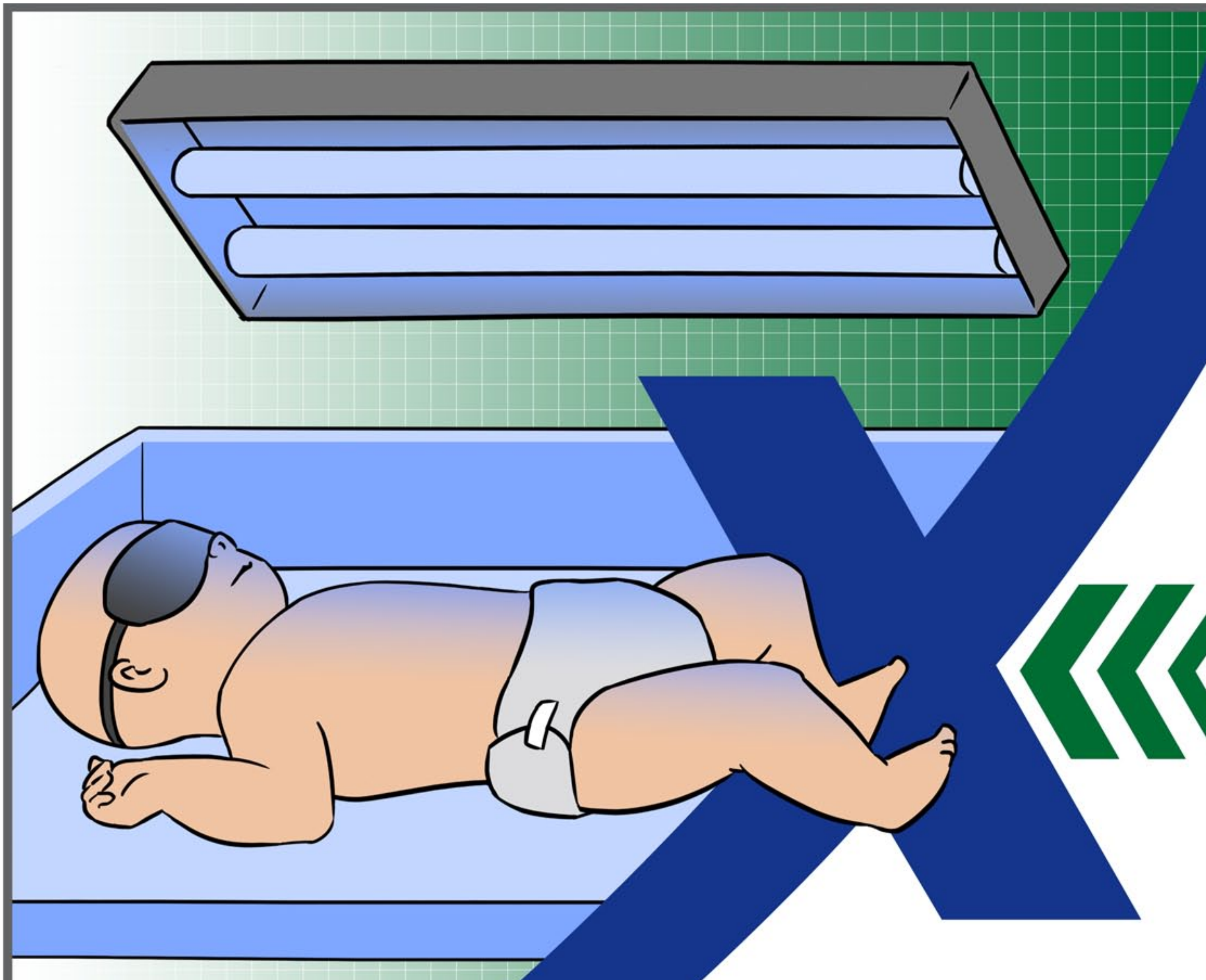


# Medical Technology for the Developing World

TechXcite Discover Engineering

Facilitator's Guide

# Module Overview

In this TechXcite: Discover Engineering module, youth are introduced to the challenges biomedical engineers face when designing devices for developing countries. Most medical technologies cost too much to maintain or require special knowledge to operate. Versions of these devices that are easier to use and require less maintenance can make a huge difference in the lives of people in resource poor environments. Engineering World Health (EWH) is a non-profit organization dedicated to working with engineers to develop these types of solutions.

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

**Activity 1:** Examine electrocardiogram electrodes as an example of the constraints engineers face when designing medical devices for resource poor environments.

**Activity 2:** Build a simple stethoscope and examine the importance of low-cost design.

**Activity 3:** Learn about the use of phototherapy in treating neonatal jaundice and build a low-cost calibration device designed by the engineers at Engineering World Health.

**Activity 4:** Use basic electrical components to design the most effective phototherapy unit prototype for the lowest cost and test it with the bili-meter built in the previous activity.

