Making Use of Models
Miniature Solar Panels

OVERVIEW

Using mini solar panels and multimeters, students model a variety of conditions that an operating PV system will face. They will experience the basic workings of a solar panel, explore the pros and cons of various circuitry connections, examine the effect of the earth's rotation on the panel output, and consider the effect of extreme temperatures on PV performance. In analyzing their findings, students will discuss the strengths and limitations of each model.

PRIOR KNOWLEDGE

Students will be most successful with this activity if they have some familiarity with simple circuits and have built series and parallel circuits. See *ElectroWorks* (published by the NEED project) as a possible resource. Although it is not necessary for students to have completed "Get to Know Your PV System" to be successful with this activity, those who have completed it will be able to apply their knowledge. Recommended, but not required.

TIME

1-2 45-minute class periods, depending on how many simulations you choose to do .

MATERIALS

Materials vary for each simulation. See specific listings in each simulation below.

PREPARATION

- Read over simulations and decide which ones to do.
- Note, each simulation puts more responsibility on the students than the previous ones. For example, the warm-up activity tells students exactly what to do, step-by-step. The later simulations have the students making more plans and decisions on their actions carrying out the activities.

- The following simulations are outlined:
  - Warm-Up Activity – Seeing the Mini-Solar Panels Work and Using a Multimeter
  - Simulation 1 – Exploring PV Array Circuitry
  - Simulation 2 – PV Tilt and Orientation
  - Simulation 3 – PV Performance and Extreme Temperatures
  - Simulation 4 – PV Performance and Cloud Conditions (student – designed)
- Get needed materials and make copies of student worksheets.

PROCEDURES

See teacher notes for each simulation.

NOTES

For any combinations of simulations, it is recommended that you close with a discussion of how and why scientific models are both useful and limited. At the end of the simulation descriptions are teacher notes for leading a discussion on modeling and sample “charts” of the strengths and limitations of each simulation in this activity.

Warm-Up Activity
Seeing the Mini-Solar Panels Work and Using a Multimeter

Materials - For each group of 2-3 students:

- 2 miniature solar panels
- 1 kit motor with a propeller or cardboard disk stuck on its shaft
- 1 digital multimeter (device that measures power)
- 1 pair of aligator clip wires
- light source – either a sunny day or a 100W incandescent light bulb
- 2 pieces of masking tape

Procedures

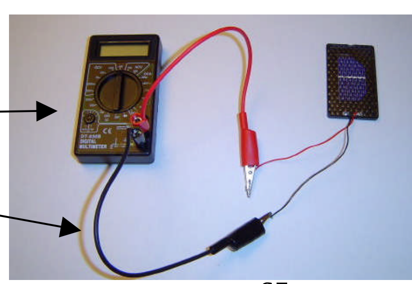
1. Use a small piece of masking tape to label your mini-panels #1 and #2. For each of the steps below, expose the panel to bright sunlight or a 100W light bulb when you are taking a measurement.

2. Test the panels - Using one panel at a time and the motor, see if you can connect the wires so that the motor turns when light shines on the panel. Draw a sketch below showing how you connected the wires. Label all parts (including the + and – terminals on the mini-panel).

Can you make the motor turn the opposite direction? How?

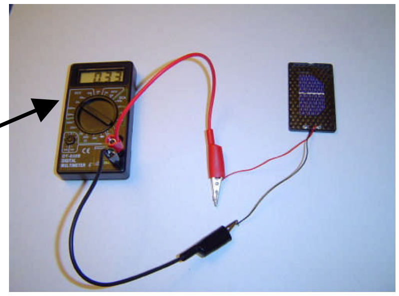
3. Using the Multimeter

   a. Disconnect the motor. Connect the multimeter to the wires of the solar panel. The negative terminal (black wire) should be connected to the black clip whose end goes into the hole marked "com." The positive terminal (red wire) should be connected to the red clip whose end goes in the hole marked "VAdcΩ." See the picture below.



b. Voltage Measurements – Twist the knob in the middle of the multimeter so it points to the number 20 in the DCV area (see the picture below). Now the meter is acting as a voltmeter. The number may fluctuate (change) a little, watch it for a few seconds and then record the voltage.

