Illuminate Me: Merging Conductive Sewing, Technology, and Solar Power

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DESCRIPTION: Light up your clothing using solar power! For this unit, students will attach thin, flexible solar modules to a bike helmet and recharge NiMH rechargeable batteries for a renewable energy battery pack. The rechargeable batteries will be used to light up bright LEDs via conductive thread and a programmed microcontroller.

This lesson is great for a culminating project since it integrates three major components: sewing circuits with conductive thread, programmable hardware, and energy transformations using photovoltaics.

Even if you and your students do not know programming, you can still be successful with downloading prewritten programs.

The main lesson is based on the Light Up Angler Fish written by Adafruit's Becky Stern and can be found on Adafruit's website https://learn.adafruit.com/light-up-angler-fish-embroidery.

GRADE LEVEL(S): Grades: 7,8 (could be expanded for students in 9-12)

SUBJECT AREA(S): Electricity, Electronics, Conductive Thread, Solar Energy, Wearable technologies, Programming, Arduino, Battery charging

ACTIVITY LENGTH: 10-15 class periods; this lesson was designed as a culminating activity.

LEARNING GOAL(S):

1. Students will design and sew a wearable circuit using conductive thread.
2. Students will program a wearable microcontroller to light up garment with bright LEDs.
3. Students will incorporate solar power into a wearable garment project by recharging NiMH batteries for a renewable energy battery pack.
4. Students will apply knowledge of circuitry and energy transfer to maximize design.

NEXT GENERATION SCIENCE STANDARDS:

MS-PS1-3 Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.

MS-PS3-5 Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Engineering Standards

MS- ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

COMMON CORE STATE STANDARDS:

Key Ideas and Details:
CCSS.ELA-LITERACY.RST.6-8.3

- Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

Craft and Structure:
CCSS.ELA-LITERACY.RST.6-8.4

- Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 6-8 texts and topics*.

Integration of Knowledge and Ideas:
CCSS.ELA-LITERACY.RST.6-8.7

- Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

Materials List

Equipment for each student:

Hardware

- 1-Adafruit's **FLORA**-Wearable electronic platform: Arduino-compatible
- 1 to 2-Adafruit's FLORA RGB Smart NeoPixels
- USB A/**Micro** B cable (for downloading, can be shared)
- Flexible Solar modules (1.5-4.8 V), variety for testing
- 3 x AAA Battery Holder with on/off switch and 2-Pin JST
- 3 x AAA NiMH rechargeable batteries (1000mAh)
- Computer with Arduino software installed:
    - *https://learn.adafruit.com/adafruit-arduino-ide-setup/arduino-1-dot-6-x-ide*

Other Materials

- Illuminate Me Labsheet 1.1
- 1-Garment (Example: T-Shirt, tie)
- 1-Bike, boarding, or ski helmet
- Conductive thread (2-3 yards per project)
- 1-needle (largest eye #3/9)
- Embroidery hoop to stabilize fabric
- Tracing paper or fabric marking pen (white colored pencil works)
- Embroidery floss in various colors
- Clear nail polish or fray check
- Multimeter
- 1 page from large pad of unlined chart paper for pattern
- File folder or similar heavy paper
- Wire stripper
- Sharp scissors for cutting conductive thread
- (Optional) Soldering iron if soldering wires for connections
- (Optional) Velcro dots to secure Arduino to garment may be used

Vocabulary

Pattern: A life size paper drawing of your project showing the outline drawing along with all of the stitching lines. Anything fashioned or designed to serve as a model or guide for something to be made: *a paper pattern for a dress.*

Flora v 2: FLORA is Adafruit's updated fully-featured wearable electronics platform. It's a round, sewable, Arduino-compatible microcontroller designed to empower wearable projects.

NeoPixel v2: Adafruit's second version of tiny smart pixels. Designed specifically for wearables, the updated Flora NeoPixels (LEDs) have a constant-current driver. The pixels are chainable - so you only need 1 pin/wire to control as many LEDs as you like. They're easy to sew, and the chainable design means no crossed threads.