# Table of Contents

# TechXcite: Discover Engineering

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

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

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

### Online Support

The TechXcite website (techxcite.org) contains additional material to facilitate implementation of this module. There are videos, Facilitator's Guides, Youth Handouts, and kit inventories with vendors and pricing for each item required. Although the curriculum is written with a focus on middle school youth, it has been successfully implemented at both the elementary and high school levels. Anyone can download copies of the Facilitator's Guide and Youth Handouts from our website. There are links to additional resources for information about the module topics and ideas for further activities and exploration.

### Training Videos

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

### Engineering World Health

Engineering World Health is a non-profit NGO (Non-Governmental Organization) that specializes in creating and running Biomedical Equipment Technician Training (BMET) programs in Ghana, Cambodia, Rwanda and Central America. In addition, it works closely with engineering students and staff at over 40 Universities around the world to support, encourage and oversee appropriate technology development for resource-poor settings. EWH also runs a hands-on equipment repair institute in Central America and Tanzania for college students and professionals.

For more information, please visit their website: www.ewh.org. For questions or feedback regarding the EWH Science, Technology, Engineering and Math (STEM) Health Program, please contact: STEMHealth@ewh.org.

# Using this Guide

The Facilitator's Guide for each activity follows the same format. Below is what you can expect to find in each section. At the beginning, you will be given basic information about the activity. This includes:

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

## Introduction and Activity Closure

The Introduction and Activity Closure are scripted. You may read these sections verbatim to students. Instructions that are not to be read to students, as well as answers to questions, are in brackets/italics.

## Facilitating the Activity

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

## Exploration Questions

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

# Activity 1: Reusable Electrodes

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

## Materials

Note: When planning for this activity you may choose from a couple options depending on your needs and time constraints. An easily accessible conductive gel can be made from a variety of solutions but we have offered two here. The gel simply needs to allow a good connection between the skin and electrode and provide a conductive path for heart signals.

### Each group needs:

- Conductive gel
  - Option 1 (Recommended):
    - Gel body wash or liquid soap, preferably a body wash or soap that is on the thicker side
  - Option 2:
    - Small cup
    - Spoon
    - 1 Teaspoon salt
    - ½ Teaspoon flour
    - Small amount of water
- 2 Bottle cap liners **(See Getting Ready)**
- 2 Nickel-plated brass sewing snap, size 3
- 2 Alligator wires
- 2 Medical-grade disposable electrodes
- Multimeter

### Each class needs:

- 4 Rolls of medical tape
- Paper towels (Not included in kit)
- Water (Not included in kit)

### Youth Handouts:

- Common Challenges in Resource-Poor Settings (Optional)
- Reusable Electrodes

## Getting Ready (30 minutes)

- Make the reusable electrocardiogram (ECG) electrodes at home by following the instructions in the guide provided on pages 14-15.
- Make sure you either have a place to get water or a container with water.
- Have paper towels on hand for wiping up the conductive gel and any water that may spill.
- Check the multimeters to make sure the batteries are working and replace if necessary.

# Activity 1: Reusable Electrodes

## Learner Outcomes

- Explain that engineers creating medical devices for developing countries face design challenges that are different from those in the developed world.
- Explain that consumables, which are often required for the correct and successful use of medical devices, are a problem for hospitals in developing countries because they can be expensive or inaccessible.
- Explain that electrical signals cause the heart muscle to contract and pump blood through the body.
- Explain that electrodes are used to reduce the electrical resistance of the connection to the skin, making measurement easier for heart rate monitors.

## Vocabulary

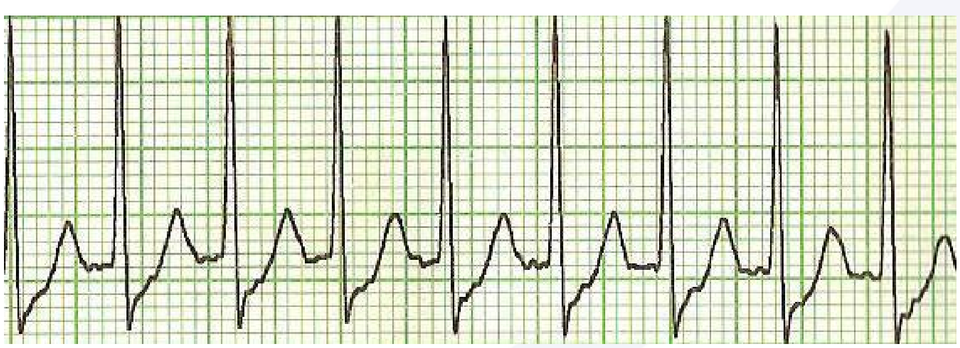
| Word | Definition |
|---|---|
| Consumable | An item that is disposable and gets thrown away after use. Examples include bandages, syringes, tongue depressor, etc. |
| Electrocardiogram (ECG) | A graph of the heart's electrical signal pattern (displayed on the screen of the electrocardio*graph* machine). |
| ECG Electrode | A small electrically conductive pad that attaches to the skin in order to better measure electrical signals inside the body. |

## Introduction

[*Before starting the activities, show your class the following video: vimeo.com/36504958. It will give them the context needed to understand the issues hospitals in developing countries face. It will also show them how to assist developing-world hospitals in the future, as university students.*]

Around 80% of the world's population spends less than $100 per person on health care every year, while the majority of medical equipment is designed in countries that typically spend over $2,000 per person per year. This means that a significant portion of medical devices are too expensive for the majority of the world's population. In this module, we're going to explore ways engineers can help address these problems.