Knob set at 20 DCV



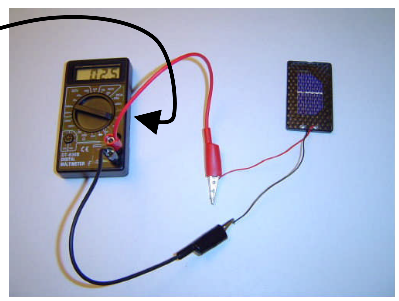
Voltage of Mini-panels under sun / 100 W bulb

Panel #1 ______ (V)

Panel #2 _______(V)

c. Current Measurements – Keeping the wires connected as for the voltage measurements, twist the knob so it points to the 200m in the DCA area. Now the meter is acting as an ammeter. The number in the display may fluctuate a little. Watch it for a few seconds and then record a value.

Knob set at 200m DCA



NOTE: Since these panels produce current in the range of milliamps, your answers will be in the range of milliAmps (or 1000ths of an Amp). To convert them to Amps, you will need to divide by 1000.

Current of Mini-panels under sun / 100 W bulb

Panel #1 _______ (mA) = _________ Amps (divide the mA by 1000)

Panel #2 _______ (mA) = _________Amps (divide the mA by 1000)

d. Power Calculations – To determine the amount of power produced by the mini-panel, use the relationship that voltage x current (amp) = power (watts).

Power Output of Mini-Panels

Panel # 1 ____________ x ___________ = _________ Watts
Volts Amps

Panel # 2 ____________ x ___________ = _________ Watts
Volts Amps

Congratulations! You have now completed testing your tools and your equipment!

Simulation 1 – Exploring PV Array Circuitry – STUDENT GUIDE

Note: You should review series and parallel circuits before doing this simulation. You should also discuss the meaning of the terms QUALITATIVE and QUANTITATIVE.

Materials - For each group of 2-3 students:

- 2 miniature solar panels
- 1 kit motor with a propeller or cardboard disk stuck on its shaft
- 1 digital multimeter
- light source – either a sunny day or a 100W incandescent light bulb
- 2 pieces of masking tape

Procedures

1. Use a small piece of masking tape to label your mini-panels #1 and #2. For each of the steps below, expose the panel to bright sunlight or a 100W light bulb when you are taking a measurement.

2. Using 2 miniature solar panels and the motor, compare the behavior of the motor for the panels connected in series and parallel. Draw a diagram of each circuit arrangment below.

SERIES	PARALLEL

Which configuration seems to produce more power in the motor? This is a QUALITATIVE observation.

3. Using the multimeter, compare the voltages, currents, and power productions for the panels wired in series and parallel. You are now collecting QUANTITATIVE data to correlate with your QUALITATIVE observation.

Data:

Distance from light source ___________________ (keep this constant for all measurements). Why? ____

Configuration	Voltage (V)	Current (mA)	Current (A) (divide mA by 1000)	Power (Watts)
Series				
Parallel				

Does your QUANTITATIVE data match up with your QUALITATIVE observations? If not, go back and repeat until they do.

Why is this important?

4. If power production were your only concern, which wiring arrangment would you recommend for modules in a PV array?

5. In a real-world situation, scientists and designers need to consider the effect on power production of a module being covered in shade or breaking down. Devise a way to simulate and test this possibility for each configuration – series and parallel.

Describe what you will do to simulate a shaded or malfunctioning module.

QUALITATIVE Observations:

Series configuration:

Parallel configuration:

QUANTITATVE Data:

Distance from light source ___________________

Configuration	Voltage (V)	Current (mA)	Current (A) (divide mA by 1000)	Power (Watts)
Series				
Parallel				

6. What wiring configuration would you recommend for a system that will tolerate some shaded or malfunctioning modules?

7. Most Ohio Solar Schools have a PV array composed of 20 modules. Determine its wiring configuration (you may need to check with your teacher). Do you have any hypotheses why it was wired this way?

Simulation 1 – Exploring PV Array Circuitry – TEACHER NOTES

Note: You should review series and parallel circuits before doing this simulation. You should also discuss the meaning of the terms QUALITATIVE and QUANTITATIVE.

