 minutes) - Demonstrate how to add one component to the circuit - an alligator lead (Teacher tip: The alligator leads were the cause of a short circuit in several students’ work during this challenge). If the LED continues to light, you know the alligator lead is working. Continue with this process, adding in a component at a time until you have a series circuit with two modules, a switch and an LED. This demonstrates to students how to start from the beginning or deconstruct their connections when troubleshooting a circuit.

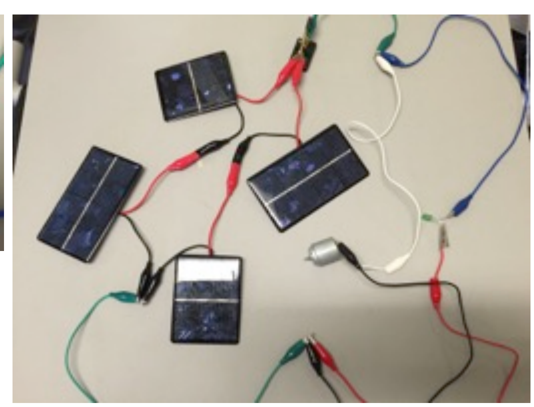
(5 minutes) - Explain to students how they will be split into groups to find a fault in a circuit. Hand out the worksheet “Lesson 3: Part 3 Solar Circuits” that guides them through the process of determining the fault in a circuit. The goal is for students to explain where the fault was found and how to fix it. Show students the different stations and explain that each one has a different issue and it is their job to fix it. Send students off to each station to work.

(20 minutes) - Student work time. Encourage students to add diagrams to their Claim-Evidence-Reasoning in order to clearly demonstrate where the fault occurred and troubleshooting procedures. This will help prevent you from checking all circuits when students begin building their houses. As students work, ask them to choose one person to represent their group and share their findings.

(10 minutes) - Share what each group found. Stress the following: make sure negative attaches to positive, test the component to make sure it is working in a simple circuit, add solar modules as needed to get the right amount of voltage for the circuit, and make sure the attachments to create a parallel circuit are parallel when they grip the alligator lead and not touching. Debrief the class by telling them they will need to use these skills as we face a design challenge.







Lesson 4 - Designing The Walls for the Mini-House

AUTHOR: Bev Satterwhite

DESCRIPTION: This is a design challenge for students to work through. In previous lessons, students will have found that two 2 V in a combination of series and parallel connections with two 1.5V solar modules were needed in order to light the LED and the solar motor. Based on this idea, students will need to design a roof and walls that would ultimately hold the solar cells and yet allow the house to fit on an 9" X 12" sheet of paper. This lesson has a strong mathematical connection and will need several days for the design process. The possibilities are endless and the outcomes will be a result of innovation.

GRADE LEVEL(S): 4, 5, 6

SUBJECT AREA(S): Solar Energy, mini-houses, design challenge, Electricity and Circuits, Solar Home Design, Photovoltaics, Photovoltaic Installation

ACTIVITY LENGTH: several days

LEARNING GOAL(S):

1. Students will use the design process to create a roof to hold an adequate number of solar modules to power an LED and a fan.
2. Students will understand how to make a geometric net (a 2D drawing that when folded creates a 3D shape) for designing a roof.

NEXT GENERATION SCIENCE STANDARDS:

- 4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
- 4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.
- 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

COMMON CORE STATE STANDARDS:

- CCSS.MATH.CONTENT.4.MD.A.3 Apply the area and perimeter formulas for rectangles in real world and mathematical problems.
- CCSS.MATH.CONTENT.4.MD.C.5 Recognize angles as geometric shapes that are formed wherever two rays share a common endpoint, and understand concepts of angle measurement.
- CCSS.MATH.CONTENT.4.MD.C.6 Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

***Area, perimeter, and volume standards can also be added into this design challenge, depending on your overall goals.

Materials List

Students need access to many different supplies for this design challenge including:

- different types of paper: cardboard, foam poster board, poster board, tag board, cardstock
- different types of tape: duct tape, packing tape, masking tape, electrical tape, etc.
- leads (8 per group), or insulated copper wire (4 strands)
- 3 mm LED lights (2 per group)
- grain of wheat bulbs (2 per group)
- DC motor (1 per group)
- simple switch (1 per group)
- 2 V, 1.5 V and .5 V solar cells available for student use
- protractors

Other Supplies

- rulers
- scissors (if you have an adult who can supervise use of Exacto knives, this may be helpful)
- hot glue gun (again with supervision)
- graph paper (1 cm, 1 inch)

Vocabulary

Students apply academic vocabulary found in previous lesson sections above.