First, we'll look at the issue of consumable parts for medical equipment and how engineers develop low-cost solutions for resource-poor countries.



# Activity 1: Reusable Electrodes

An **Electrocardiogram (ECG)** is a simple, painless test used to detect irregularities in the heart's activity. During each heartbeat an electrical signal travels through the heart triggering the muscles to contract and pump blood through the body. The tiny electrical signal from the heart can be measured at the surface of the skin using **ECG electrodes**. Typically, the electrode are discarded after use to avoid the spread of disease.

A major challenge in the developing world is providing ECG electrodes. Electrode pads are cheap and readily available in the USA but are difficult to acquire in poor countries. Even if a hospital in a resource-poor environment receives a donated ECG machine, they might not be able to find or to afford the electrodes. Fortunately, engineers at Engineering World Health (EWH) have developed a low-cost, locally available, reusable electrode design to address this challenge. You will be exploring their innovative design solution today in this activity.

## Facilitating the Activity

1. Place students in pairs and distribute youth handouts.
2. Demonstrate for the students how to measure the resistance of the body through taking a resistance measurement on the wrist/forearm.
    a. Remind students that the multimeters are not toys and they should be careful with the probes because they are sharp.
    b. Turn the multimeter on, and set it to 2 mega ohms (2M under the Ω).
    c. Touch the multimeter probes to two points on the body.
    d. If the number 1 is displayed, the resistance is greater than 2 MΩ (2000 kΩ) which exceeds the upper limit of the multimeter's measuring ability. Some students may get this reading if their skin is dry. Nothing is wrong; the low cost multimeter can't measure very large resistance values.

3. Ask students to follow the instructions on the youth handout.

    First, they will take measurements of their body resistance with no electrodes. Then students will test the reusable electrodes with and without conductive gel. Then they will test the commercial electrodes, and finally, the gel by itself (with no electrodes).

    Note: The *commercial* ECG electrodes are already equipped with conductive gel. Also, additional pressure placed on the electrodes may be needed to receive a measurement from the multimeter.

4. During the activity, walk around and help students take the measurements. You may ask groups to think about what the pros and cons of the reusable versus disposable electrodes are to prepare them for the discussion after the activity. Encourage the students to explore additional questions and measurements.

# Activity 1: Reusable Electrodes

5. There are blank rows in the table for the students to develop their own experiments. An additional table is provided for the students to rank each option from lowest resistance to highest resistance or best to worst. Below are a few potential variables students might explore:
   a. Conductive gel vs. water (with or without the reusable pad)
   b. Pressing the lead against the skin vs. just touching it to the skin
   c. Wrist resistance vs. resistance of other parts of the body (for instance ankle to wrist).

## Variations

You may wish to look for a variety of possible gel like substances and have the class determine the best one. For example, the class could experiment with liquid soap, flour/salt paste, ketchup, mustard, lotion, etc. and list the pros and cons of each one.

## Activity Closure

The United States and other developed countries are accustomed to seeing modern medical equipment in hospitals. When this equipment is replaced, the old units are sometimes donated to developing countries where they are badly needed. Unfortunately, not all donated equipment is actually used. It is important to make sure that the donated equipment is in working condition and contains all the items required for operation, as well as a plan for preventative maintenance and repair.

ECG electrodes are just one example of often overlooked items required for operation. They may not seem important or particularly costly, but they make a big difference when it comes to getting accurate readings and the cost adds up quickly over time. Another example of a costly consumable is x-ray film. A donated x-ray machine is useless if the film is not readily available.

Fortunately, EWH is working with engineers and university students to make a difference by addressing a number of problems related to medical equipment use in resource-poor settings. Their goal is to repair vital medical equipment and find workable solutions (such as reusable electrodes) for the numerous challenges faced by these communities. [*See "Common Challenges in Resource-Poor Settings" handout*.]

# Activity 1: Reusable Electrodes

### Exploration Questions

1. What were the advantages and disadvantages of the commercial disposable electrode?

   [*Advantages:*
   - *Infection is reduced by always throwing away the pad after use.*
   - *Medical tape is not needed because the pad is already adhesive.*
   - *Quick turnaround time. The machine can be used on a new patient very quickly by simply using a new pad.*

   *Disadvantages:*
   - *Throwing away electrodes for every patient can be costly and would be difficult in resource-poor settings where obtaining the electrodes can be difficult.*]

2. What were the advantages and disadvantages of the reusable electrode?

   [*Advantages:*
   - *It does not have to be thrown away so there is no ongoing expense.*
   - *It is easy to make so, if there are no electrodes available, these could be made quickly. If it breaks it can be fixed quickly as well.*
   - *It can be disinfected between uses to reduce cross-contamination.*

   *Disadvantages:*
   - *Disinfecting it takes time so it takes longer to switch between patients.*
   - *If not properly disinfected, there is a chance of cross-contamination whereas with disposables, there is not.*
   - *Some patients are allergic to nickel so they may not be able to be used on everyone or, if the allergy is not too bad, the reusable electrodes may only be used for short durations. However, the gel may provide enough of a barrier between nickel snap and patients skin that it is not an issue.*]

3. Did the gel (body wash, liquid soap, etc.) lower the resistance? Why? What are some other ways to lower the resistance?