Materials - For each group of 2-3 students:

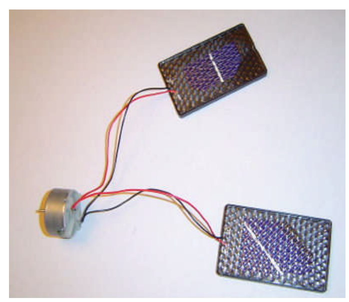
- 2 miniature solar panels
- 1 kit motor with a propeller or cardboard disk stuck on its shaft
- 1 digital multimeter
- light source – either a sunny day or a 100W incandescent light bulb
- 2 pieces of masking tape

Procedures

1. Use a small piece of masking tape to label your mini-panels #1 and #2. For each of the steps below, expose the panel to bright sunlight or a 100W light bulb when you are taking a measurement.

2. Using 2 miniature solar panels and the motor, compare the behavior of the motor for the panels connected in series and parallel. Draw a diagram of each circuit arrangment below.

series circuit



parallel circuit

Which configuration seems to produce more power in the motor? This is a QUALITATIVE observation.

Series should make the motor appear to spin faster.

3. Using the multimeter, compare the voltages, currents, and power productions for the panels wired in series and parallel. You are now collecting QUANTITATIVE data to correlate with your QUALITATIVE observation.

   Data: *These are sample values…fluctuations will occur and values will vary from panel to panel and under different light conditions (especially for the current). However, there should be a clear pattern of more power produced by the series circuit.*

   Distance from light source ___________________ (keep this constant for all measurements). Why? *So that comparisons between series and parallel are valid. This is a good opportunity to talk about control variables.*

Configuration	Voltage (V)	Current (mA)	Current (A) (divide mA by 1000)	Power (Watts)
Series	1	120	0.120	.120
Parallel	.5	100	0.1	.05

   Does your QUANTITATIVE data match up with your QUALITATIVE observations? If not, go back and repeat until they do.

   Why is this important?

   If they didn't match up, that might suggest one of the types of observations is flawed. It can be easy to get mixed up when taking a lot of numerical data, it's good to have a qualitative observation as a "reality check" to make sure the results make sense.

4. If power production were your only concern, which wiring arrangment (series or parallel) would you recommend for modules in a PV array? *Series*

5. In a real-world situation, scientists and designers need to consider the effect on power production of a module being covered in shade or breaking down. Devise a way to simulate and test this possibility for each configuration.

   Describe what you will do to simulate a shaded or malfunctioning module.

   Turn the mini-panel over or cover it with a dark piece of paper.

QUALITATIVE Observations:

Series configuration: *When one panel is covered, power production goes way down and may even stop.*

Parallel configuration: *When one panel is covered, power production doesn't seem to be affected as dramatically.*

QUANTITATIVE Data: *These are sample values taken with a 100W light bulb source at a distance of approximately 2.5 cm from the panels. Fluctuations will occur and values will vary from panel to panel and under different light conditions (especially for the current). However, students should observe a significant voltage and current drop for a covered panel in the series arrangement. There should be a negligible change in voltage and possibly a small drop in current for parallel.*

Distance from light source: 2.5 cm

Configuration	Voltage (V)	Current (mA)	Current (A) (divide mA by 1000)	Power (Watts)
Series – ideal conditions	1.0	120.	.120	.120
Series – non-ideal conditions	0.63	0.3	0.0003	0.00019
Parallel – ideal conditions	0.5	75	.075	0.0375
Parallel – non-ideal conditions	0.48	68	.068	0.0333

6. What wiring configuration (series or parallel) would you recommend for a system that will tolerate some shaded or malfunctioning modules? *Parallel circuits.*

7. Your PV array is composed of 20 modules. Determine its wiring configuration (you may need to check with your teacher). Do you have any hypotheses why it was wired this way?

   Most of the Ohio Solar Schools are wired one of two ways:
   - *2 sets of 10 modules in series. Then those 2 sets are in parallel*
   - *5 sets of 4 modules in series. Then those 5 sets are in parallel.*

   The various configurations take advantage of the benefits of both series and parallel circuits. The decisions on which way to wire them may have depended on types of inverters and other pieces of equipment in the system.