Lesson Details

Planning and Prep

Make copies of the worksheet "Lesson 3: Solar Mini-House Design Challenge." Use this opportunity to consider the different ways students may choose to wire the solar modules, and try practice the proper way to attach the solar modules to the alligator leads. As students work through the design process, they will need to troubleshoot ideas like making the roof sturdy enough to hold multiple solar modules, or creating walls with the right angle to optimize voltage. Try making a house yourself before this lesson, as it will be key to understanding students' diagrams and ideas. Also, consider the direction that you want your solar modules oriented and how that affects your roof design (and stability!). A shed roof concept would be the best idea for this project as shown below. That way, the walls incorporate the angles and will make it easier for the students to achieve the right angle. Research tiny houses, floor plans, and houses with solar arrays. Compile images that will work best for your students.

Student Background

Students participating in this lesson should be familiar with the following:

- How to determine angle of the roof
- How to measure area and perimeter
- How to wire the circuit to light an LED and a fan
- Engineering design process

Educator Background

Educators leading this lesson should be familiar with the following:

- Engineering design process
  (Engineering is Elementary provides excellent resources for examples of this in action. http://www.eie.org/overview/engineering-design-process)
- Charging a battery with solar cells
- Wiring a circuit with batteries and solar cells
- Troubleshooting solar circuitry

Lesson sequence

(10 minutes) ~ Introduce the design challenge to students with the worksheet "Mini Solar House Design Challenge." Begin taking the students through the design process by first asking students what they know based on the challenge. Use the Think-Pair-Share tool to have students come up with as many questions as they can about the design process for their home. Keep track of the questions so that they can be answered as students work to explore the materials list and their plans. One method could involve writing all of the questions on the board or typing them up for a poster so that they can be answered by those who wrote them as they are designing/building their homes and show their solutions visibly. Remind students that the end result will be presented to the class and that students need to keep track of the steps they took. Share the rubric from the assessment section with students.

(10 minutes) ~ Prepare students by showing pictures of various houses with solar panels. As you show the students the pictures, ask them to search for 2D shapes that were used in creating the roofs. While rectangles will be easy to spot, pointing out triangles or right trapezoids will be important in the design process. Direct students back to the Engineering Design Process,

which should be visible on the board or wall, where they can imagine a solution as they look at existing structures with solar cells.

(The remainder of this lesson will take place over several days) ~ Once students are in groups - groups of 3 would be best - give students graph paper and ask them to create a plan for their roofs. In their diagrams, students should include angle measurements (referencing their findings from earlier in the unit), length, width, and height of the walls and roof. Students should include a written paragraph describing materials to make the roof and walls as well as how to stabilize the solar cells. This would be best added to science journals and then later used in their presentations.

Students then move to the creation phase. At this point, teaching students how to make a pattern for the roof may be necessary depending on your group of students.

Allow students plenty of time to create their ideas and use materials that meet the constraints and criteria of the design challenge. When students make changes to their plans, they need to stop and add this to their journals so that they can see the design process in action.

Once the roof is designed, students can then go on to creating the walls for their houses and deciding the layout within the house. The walls should be a right trapezoid and would be created adding a triangle with the measurements from the first investigation to a rectangle to achieve the proper height for a tiny house. All measurements should be done to scale where 1 cm is equal to 1 foot. As students work on the layout, they need to sketch where the LED and fan will be placed, as well as the switch. The ceiling would be the best place for this. You may want to encourage students to make the interior separate from the outside walls so that the roof of the house and/or walls can be lifted off for the purpose of circuitry. (See the picture on the right to understand how the interior is separate from the exterior.)

The end to this design challenge would lend itself to strong discussions about what happens at different times throughout the year. Will the angle of the roof still be correct? What kind of problem solving is needed to design a roof that will work throughout the year? Which direction will the cells need to face? The questioning format could lead to several extensions.

Take time to set up the complete village and have students present their finished models and designs. See the rubric included below, which could be used with various engineering challenges.