   [*Yes. Wet skin has lower resistance than dry skin because water conducts electricity and improves the connection to the skin. Dry skin usually has a resistance of at least 1-2 MΩ (1000-2000 kΩ) while wet skin is only a few hundred ohms.*

   *Pushing the electrodes against the skin lowers the resistance and brings the lead closer to the blood stream, which is the best conductor in the body.*

   *Note: The readings will move around a fair amount. Also, the further the leads are from each other, the larger the resistance. This is because the electrical signal has to travel through more of the body.*]

4. Why are the electrodes attached to the body with tape?

   [*The answer is not just to reduce resistance, since metal pushed against the body would reduce resistance without tape. It's to hold the lead in place. At least 3 electrodes are used for a true ECG measurement so it would be very difficult for a doctor to hold the leads in place without adhesive. Movement along the skin or a change in how hard the electrode is pressed into the skin can increase or decrease resistance and affect the very small electrical signals being measured.*]

# Activity 1: Reusable Electrodes

5. The two acronyms for electrocardiogram—ECG and EKG—can be used interchangeably, and in many places, EKG is actually more common. Why?

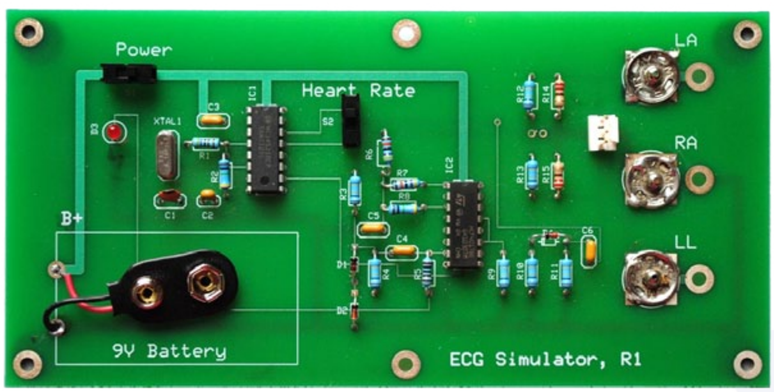
   [*The acronym EKG originated from the German "elektrokardiogramm" but was adopted even in non-German-speaking countries because the pronunciation of a soft "C" makes it easy to confuse ECG with EEG (electroencephalogram), especially under traumatic conditions. The hard "K" eliminates the potential confusion.*]

### Optional Extension: ECG Simulator Kit

Your program can make a difference by putting together devices used to test electrocardiogram (ECG) machines in resource-poor settings through the efforts of Engineering World Health.

As you will discover in Activities 3 and 4, a simple system to help technicians test used and donated medical equipment can make a large difference. EWH makes an inexpensive ECG simulator kit that your program can assemble. These simulators are then sent back to EWH to be used by the technicians participating in the Biomedical Equipment Technician training programs in developing countries throughout the world.

The kits ask students to solder which requires a bit more supervision than the activities in this module, but it can be a very rewarding project for a program to follow up these activities. For more information, visit the EWH website: www.ewh.org.



# Getting Ready: Reusable Electrodes

## Materials

- Bottle caps
- Nickel-plated brass sewing snaps, size 3
- Flathead screwdriver
- Utility knife (boxcutter, X-Acto, or other sharp-bladed knife)
- Optional: tweezers/forceps
- Pot
- Water
- Stove

## Procedure

See the plastic lining on the inside of the cap? That's what you want. The lining is 36mm low-density polyethylene plastic. It will provide mechanical support for the electrode, which is the snap button, and help ensure that it has continuous contact with the patient's skin.

Part 1: Boil and Peel

1. Boil the bottle caps in water for 30 minutes.
2. Peel off the lining. Start by prying up the edge with the screwdriver and carefully pull the rest out with fingers, tweezers, or forceps.
3. It may become harder to separate as the cap cools. In that case, try heating the cap in the water again for a few seconds then remove it and finish peeling.

   Note: It's okay to use plastic liners that tore a little bit when you separated them, as long as they didn't tear in the middle.

# Getting Ready: Reusable Electrodes

Part 2: Assemble the Pad

1. Cut an "X" in the center of the lining to make a hole no larger than 1 cm.
2. Insert a nickel-plated brass sewing snap into the hole.
3. Trim the tiny corners of plastic from the edge of the button nub to help expose it.