Simulation 2 – PV Array Tilt and Orientation – TEACHER NOTES

Materials

For each group of 2-3 students:

- 1 miniature solar panel
- 1 digital multimeter
- 1 pair of aligator clip wires
- Student worksheets

For whole class

- 100W (or higher) incandescent bulb on an easily moveable lamp-base (to represent the apparent movement of the sun across the sky)
- Signs to label North, South, East, and West sides of classroom

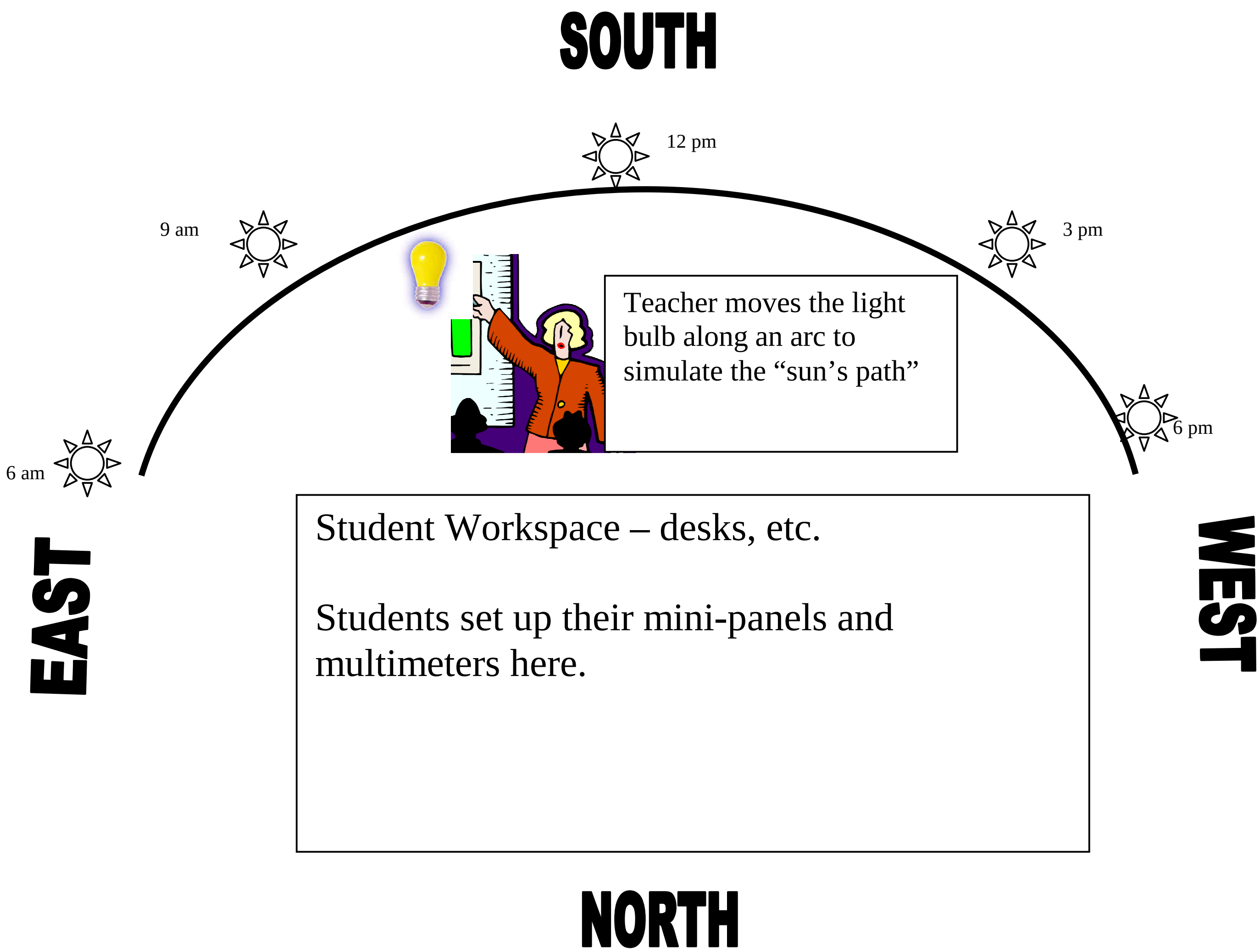
Procedures

In this simulation, students have 3 chances to determine how to design PV array placement so that it will produce the most power during the course of a day. Students work in groups of 2-3 and each group will use a mini-solar panel to represent the PV array. The sun will be represented by a 100W light bulb on an easily moveable lamp base with a long extension cord. To simulate the movement of the sun across the sky, the bulb is moved in a large arc from the east to the west side of the classroom.