LED: short for light-emitting diode. LEDs contain an electroluminescent material—a material that glows when electrical current flows through it. LEDs are polarized. That is, they have a (+) and a (-) side and will only light up when current flows from their positive (+) to negative (-) side. If you attach an LED backwards in your circuit, it will not work. LEDs are more efficient than most other light sources, they produce more light with less energy than most other types of lights.

Circuit stitching path: the path or route that the circuit will follow from one point to another.

Circuit: a network of electrical devices. It is generally a closed loop that includes a power supply and other electrical elements like LEDs (or other "loads" where work is performed) and switches. The loop structure enables the flow of electric current from (+) to (-).

Conductive: a conductive material is one that an electrical current flows through easily. Metals like copper, silver, and aluminum are highly conductive. Conductive materials in the conductive (stainless steel) thread are used to sew components together. The opposite of a conductive material is an insulating material. Insulating materials—like plastic, glass, and fabric—resist the flow of electricity. Electrical current does not flow through insulating materials.

Conductive Thread: A thin, strong, smooth 2 or 3 ply thread made completely of 316L stainless steel. Thicker than every day polyester or cotton thread but still thin enough to be sewn by hand in medium-eye needles. This may be sew-able by a sewing machine that can handle 'heavy' thread. It also has fairly low resistivity, 10 ohms per foot so you can use it to drive LEDs and other electronic components that require less than about 100 mA. Because it is made of stainless steel fibers, it will not oxidize like silver does and your projects will not 'stop working' because of oxidation after a few months; plus, it is safe to wash.

Tap pad: A metal eyelet around the outside of the Flora. There are 14 sewing tap pads (eyelets) on the Flora for attachment and electrical connections. Data buses are interleaved with power and ground pads for easy module and sensor attachments without worrying about overlapping traces, which are not possible with conductive thread.

Running stitch: the most basic stitch in hand sewing. Also called a straight stitch. This stitch is created by passing a needle and thread up and down through a piece of fabric along a line. A good running stitch consists of neat, even stitches of about 1/4” (6mm) in length.

C: (programming language): a general-purpose programming language developed in the late 1960s by Dennis Ritchie, a researcher at AT&T Bell Labs. All Arduino programs are written in C. However, the Arduino environment has many features that aren’t part of standard C, including built-in procedures like digitalWrite and delay, so the Arduino language can be said to be a dialect (or version) of C. **C** is one of the most widely used programming languages in the world.

Code or **source code**: a collection of instructions that will be carried out by a computer and that are written in a programming language. Any piece of an Arduino program can be called code.

Parallel circuit: a circuit containing multiple pathways along which current can flow. Components in a parallel circuit for this activity will have all of their (+) sides connected together and all of their (-) sides connected together. Voltage does not add in parallel, as it does in series.

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Lesson Details

Planning and Prep

This lesson has **three main components**: sewing circuits with conductive thread, the programmable hardware, and transfer of solar energy in order to recharge batteries or to power the project.

This lesson should be taught when students already have a good understanding of series and parallel circuits, short circuits, have already learned how to use a multimeter, have a basic understanding of solar energy, have had some experience with basic sewing skills and an understanding of programming in C. Although, the programming should not deter you from doing this project because prewritten programming is accessible and can just be downloaded to the Flora.

Teacher Prep

This project has a lot of steps so making your own project first for a sample will help you explain the sewn circuit pathways. You will use your project for explaining during the construction process.

For day 2: Make and cut out enough copies of the Flora and Neopixel photocopies (**Illuminate me Labsheet 1.1**) so that each student has them to glue onto their paper pattern.

Student Background

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

- Series and parallel circuits
- Direct Current
- Short Circuits
- Sewing basics, (stitching, running stitch, how to use an embroidery hoop)
- How to thread a needle for sewing
- Possibly a pre design project such as **Beaming Conductive Ties** or Electronic Bookmark from Sew Electric (http://sewelectric.org/diy-projects/bookmark-book light/collect-your-tools-and-materials/)
- How to use a multimeter. (A good tutorial is on Adafruit's website-Collin's Lab, multimeters)
- Basic programming with Arduino programming or a mentor to help with the programming of the NeoPixel part of the project.