*Congratulations, you made an ECG pad! They're washable and reusable up to 100 times.*

# Activity 2: Low-Cost Stethoscope

**Time Required:** 30 minutes **Group Size:** 2

## Materials List

### Each group needs:

- Plastic tubing (2 ft, 7/16-inch outer diameter)
- Medium funnel
- Balloon (Allergy warning: contains latex)
- Stopwatch
- Masking tape

### Each class needs:

- Medical stethoscope (Optional)
- Scissors

### Youth Handouts:

- Common Challenges in Resource-Poor Settings
- Low-Cost Stethoscope

## Getting Ready

- None

## Learner Outcomes

- Measure pulse.
- Explain that a stethoscope listens to blood moving through the heart, and amplifies lung and abdominal sounds.

## Vocabulary

| Word | Definition |
|---|---|
| Stethoscope | An instrument used by doctors to amplify sounds inside the body, such as the heartbeat. |
| Pulse | The rhythmic contraction and expansion of the arteries with each beat of the heart. |

## Introduction

The heart contracts and expands to pump blood—carrying vital nutrients and oxygen—throughout the body. When we exercise, our bodies need more nutrients so our heart rate increases. Your heart rate, or **pulse**, can change dramatically between exercise and rest. A typical resting heart rate is between 60-90 beats per minute (BPM), whereas an exercising heart can beat up to 200 BPM.

In the last activity, we learned that ECG machines are used to measure the weak electrical signals generated when the heart beats. We also looked at problems with using those machines in developing countries.

# Activity 2: Low-Cost Stethoscope

Fortunately, there are simpler ways to measure heart rate, such as a stethoscope.

Invented in 1816, the stethoscope was one of the first non-lethal instruments for exploring internal anatomy. This marked a major step in the understanding of sickness and disease as, prior to this time, disease was thought of as a collection of symptoms rather than an underlying problem with a person's internal systems.

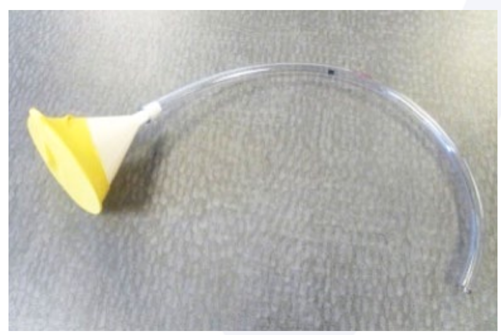
The modern stethoscope uses a simple drum-like mechanism to pick up vibrations and amplify various sounds inside the body. When the chestpiece is placed over your heart, the doctor is specifically listening for two sounds: "lub" (the sound of the first set of heart valves closing) and "dub" (the sound of the second set of heart valves closing). In between, the heart should be quiet. The resulting diagnosis will depend on the exact sequence, timing, and type of sounds the doctor hears.

In this activity, you will use your fingers to manually detect your heart rate and then build your own stethoscope from inexpensive materials.

## Facilitating the Activity

1. Place students in groups of 2-3.
2. Help students find their own pulses on the wrist or the neck.
3. Start the stopwatch and instruct students to begin counting their heartbeats. Tell them to stop after 10 seconds has passed. They will then multiply the number of beats by 6 to determine their resting BPM.
4. Have everybody stand up and get their heart rates moving as a group. For example, you could have them run in place or do jumping jacks for 15-20 seconds.
5. Use the stopwatch again to count the number of beats in 10 seconds and determine their active BPM.
6. Instruct students to follow the instructions in Part B to build the stethoscopes.

   Note: Students with a Latex Allergy may not be able to participate in the handling of the balloon.
7. Ask students to test their stethoscopes on themselves. If a real medical stethoscope is available, let them pass around and test the real stethoscope.



## Activity Closure

Let's review what we've observed and learned today. Your pulse, or heartbeat, can be used as a general measurement of overall health and fitness level. Measured in beats per minute, the resting heart rate of an average adult is somewhere between 60-90 BPM. A well-trained athlete, on the other hand, usually has a resting heart rate around 40-60 BPM as the heart adapts to the increased demands of training by growing stronger, larger, and more efficient—just like any other muscle in the body.

The two main ways to monitor pulse are manually and with a stethoscope. The benefit of using a stethoscope over just holding fingers over the neck or wrist is that a stethoscope allows you to hear the valves closing and blood moving through the heart and arteries. This gives the doctor critical information about the health of your heart and how well blood is flowing, not just the rate.

# Activity 2: Low-Cost Stethoscope

### Exploration Questions

1. Try using the medical stethoscope to listen to your heart as well. What differences do you notice?

   [*The sound is clearer with the real stethoscope*.]

2. Do doctors face any challenges using stethoscopes in resource-poor environments that are not faced by doctors in western hospitals?

   [*No. The stethoscope has no consumable parts, it is inexpensive, rarely breaks, and is easy to use. Donated stethoscopes or even new ones work just as well for doctors in the developing world as they do in the developed world*.]