As a class, you will determine which directions are North, South, East, and West in the classroom. *(Depending on the set-up of the class, you may wish to define a "North" that is different from actual north).* The "sun" will rise in the East and set in the West. Since Ohio is in the northern hemisphere, the sun moves in an East to West arc in the Southern portion of the sky *(if Ohio were on the Equator, the sun would move directly overhead).* The students set up their arrays at their workspace/desk. Each group decides their panel's placement including the direction (N,S, E, or W) it will face, and what angle/tilt it will make towards the sky.

Once all groups have made their initial set ups and have secured the panels at proper placements *(small pieces of cardboard and tape may be useful)*, turn off overhead lights and close shades to minimize effects from other light sources. Begin the simulation of a day by turning on the 100W bulb in the east as if it were the sun rising. Explain that students will take data (voltage and current measurements with the multimeter) at 5 times during the day: 6 am, 9 am, 12pm, 3 pm, and 6 pm. As you move the "sun" in an arc, stop at these "times" so students can record data. For a possible classroom set up, see the picture below.

After a single "day" has passed, pause for students to calculate power production. After discussion about what seemed to work and what did not *(e.g. facing a panel due east is good in the morning, but not so great in the afternoon. Panels should face south to maximize sunlight throughout the day).* Allow students time to set up another panel placement. Simulate a second "day," pause for students to compute power production, and open discussion. Students may hypothesize that panel system that tracks the sun's movement would be optimum. Allow time for students to set up a third panel arrangement, and simulate a third "day." Have students graph power production vs. time for each of the days on a single graph (see handouts). Ask students to draw some conclusions about panel placement and power production based on their graphs. *Hopefully, students will come to the conclusion that a system that faces south and tracks the sun's movement across the sky would allow for maximum power production*. Explain that some systems are designed to do so. Discuss possible pros (maximum direct exposure to sunlight) and cons (cost and need for maintenance. For this simulation, it is very important to discuss strengths and limitations of the model and emphasize that the sun does not actually move across the sky - the earth rotates so that the sun appears to move.*



* An activity exploring common misconceptions about the movement of the earth and sun can be found at http://www.wattsonschools.com/activities.htm under "Sun Misconcpetions" in the Lower Elementary Section. Note: the entire www.wattsonschools.com website has many excellent activities and lessons.

Simulation 2 – Observations and Data Sheet

Trial 1

Draw a sketch or diagram that indicates the panel placement. Show the direction it faces and the degree of the tilt, if appropriate. If it faces straight up to the sky, it has a tilt of 0°

Panel tilt in degrees:

Panel direction:

Data for Trial 1: We will measure voltage and current at different times of the "day" to determine the power production. Note: because the light levels may be low *(you will be farther from the bulb than in other simulations)* it may be necessary to use the 2000µ setting on the DCA section of the ammeter (µA is symbol for microamps). The number you calculate for power using the relation Power = Voltage x Current will be in millionths of a Watt, also know as microwatts, with the symbol µW.

Time of "Day"	Voltage (V)	Current (µA)	Power (µW)
6:00 am			
9:00 am			
12:00 pm			
3:00 pm			
6:00 pm			

When did you seem to get the most power?

How can you vary your panel placement to get more power for Trial 2?

Trial 2

Draw a sketch or diagram that indicates the panel placement for Trial 2. Show the direction it faces and the degree of the tilt, if appropriate.

Data for Trial 2:

Time of "Day"	Voltage (V)	Current (μA)	Power (μW)
6:00 am			
9:00 am			
12:00 pm			
3:00 pm			
6:00 pm			

When did you seem to get the most power?

How can you vary your panel placement to get more power for Trial 3?

Trial 3

Draw a sketch or diagram that indicates the panel placement for Trial 3. Show the direction it faces and the degree of the tilt, if appropriate.