Educator Background

An overview and similar project can be found on Adafruit's website under the Light Up Angler Fish Embroidery (https://learn.adafruit.com/light-up-angler-fish-embroidery). I have expanded this project and written more specific instructions for use in the classroom. I also wanted to use rechargeable batteries for the battery pack, so I wrote a lesson to challenge students to make a renewable energy battery charger, which is included as a handout in this lesson packet.

Lesson Sequence

Part One- Designing the garment and sewing with conductive thread.

Day 1: Introduce the design problem/scenario: Bikers in Portland, Oregon and many other locations are being hit and even killed due to not being seen by motor vehicles. Help solve this problem by engineering brightly lit clothing that will be powered by solar panels during the day. The flexible solar panels will be attached to the bike helmets and charge their batteries from a renewable energy source.

- Read the article from kidhealth.org by searching "bike safety for teens."
- Article on necessity of high visibility for bikers: https://road.cc/content/news/95353-study-says-cyclists-should-make-themselves-seen-reflective-clothing-not-hi-vis
- If possible, visit a clothing factory or have a garment maker come to your school. If this is not possible, research clothing and how it's made.
- We All Need Clothes video: *http://classorbit.com/object/everybody-needs-clothing-video*

Garment Stitching Design: Students will search online or draw their own simple black & white *outline* drawing. Then they will enlarge the outline drawing to fit their garment (T-shirt or other fabric) using large white chart paper. This will be the **pattern**. Homework–drawing completed for next day.

Days 2- 4: Drawing out the conductive pathways onto design pattern. Discuss the circuit pathways that the conductive thread will need in order to be sewn from the **Flora** to the **Neopixel**(s), demonstrating with the Flora under the document camera. Discuss how the **conductive thread** is like a wire and can't touch or cross another stitching line (including the knotted strands). If you have made a sample, show this as you explain the pathways.

Figure 1: Pattern design on top of T-shirt with Flora placed on top.

Connecting the Flora to the NeoPixel on the pattern drawing:

Using separate colored pencils, students need to draw their ***circuit stitching path*** from the Flora, making sure their future stitching lines do not touch or cross.

- Draw a **green** stitching line from the GND **tap pad** (next to the D6) on the Flora to – (negative) tap pad on the NeoPixel.
- Draw a **red** stitching line from the **D6** tap pad on the Flora to inward facing arrow ç on the NeoPixel tap pad.
- Draw a **blue** stitching line from the **Vbatt** tap pad on the flora to **+** (plus) on the NeoPixel.

Have students cut out the photocopied paper copies of the Flora microcontroller and NeoPixel(s) and glue onto pattern (large paper) before they draw their circuit lines.

Note: This might seem like repetitive steps and that students could just draw onto their shirts but I found that the pattern helps students by giving them something to look back at for guidance and also it gives the teacher a chance to see if they have the circuits drawn correctly before sewing.