# Activity 3: Building a Bili-meter

**Time Required:** 60 minutes **Group Size:** 2-3

## Materials List

### Each group needs:

- Phototherapy test light:
  - 1 Breadboard
  - 1 Battery (9 V)
  - 1 Battery snap
  - 2 Resistors (1 kΩ)
  - 1 Blue LED
  - 1 White LED
  - 10 Jumper wires
  - 2 Alligator leads
- Bili-meter:
  - 1 Blue glass filter
  - 1 Solar cell
  - 1 Piece of black construction paper
  - 1 Roll of clear tape
- 1 Yard stick or tape measure
- 1 Multimeter
- 1 Pair of scissors

### Youth Handouts:

- Common Challenges in Resource-Poor Settings
- Building a Bili-meter

## Getting Ready (10 minutes)

- The 9 V batteries should have a consistent voltage in all groups. If one group's 9 V battery has a significantly lower voltage than the rest of the groups, their bili-meter measurements will be lower.
- Make sure the multimeters work properly before beginning the activity.
- Cut black construction paper into 3" x 2" rectangles (or enough to cover the solar cell completely).

## Learner Outcomes

- Explain that neonatal jaundice affects many babies because of excess bilirubin in the blood.
- Explain that phototherapy is an effective treatment for neonatal jaundice.
- Explain that donated phototherapy lights are often used ineffectively in developing countries because of either improper device maintenance or improper usage.
- Design and build a simple phototherapy unit.
- Explain the difference between parallel and series circuits.

# Activity 3: Building a Bili-meter

### Vocabulary

| Word | Definition |
|---|---|
| **Bili-meter** | A biomedical device which measures light intensity levels emitted by phototherapy units to ensure they are working properly. |
| **Bilirubin** | A brownish yellow substance found in bile. The liver of newborn babies sometimes cannot break down bilirubin causing jaundice. |
| **Jaundice** | A yellow-orange discoloration of the skin, whites of the eyes, etc. due to an increase of bilirubin in the blood. |
| **Phototherapy** | The use of light in the treatment of disease. |
| **Parallel circuit** | A circuit with more than one path for current to flow. |
| **Series circuit** | A circuit with only one path for current to flow. |

### Introduction

Up to 60% of babies develop a condition called neonatal **jaundice** during the first week or so after birth. This is caused by the condition hyperbilirubinemia (hyper-bil-uh-roo-buh-nee-mee-uh), an unhealthy buildup of **bilirubin** in the blood. Bilirubin is produced in the liver during the breakdown of red blood cells and is normally removed from the body with other wastes. However, if the body has trouble processing the compound, it can start to build up—potentially causing damage to brain cells and resulting in the development of jaundice, or a yellowing of the skin and whites of the eyes.

The condition usually subsides on its own within a few days, but some cases require treatment in the form of **phototherapy**. There are many different types of phototherapy, depending on the condition being treated, but all consist of exposure to a specific type of light. Babies born with jaundice are exposed to blue light, with a wavelength between 460-490 nanometers, which is absorbed by the skin and helps convert bilirubin into a compound that can be easily excreted by the baby's body.

Phototherapy machines are commonplace in Western hospitals and are often donated to hospitals in developing countries such as Honduras, Tanzania, or India. Donating medical equipment can be a big help in developing countries, if done properly. Unfortunately, one of the biggest issues with donated phototherapy units is that, when the bulbs burn out or become damaged, replacement bulbs are difficult to acquire.

What other problems might hospitals in resource-poor environments have when using a donated phototherapy machine?

[*Give students a minute to think about it and, if they have trouble coming up with ideas, you can tell them to refer to their Common Challenges in Resource-Poor Settings handout. Below are a few possible answers:*

- *Phototherapy machines are sometimes misused.*
- *The distance from the baby to the phototherapy unit is not calibrated and therefore the baby might not receive a successful dose.*
- *Multiple babies are placed under a single machine.*
- *Babies are not placed under the light long enough due to a shortage of phototherapy units.*

# Activity 3: Building a Bili-meter

- *Incorrect replacement bulbs are used.*
- *Electricity is too expensive to run the phototherapy units.*]

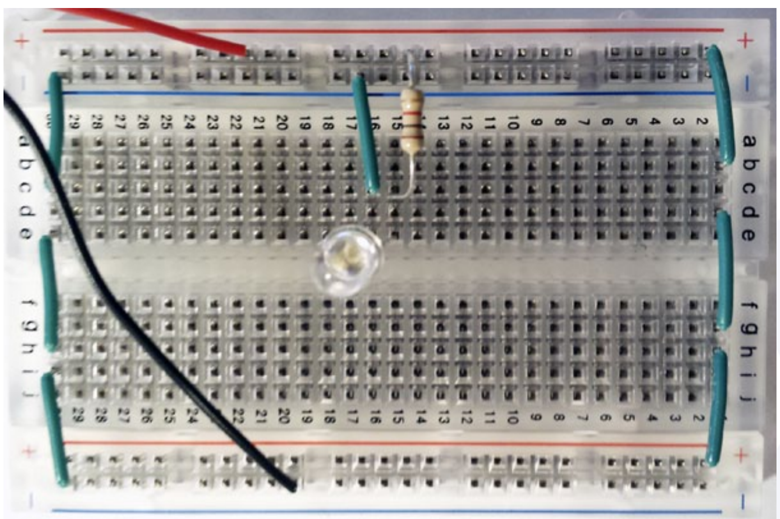
To determine whether or not a piece of medical equipment is functioning properly or calibrated correctly, hospitals are equipped with a variety of biomedical test equipment. In the case of phototherapy, a **bili-meter** is used to measure the light intensity of the phototherapy unit.