Data for Trial 3:

Time of "Day"	Voltage (V)	Current (μA)	Power (μW)
6:00 am			
9:00 am			
12:00 pm			
3:00 pm			
6:00 pm			

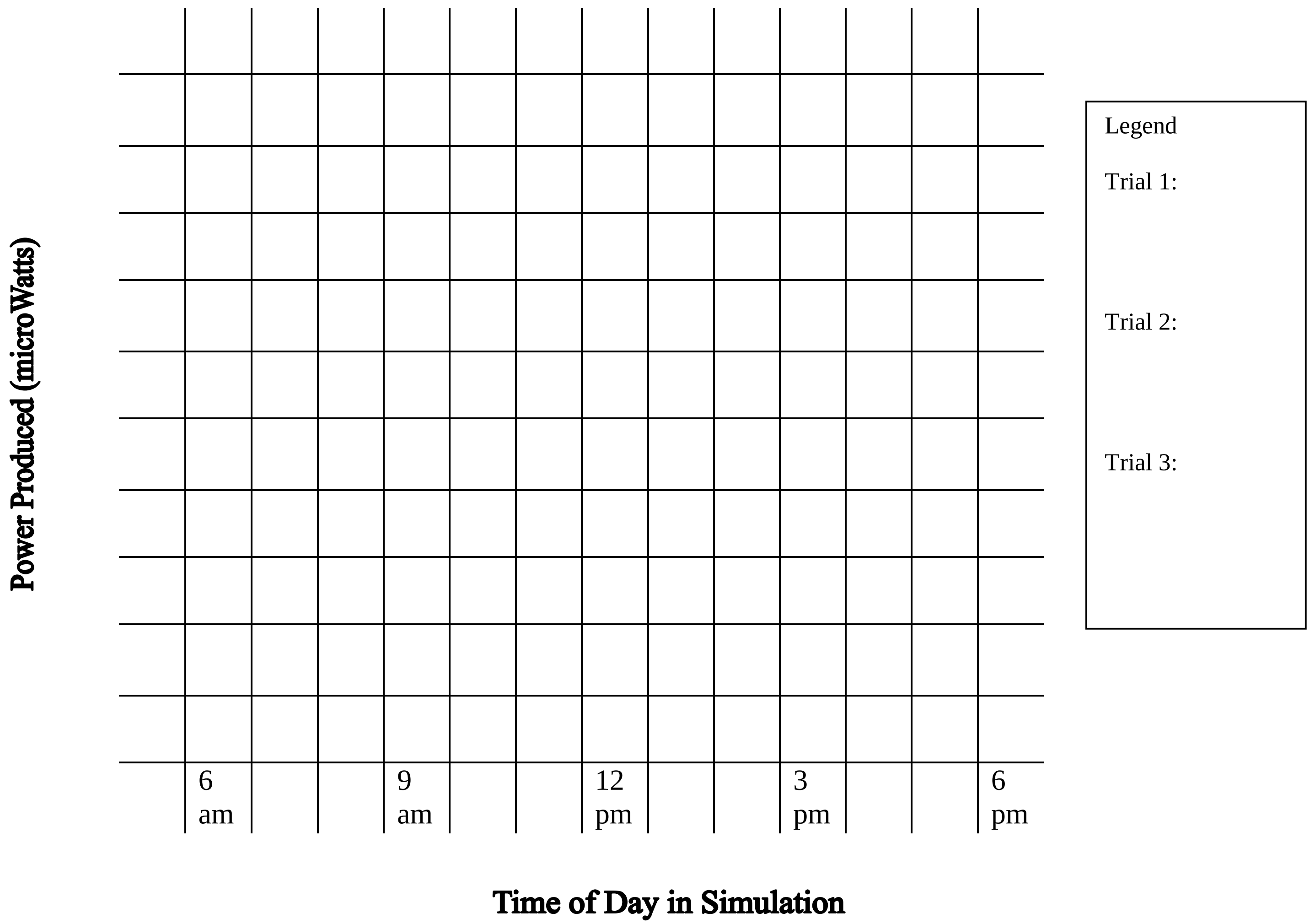
When did you seem to get the most power?

If you were to run another trial, how would you change the panel placement to try to get more power?

How do you decide when you've completed enough trials and collected enough data to start analyzing your results and making conclusions?

Simulation 2 – Data Analysis

From looking at your results, you may have an idea which trial produced the most power. However, a great way to present your data and look for other patterns is to graph the values. Graph your power production for each trial using the graph below. Choose a different color or symbol to represent each trial and make a key for them in the legend.



Make 3 statements based on your graphed results.