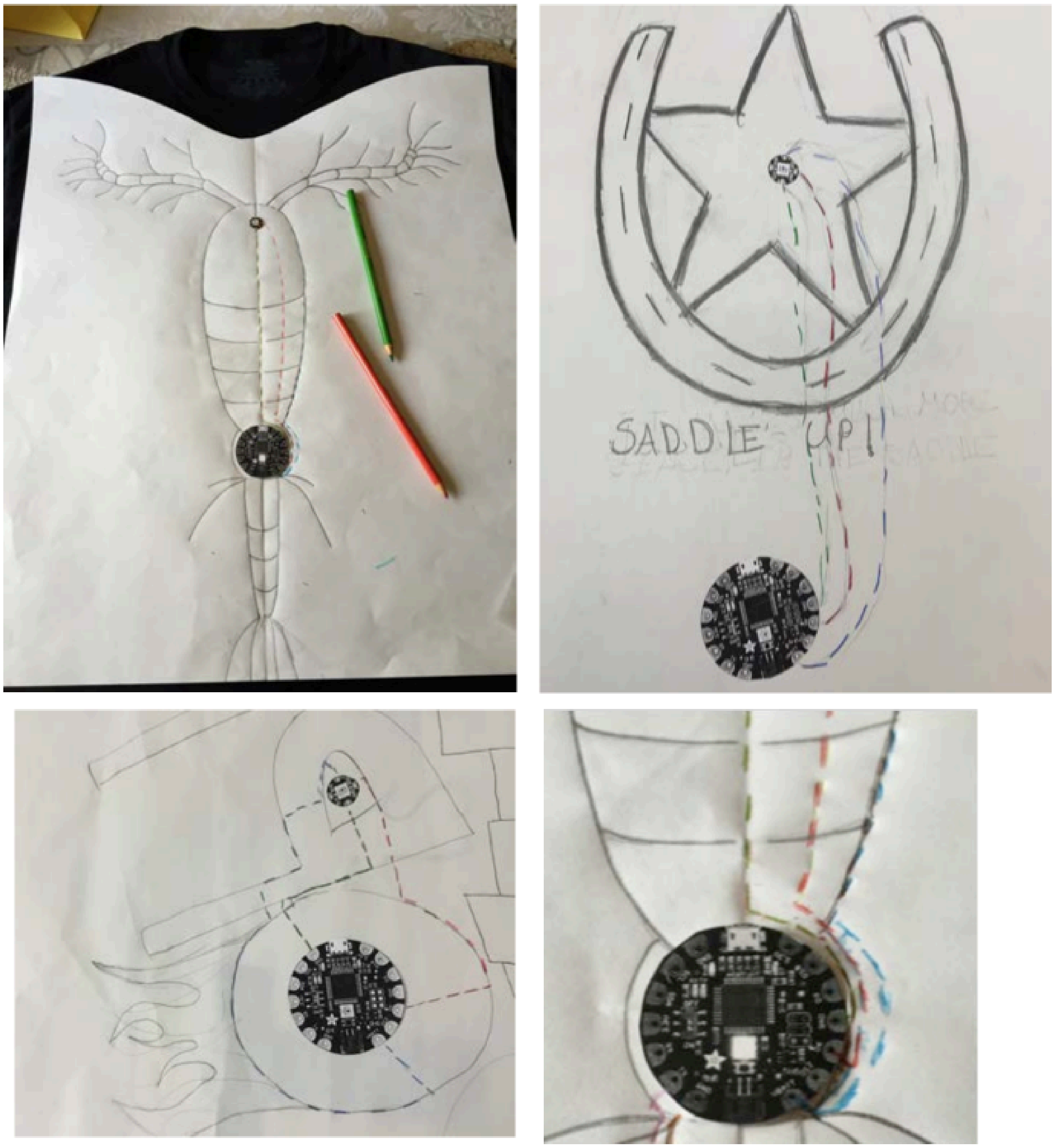


Figure 2: Patterns with circuit stitching paths.

Days 5-7: Tracing Circuit and Sewing With Conductive Thread

Trace the final circuit from pattern onto material or garment (Tshirt, etc.) using tracing paper, a material marking pencil, or Taylor's chalk (after tracing students can trace over the design with white or yellow colored pencils). Before sewing, students need to position one layer of material into an embroidery hoop and tighten. You will need to demonstrate how this is done since very few students will have used these before. Double check to make sure students have only *one layer* of material if using two layers (only one side of a T-shirt). Additional help might be placing a piece of cardboard between the two layers so students don't sew through the two layers.

Demonstrate how to thread a needle, tying a knot in one end, and stitching with conductive thread. Many students will not have any previous exposure to sewing. Also demonstrate a **running stitch** if students have not been exposed to sewing.

Tip-1: Have students check connectivity after they sew *each* circuit using a multimeter. This will save problem solving later if the system isn't working. Make sure students use their patterns for sewing with the conductive thread. Give help as needed.