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Assessment

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Brainstorm	Students use prior knowledge and lesson content knowledge to brainstorm a clear, focused solution to the problem. Idea is aligned to design challenge.	Students brainstorm a clear, focused solution to the problem that is aligned to the design challenge.	There is no evidence of brainstorming.
Design/Plan	Students propose and design a solution that aligns with the criteria, constraints, and intent of the problem. Design sketch is complete and includes labels, measurements and a paragraph to explain idea.	Students proposes and designs a solution that shows some alignment with the criteria and/or constraints and/or intent of the problem. Design sketch is detailed but may be missing labels and/or measurements and/or paragraph.	Student has a solution to the design problem, but may not be aligned to the criteria, constraints and intent of the problem. Sketch may be missing or lacks labels, measurements and paragraph.
Model	Students build a working model that aligns with the criteria, constraints, and intent of the problem.	Students built a working model.	Students building is incomplete.
Redesign	Students demonstrate revisions based on knowledge, research and problems that arise. Detailed and accurate notes of changes are kept and diagramed. Notes utilize data to support changes made.	Students demonstrated revisions. Some notes were kept but may be incomplete.	There is no evidence of revisions.
Presentation	Students present a summary of results to the class. The students are prepared, knowledgeable and communicate clearly the design plans and revisions. Students explain how the design solves the original problem.	Students present a summary of results to class but was not fully prepared and may not have communicated their ideas clearly, or did not have a clear explanation of how the design met the criteria.	Students may have made a presentation that was incomplete and were not prepared.
Teamwork	Students work together in a safe, respectful, kind and responsible manner. Evidence of each student's contributions is clearly shown.	Students worked together in a safe, respectful, kind and responsible manner. There is not evidence of each student's contribution.	Students did not work well together and there is not evidence of each student's contribution.

Lesson Extensions

This unit can be integrated with another unit where social studies and math are addressed.

Social Studies Integration - Based on "Democracy in Action" by Margit E. McGuire, Ph.D: Create a critical incident for the community you have built within your classroom (http://www.teachinteract.com/c/storypath.html). The incident could be that a member of the community planted a tree that would directly block his neighbor's solar cell. How should this problem be solved in a democracy? How do the rules in a community help us to make decisions and how would a community forum allow all voices to be heard? A second incident could occur when the weather remains cloudy for a long period of time. How could the community overcome this problem? How could you add a battery to the circuit or connecting the houses on a grid assist community members with overcoming this problem? Another solution might be to create a solar farm outside the community to charge the rechargeable batteries. You could grow the community, as well, to include businesses. The community options are limitless.

Math - Based on Mathscape's From the Ground Up: Modeling, Measuring, and Constructing Homes, determine the cost of adding walls to the structure. Based on current prices at the local hardware store, how much would the interior walls be to add into the houses? This would encourage students to find the area of the walls and then use multiplication with decimals to calculate the final cost.

World View – Even in the past couple years, solar energy has made incredible advancements in terms of costs, technology adaptability, and implementation policy across the globe. Currently we are seeing developing countries increase their demand for power in scenarios lacking in transmission infrastructure and in a world where global policy is making the move to shift away from fossil fuels (Learn more about the COP 21 here: http://www.cop21.gouv.fr/en/ and read the Agreement: http://unfccc.int/paris_agreement/items/9485.php). This provides them both an immense challenge as well as an opportunity of implementing thoughtful, progressive uses of long-term renewable energy resources.

There are currently many different uses of solar in single piece designs for applications in rural areas. These have long been directed as one-off solutions to people in villages across the world. For more background, here a few interesting examples below:

"Solar Powered Camels Carry Medicine Across the Desert" - http://inhabitat.com/solar-powered-camel-clinics-carry-medicine-across-the-desert/

"11 Ingenious Solar Projects Impacting the Developing World" - http://mashable.com/2014/01/13/solar-energy-developing-world/#7ro24Zb9mkqg

While these are interesting projects to engage your students in solar circuitry as solutions to real-world problems, these barely scratch the surface of the resource development complications facing people in these regions. It is important that a discussion of these types of solutions does not obscure the potential for applications with a much broader impact. Solar micro grids, or self-sufficient distributed generation systems used in rural areas, have the potential to create a scenario where developing countries could "leap frog" over building landline infrastructure for distribution entirely and build their energy infrastructure on a foundation of renewable resources (like mobile phones did for some parts of the world). Check out the links below for more information on micro grids:

“How Solar Based Microgrids Could Bring Power to Millions” - https://www.technologyreview.com/s/429529/how-solar-based-microgrids-could-bring-power-to-millions/

“Solar Microgrids in South Africa Electrify and Boost Economic Development” - http://www.renewableenergyworld.com/articles/2016/08/solar-microgrids-in-south-africa-electrify-boost-economic-development.html

Solar Electric Light Fund’s Projects - http://self.org/current-projects/

“How Microgrids Can Help Developing Nations Leapfrog the Landline” - https://www.greenbiz.com/blog/2013/08/01/how-microgrids-can-help-developing-nations-leapfrog-landline

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