In this activity, you're going to explore a solution designed by engineering students partnered with Engineering World Health to find an inexpensive way to calibrate and test phototherapy units. Later, you will design, build, and test your own sustainable low-cost phototherapy unit.

### Facilitating the Activity

1. First, students will make a bili-meter using the instructions in the youth handout. The blue filter should fit snuggly into the construction paper cutout.
2. Students will then create a simple circuit with one blue light-emitting diode (LED) using the circuit diagram and wiring table in the Youth Handout.

   Instruct students on how a breadboard is wired (i.e. which holes are connected vertically and which are connected horizontally) and let them experiment. There are numerous ways to connect the circuit on the breadboard. Have them reconfigure the connections in their circuit to better understand how the breadboard works. For example, they could choose not to use the jumper wires and simply stretch the legs of the LEDs to the other side of the breadboard or stretch the legs of the resistors. Knowing how to use a breadboard will be vital when they design their phototherapy unit prototype in the next activity.

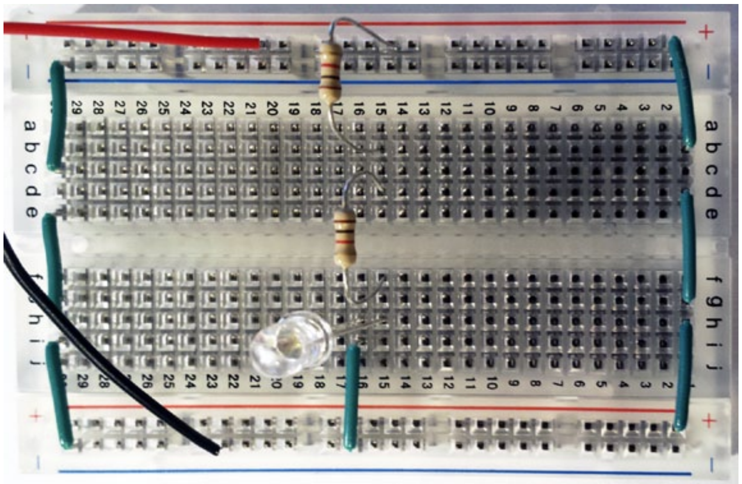


3. Using the blue LED circuit, they will test their bili-meter by taking readings at 5, 10, 15, 20, and 25 inches away from the light. Each measurement will be recorded in the provided table and plotted on a graph. They will connect these points with a *dashed* line.
4. They will then repeat this process with a white LED and connect the plotted points from the white LED measurements with a *solid* line.

# Activity 3: Building a Bili-meter

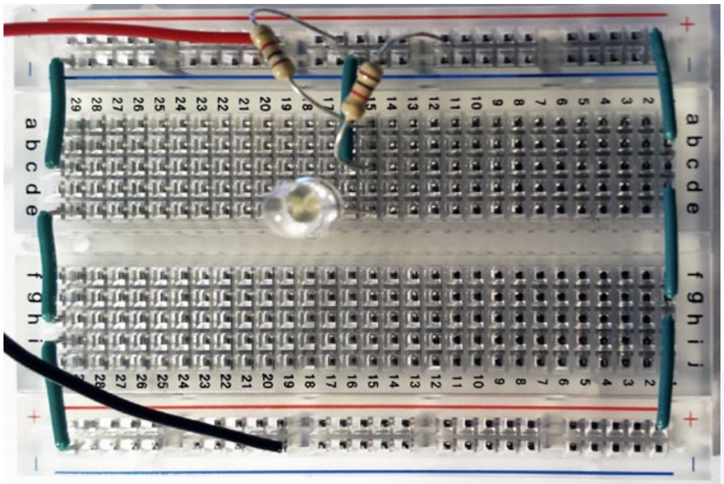
5. Next, students will build two other circuits: 2 resistors in series and 2 resistors in parallel. Make sure they understand the difference between these two configurations.

   A series circuit, like Christmas lights, requires a continuous connection for the circuit to work because there is only one path for the current to follow. If one light burns out, all of the lights turn off.



*Two Resistors in Series*

   The second arrangement is a parallel circuit. Parallel circuits have more than one path for the current to flow. Unlike series circuits, a parallel circuit can continue to provide electricity to other parts of the circuit even when one part is turned off, obstructed, or damaged. House wiring is a good example of a parallel circuit. If you turn one light off in your house the other lights still continue to work.