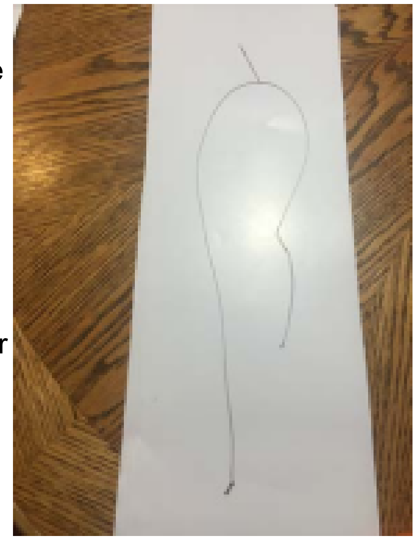


Figure 3: Threaded needle.

Student Steps for Sewing With Conductive Thread:

Step 1: Place your FLORA microcontroller and single Neopixel on the taut fabric.

Step 2: Thread a needle with 2-ply conductive thread and tie a knot on *one end*.

Step 3: Pierce the fabric from back to front next to the pad marked D6 on FLORA. Make a few stitches through the D6 hole, securing it to the garment.

Step 4: Following the path drawn on your pattern, take the needle and conductive thread and poke up through fabric close to the Flora. Now use a running stitch (with stitches no larger than one cm in length) to sew a conductive pathway stitching line from the GND **tap pad** (next to the D6) on the Flora to **–** (negative) tap pad on the NeoPixel.

Step 5: Make a few loops through the **–** (negative) tap pad on the NeoPixel in order to secure it to the garment ending at the back side. Check for connectivity after you sew circuit using a multimeter (see instructions below). Tie a knot and seal the knot with clear nail polish (or fray check) if you have a good circuit. When *the nail polish has dried*, cut any loose ends close to the knot so you don't cause any short circuits.

Step 6: Thread another needle and following the path drawn on the pattern, repeat to make a connection from **VBATT** on FLORA to **+** on the pixel, and likewise from **GND** to **–** (negative). You will now have *three* independent paths sewn from the main board to the pixel.

Step 7: Double check your circuit for stray threads, and get ready to load it with a program that will change the NeoPixels colors when you turn the FLORA to "on".

Day 8: Students will need to use a multimeter to check to see if each circuit path has connectivity. Demonstrate how to use the multimeter and help students problem solve. You can preload a test-strip program from the Adafruit website onto the Flora microcontroller so that students can test to see if their NeoPixel is working. This is very helpful when it comes to trouble-shooting and students are excited to see that their circuits are working.

Days 9-10: Using Embroidery Floss, students sew the remaining outline design with chosen colors. Students may want to take this home to finish their designs. The time involved will depend on how basic or complicated designs students have created for their garment.

Part Two-Programming the Flora Microcontroller

Days 11-12: Even if students only have a basic knowledge of coding, they can still be successful with this project. The initial code can be downloaded from the Adafruit website (https://learn.adafruit.com/light-up-angler-fish-embroidery/code) and then you can instruct students on how to modify the code to change the colors and pattern sequences.

A helpful website is https://www.rapidtables.com/web/color/RGB_Color.html.
It is suggested that you download the strand test onto the Flora prior to students working with the FLORA, that way students can test to see if their circuits are working after the sewing is complete and it is a great motivator to see that their hard work has paid off.

Part Three-Designing a Solar Battery Charger-Converting to Solar

Days 12-17:
See the Solar Battery Charger Challenge student Sheet.

Note: *Prior to the lesson*, the 3 rechargeable NiMh batteries per student need to be discharged. There are a variety of ways to do this but it does take time. We hooked the battery packs up to small motors to drain the batteries a bit.

The lesson on charging the solar panels is set up as an inquiry lesson and works best outside in sunlight. If you need to, light stands for classroom use can be used and can be made out of PVC pipe.

If students are using solar for their project, you will need to cut and strip a small section of the wires from the battery pack and the FLORA connector in order to connect to the solar panels. See below.