Simulation 3 – PV Performance and Extreme Temperatures
STUDENT GUIDE

In this simulation, you will model extreme heat and cold temperatures on a PV array by examining how the power production of the mini panel is affected when sprayed with cold spray or heated up with a hair dryer. Before getting your supplies and starting the simulation, complete this planning sheet *(Thanks to Ron Whitacre of New Albany – Plain Local Schools for inspiring this simulation).*

Rationale: What meteorological conditions are you modeling with this simulation?

Model Design: When you set up your panel and multimeter, you will need to make sure the panel stays a fixed distance from the light source for each temperature you test. Why is this important?

Draw a sketch of your system below and indicate the distance (in cm) from the light source to the panel.

Procedure: Imagine yourself doing the simulation. What steps do you need to take? Write them out below, as if for another person to follow your directions.

Data Collection: Using what you have learned from earlier simulations, create a data table in the space below to collect your power production data. Hint: there will be 3 different temperatures to test.

Analysis and Conclusions: From your data, what can you conclude about the effect of extreme heat and cold on a solar panel?

Real World Connection: How can you use your results to predict the power production of a PV array during different seasons?

Simulation 3 – PV Performance and Extreme Temperatures
TEACHER NOTES

Materials

For each group of 2-3 students:

- 1 miniature solar panel
- 1 digital multimeter
- 1 pair of aligator clip wires
- thermometer
- Student Guide

For whole class

- 100W (or higher) incandescent bulb on an easily moveable lamp-base
- A few hair dryers (to simulate extreme heat)
- Cold Spray (can be found at sporting goods stores)

Procedures

In this simulation, you will model extreme heat and cold temperatures on a PV array by examining how the power production of the mini panel is affected when sprayed with cold spray or heated up with a hair dryer. Before getting your supplies and starting the simulation, complete this planning sheet *(Thanks to Ron Whitacre of New Albany – Plain Local Schools for inspiring this simulation).*

- **Rationale:** What meteorological conditions are you modeling with this simulation?
  Cold = winter weather, Heat= summer weather

- **Model Design:** When you set up your panel and multimeter, you will need to make sure the panel stays a fixed distance from the light source for each temperature you test. Why is this important?

  This is an example of isolating a variable, holding the distance constant while varying the temperature. This way we'll know that the effects seen are due to the changes in temperature and not due to moving the panel closer to or farther from the light source.

  Draw a sketch of your system below and indicate the distance (in cm) from the light source to the panel. *Will vary.*

- **Procedures:** Imagine yourself doing the simulation. What steps do you need to take? Write them out below, as if for another person to follow your directions. *Will vary. Look for student's attention to detail and understanding of the process.*

- **Data Collection:** Using what you have learned from earlier simulations, create a data table in the space below to collect your power production data. Hint: there will be 3 different temperatures to test.

Condition	Panel temperature (celsius or fahrenheit)	Voltage	Current	Power
Cold				
Ambient (room temperature)				
Hot				

- **Analysis and Conclusions:** From your data, what can you conclude about the effect of extreme heat and cold on a solar panel?

- **Real World Connection:** How can you use your results to predict the power production of a PV array during different seasons? Can you research that prediction?

Simulation 4 - PV Performance and Cloud Conditions (Student Challenge)

Now that you've had the chance to try some different simulations and think about their strengths and limitations as models, it's time for you to create a simulation of your own. The question you will need to try to answer with your model is:

How do different types of cloud formations affect the power output of a PV array?

Complete the steps below (1-4) on another sheet of paper to plan your simulation. Return to steps 5 and 6 after you have completed your simulation.

1. Brainstorming: Using your experience with the other simulations, how would you model the effect of different cloud formations on the PV array?

2. Design:

- What materials will you need?

- What will the different items in your model represent? For example, the light bulb moving across the classroom represented the sun moving across the sky. Or the cold spray on the solar panel represented freezing winter temperatures.

3. Predictions: What do you think your simulation will show?

4. Data Collecting:

- Describe what QUALITATIVE observations you will make:

- Make a table for recording your QUANTITATIVE measurements:

5. **Analysis and Conclusions:** After completing your simulation, discuss what you learned and what conclusions you can draw from your data. How could you improve your simulation if you were to do it again?

6. **Model Strengths and Limitations:** Create a chart showing your model's strengths and limitations.

Are you ready? Have your teacher look over your plan and give you the "okay" to start your model. Keep good records of your experiment! Good luck!