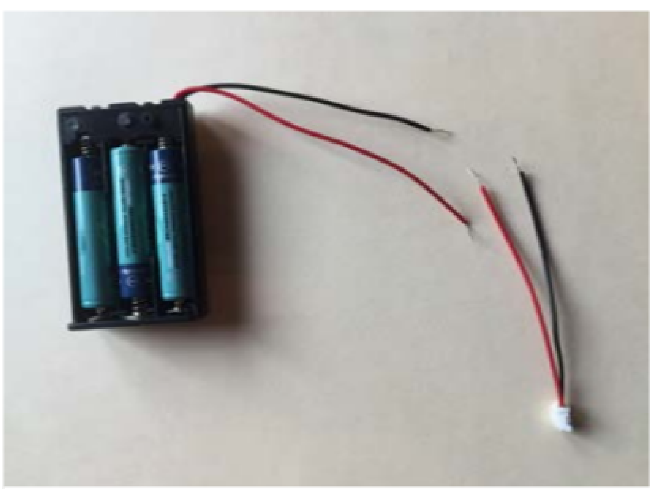


Figure 4: Battery pack cut to incorporate solar..

Materials for the solar charger:

- Variety of flexible Solar modules (1.5-4.8 V)
- 3 x AAA Battery Holder with on/off switch and 2-Pin JST
- 3 x AAA NiMH rechargeable batteries (1000mAh)
- Diode (1 **Ω)**
- 14 gauge wire

Some helpful tools:

- Soldering iron
- Goggles
- Electrical tape
- Wire strippers

Adding the solar to the project was fun and challenging. To make the recharger, students placed the flexible solar panels onto cut file folders. This way they could be bent in order to simulate the curve of the helmets.

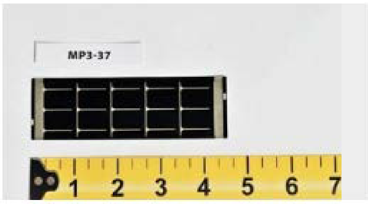
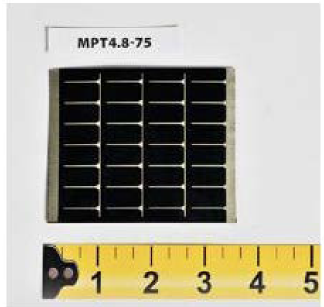
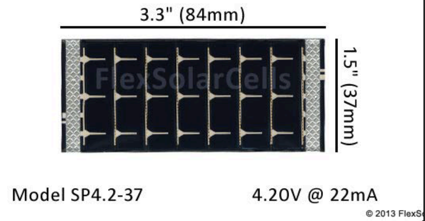
We learned that recharging NiMH batteries is a slow process if just using the lamps in the classroom and if you want to be able to continue to recharge the batteries. Something to think about is only having the solar charging to 10% of the capacity of the battery in order to "trickle charge" your batteries. This will ensure that your batteries don't have too many problems if they get overcharged! In other words, if your rechargeable battery reads "1350 mAh" as its rated capacity, it shouldn't be charged with a current greater than 135 mA. The real problem here is if the battery gets fully charged and is still wired into the circuit. If you are not leaving the circuits unattended and are in no danger of overcharging the batteries, you can get away with charging them at a slightly higher current.

We collected data for a set system, graphed the results, and then shared out the information. If you would like to extend this charging piece with your students, check out Luke Robbins' "Solar Battery Charging" lesson in this resource library.

Technology Alternative:
If you have the availability of probeware, such as Vernier's LabQuest, you can connect a 30 V voltage probe. This way you will have graphs available for your student's final presentations.

Figure 5: Vernier LabQuest 2 Data Read-out.

Table 1: Example solar panels to test

		
1.5” by 4.5”	3.0” by 3.5”	1.5” by 3.3”
Operating Voltage: 3.0 V	Operating Voltage: 4.8 V	Operating Voltage 4.2 V
Operating Current: 50mA	Operating current: 50mA	Operating current: 22mA

We tested the following panel systems. Assign testing groups based on available solar panels.

Note that you can assign all groups to wiring their solar panels together in series and/or parallel. If you students are less familiar with circuits, have them test series-only circuits. You or your students will need to ensure that the solar panels each have a voltage rating that is higher than the batteries you are charging. (If you are using a 3-AAA battery pack, which is wired in series, you will need a voltage of at least (3)*1.5 V, or 4.5 V). If you or your students use a multimeter to test these solar panels without a circuit attached, you may notice the voltage readings are higher than the rated “operating voltage.” This is to be expected.

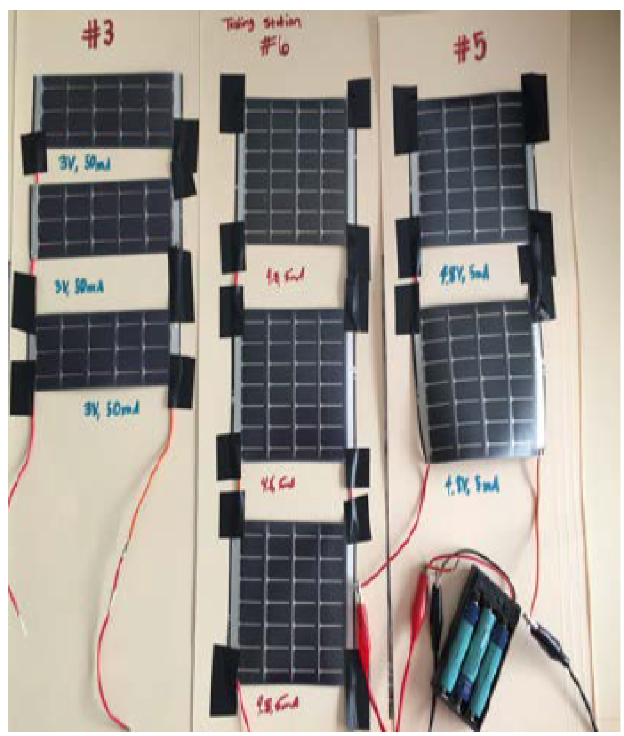


Figure 6: Solar panel testing stations for parallel circuits.

Table 2: Solar Panel Testing Groups.

Group:	Solar panels	Series: total voltage and current	Parallel: total voltage and current
1	1, 1.5” by 4.5” panels	3 V, 50 mA*	3 V, 50 mA*
2	2, 1.5” by 4.5” panels	6 V, 50 mA	3 V, 100 mA*
3	3, 1.5” by 4.5” panels	9 V, 50 mA	3 V, 150 mA*
4	1, 3.0” by 3.5” panels	4.8 V, 50 mA	4.8 V, 50 mA
4	2, 3.0” by 3.5” panels	9.6V, 50 mA	4.8 V, 100 mA
5	3, 3.0” by 3.5” panels	14.4V, 50 mA**	4.8 V, 150 mA
7	1, 1.5” by 3.3” panels	4.2V, 22 mA	4.2 V, 22 mA
8	2, 1.5” by 3.3” panels	8.4V, 22 mA	8.4 V, 22 mA

*These circuits will only be able to charge 2-AAA batteries and not the required three AAA set-up. If the “dead” batteries are each at a voltage below 1 V, you might be able to charge them up to near 1, but a reading of 1 V on a battery still qualifies as “dead.” If you are using Vernier monitoring equipment, however, this may show some very interesting results.

** Even though the voltage difference between the solar panels in series is *much* bigger than the ideal voltage for the three “charged” batteries (1.2 V * 3 = 3.6 V), this will not be a problem because the solar panels are limited to a current of 50 mA. You would NOT want to use, say, a 12V battery to charge the three AAA batteries.

Student Data Table:

Instruct students to write down their assigned combination of solar panels in the box to the left in the table then record *initial* voltage measurements from the solar panels at their station using a multimeter and record measurements in table 1. Measure at set intervals set by the class (i.e. 15 minute intervals). This should be watched and not left connected overnight.

Table 3: Student Table

Solar Panel Test Set-up:	Start time:	Check time:	Voltage:
Number of Solar panel (s):_________ Sizes:___________________________			

Diode in the circuit discussion:
What’s going to happen when we ride our bike in a tunnel, we need to go inside, or class is over for the day and the lights go off?