Models – Teacher Notes for a discussion

Whenever scientists use models to help them study a question, it is important that they take a step back and consider the strengths and limitations of the model. While they wouldn't necessarily mistake the model for the real question, it is possible to make faulty conclusions if they aren't aware of the limits of the model. They often leave out some complicating factors just to make the question a little simpler. But, at the end of the simulation, they need to think about what hasn't been included in the model. For example, a globe is a model of the earth. Let's take a minute to think about how it's a useful model and also how it's limited.

Model: Globe What it represents: Earth

Strengths	Limitations
• Helps us see how the earth is round. • Helps us see how much of the earth is covered in water, how much is covered in land. • Gives us a sense of where different countries are.	• Smaller than actual size. • Does not show weather patterns. • Does not show actual mountains, rivers, and oceans. • Does not teach us about what is inside the earth.

Here's another example: have you ever built a model airplane? When you are finished, you don't have an actual, running airplane, but you have learned a lot about many of its parts and their functions.

Model: Model Airplane What it represents: Actual plane

Strengths	Limitations
• Helps us learn many of the parts of an airplane (wings, fuselage, engine, propellers, etc). • Gives us a chance to see how the parts work together. • We can keep it in our rooms and look at it. • It's relatively easy and inexpensive to make several different ones.	• Does not actually fly. • Simplifies the mechanics and electronics systems in real planes. • Is MUCH smaller than actual size.

Think about each of the models we used in the simulations with the mini panels. Make a strengths and limitations chart for each one.

Some sample charts:

Model: Simulation 1 - mini-panels connected in series and parallel circuits
What it represents: PV arrays with many modules connected in a variety of ways

Strengths	Limitations
• Demonstrates how voltages add in series circuits so explains why some modules are connected in series. • Demonstrates how panels can be independent of each other in parallel circuits, to make a system more robust. • Gives a good sense of why arrays have sets of modules connected in series (to increase power production), which are then connected in parallel (to keep parts of the system independent). • Using a multimeter allows us to calculate actual power produced using the relation Volts x Current = Power.	• The actual arrays have as many as 20 modules; this simulation only looks at 2 panels. More panels may make the simulation more realistic. • The values of volts and amps measured from the mini-panels are much smaller than those produced from full arrays. • Covering or turning a panel over to simulate a malfunctioning piece of equipment may be an oversimplification. • We don't know how the mini-panels would be affected by wind, rain, hail, and other weather conditions that could affect power output. • We haven't considered the effects of the angle of the panel or the direction it faces.

Model: Simulation 2 - light bulb moving across the room
What it represents: A day from sunrise to sunset

Strengths	Limitations
• Helps us see how the sun's placement in the sky changes during a day. • Helps us see how the sun's changing position affects the power production of a PV array. • Helps us determine the best direction to point a solar panel to collect the most power (Southerly). • Demonstrates that a PV system that could track the sun throughout the day may optimize power production. • Helps us anticipate challenges we may face in installing full-sized systems (Is there an appropriate location and how will it be supported)? • Helps us decide the best location and angle for a stationary PV array.	• Sun does not orbit the earth, the earth rotates and orbits the sun. • The actual sun is much farther away. • Doesn't take into account how the sun's path through the sky varies with geographic location and season. • Other sources of light in the room (windows, overhead lights, etc.) may skew the results. • Doesn't include other factors such as cloudiness, storms, extreme heat or extreme cold. • The actual wattages we measure are much smaller than the wattages produced by the full-sized array. • The light bulb might not be bright enough to represent a sun. • The sun doesn't always rise exactly at 6 am and set at 6 pm. • The light intensity of the sun differs throughout the day, but the light intensity of the bulb stays the same.

Model: Simulation 3 - mini-panel sprayed with cold spray and blown with a hair dryer
What it represents: A PV panel exposed to winter and summer extreme temperatures

Strengths	Limitations
• Demonstrates panel's lowered efficiency when heated. • Demonstrates panel's raised efficiency when cooled. • Helps us anticipate challenges we may face in installing full-sized systems.	• The mini-panel didn't stay cold/hot for as long as a PV array might on one of these days. • Even on a cold day, the heat of the sun might make the PV Array warm. Refine simulation to consider when the panel is coolest (early morning) and when it will be hottest (late afternoon). • Doesn't take into account the effects of moisture and humidity.