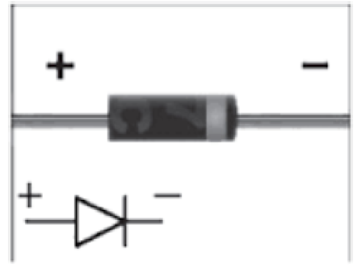


Figure 7: Diode. Image: globalspec.com

If a charging battery is left connected with no light source on the solar modules, it may leak current through the modules and slowly discharge. This leakage can be avoided by placing a diode in series in such a way as to block this reverse current. If this is done, another solar module will be needed to overcome the voltage drop across the diode during charging.

Do you need to place your diode in a certain position? The diode is like a one-way valve. It allows current to flow from the solar module into the batteries but prevents current from the batteries to flow back into the solar module.

Wrap-up/Extension:

Class Discussion of results:
After students have collected data, have each group report their findings and discuss which combination of solar panels will work best for their project. You may find that more testing needs to be conducted.

One possible battery recharger set up:
Solder the positive lead (red wire) of the 3 x AAA NiMH rechargeable battery pack to the positive side of the diode (so that if your solar panels are in a shadow the power only flows in one direction), then to the first wire on the positive side of the first solar panel. Make sure the solar panel is in the correct (positive/negative) position and are wired correctly.

Connecting the charger to the garment:
Students will need to design a way to temporarily attach their battery pack to their garment or have a system to have the solar panels attach to their helmets and charge the batteries while they are out in the sun.

Final Presentation Prompt: After spending time making your awesome wearable electronic garment you have been asked to display it at a well know garment shop in downtown Portland, Oregon. You will need to write an advertisement that explains all the aspects of your design. You may make a poster or give a demonstration using Google Slides.

Be sure to include:

- A picture of your pattern with the stitching lines drawn onto the pattern.
- A picture of your garment as you worked on sewing.
- Schematic diagram of your circuit and description.
- Picture or video of your working circuit.
- Graph (or printed pictures of graphs) of your solar battery recharging tests.
- Results of your solar battery tests.
- Picture or drawing of your battery recharger.
- Reflection questions.

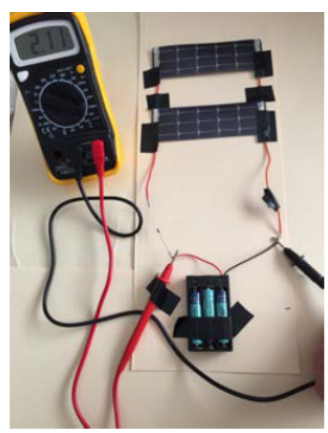


Figure 7: Solar Battery Charger Setup with Multimeter. This setup has solar panels in parallel.

Assessment

Students will be assessed on each part of the project; the design/pattern, the programming of the microcontroller (FLORA) and testing the solar battery connection.

Table 4. Grading Criteria for Grades 6-8.

Learning Objectives 6-8 Grade-Student will be able to	**Max Pts**	**Pts Earned**	**Grading Criteria**	**Instructor Initial**
Design a wearable circuit garment that people would wear out in public.	10		Outline drawing design traced onto large chart or butcher paper (project pattern) ___/10	
Design a wearable circuit pathway that has at least 1 place for the bright flashing LEDs (NeoPixel) in order to attract attention.	10		Color coded circuit pathway is drawn onto pattern as shown, including photocopied Flora and NeoPixel(s) ___/10	
Sew 3 circuits using conductive thread to the correct tap pads.	60 (20pts./ circuit)		Correctly sewed 3 circuit pathways onto garment from the FLORA to NeoPixel(s). ___/60	
Attach and blend the Flora microcontroller into the garment design.	10		Correct connections were made from the Flora tap pads to the correct NeoPixel. ___/10	
Attach solar panels and battery box to a bike helmet in order to charge batteries.	60		Correctly connected the solar panels to the FLORA or battery box in order to run circuit system. ___/60	
Uniquely program the Flora in order to light up the NeoPixels to attract attention.	30		The FLORA was programmed to have a unique set of colors and patterns for the garments Neopixel(s). ___/30	
Self evaluation of project	25		All questions were completely answered ___/25	
Present project in a final presentation	80		Completed all steps outlined below for final presentation. ___/80	
	Total:	**285 pts.**		