*Two Resistors in Parallel*

6. Students will then turn their multimeter dial to 20 mA and test the light intensity of each circuit. To do this, they should place the blue filter on the bili-meter a few inches away from the LED and record the multimeter reading. They should notice that LED in the parallel circuit produces a higher light intensity.

# Activity 3: Building a Bili-meter

### Activity Closure

In this activity we learned that neonatal jaundice, caused by an excess of bilirubin in the blood, affects over 60% of infants worldwide. The condition usually subsides on it's own but some cases require phototherapy treatment. Since a baby must be exposed to a very specific color and intensity of light, a bili-meter in needed to ensure the phototherapy unit is working correctly.

Although phototherapy units are very common in Western hospitals, many developing countries have difficulty obtaining and maintaining them. Fortunately, engineering students partnering with Engineering World Health have developed an inexpensive phototherapy unit and bili-meter that can be made with basic electrical components.

### Exploration Questions

1. What do you notice from these experiments? Which light produces the lowest bili-meter readings? Why?

   [*The white LED produces a lower current measurement than the blue LED at the same distance because the blue filter on the bili-meter is filtering out all light except in the blue part of the spectrum.*]

2. Do your plotted points produce a straight line or a curved line? Why?

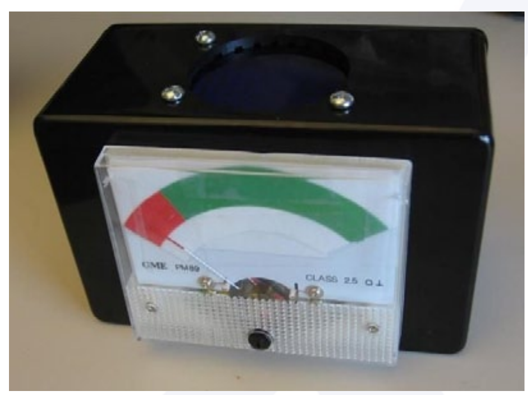
   [*The lines should be curved and decreasing with increasing distance.*

   *As the light gets farther away, it's intensity (or brightness) decreases. This is because the light spreads out from the source in every direction and becomes less dense as it covers more area. Specifically, the decay of light follows a rule known as the inverse-square law. This means that every time you double the distance from the light source, its intensity should decrease by 1/4th.*]

3. Why do you think the engineers of the bili-meter pictured below chose to use a green and red gauge rather than a digital readout like the multimeter?

   [*Communicating how to use a product is an integral part of great engineering design. As mentioned in the "Common Challenges" handout, a missing instruction manual or a manual written in the wrong language can be very problematic. The green and red meter uses colors rather than numbers and words to simplify the reading.*

   *If a phototherapy unit is working properly and kept at an appropriate distance, the bili-meter needle will be in the green. If not, it will be in the red. This concept is so universal that almost anyone, regardless of language or culture, can easily grasp it without ever opening an instruction manual.*]



# Activity 4: Phototherapy Design Challenge

**Time Required:** 90 minutes **Group Size:** 2-3

## Materials List

### Each group needs:

- Phototherapy light:
  - 1 Breadboard
  - 1 Battery (9 V)
  - 1 Battery snap
  - Resistors (1 kΩ)
  - 6 Blue LEDs
  - Jumper wires
  - 2 Alligator leads
- Bili-meter (from Activity 3)
- 12" String
- Multimeter

### Youth Handouts:

- Common Challenges in Resource-Poor Settings
- Baby Grid
- Phototherapy Design Challenge

## Getting Ready (5 minutes)

- The 9 V batteries should have a consistent voltage in all groups. If one group's 9 V battery has a significantly lower voltage than the rest of the groups then their bili-meter measurements will be lower.
- Make sure the multimeters work properly before beginning the activity

## Learner Outcomes

- Explain the purpose of a bili-meter.
- Design, build, and test a low-cost phototherapy unit.

# Activity 4: Phototherapy Design Challenge

## Introduction

There are several different types of phototherapy lamps used for neonatal jaundice treatment. These include tungsten halogen bulbs, fluorescent lamps, and most recently light emitting diodes (LED). Another type of device is a biliblanket. The biliblanket is a mat or vest that emits light and is laid directly on baby's skin. The benefit of the biliblanket is its portability, which allows treatment of some types of jaundice at home.

In hospital settings, healthcare professionals need to ensure that the correct intensity of light is being distributed evenly over the baby's body. Because the strength (or intensity) of light drops very quickly as you move away from a light source, it is important that the phototherapy unit be placed at the correct distance away from the baby. If the baby is too far away from the light source, the light intensity will be too weak to break down the bilirubin in the body.

This is where the bili-meter comes in. As you learned in the previous activity, a bili-meter can be used to calibrate and monitor phototherapy units. Now that you've built your own bili-meter, you will use it as a tool to help you design a small-scale phototherapy unit and test to make sure it distributes light evenly and at the correct intensity.

## Facilitating the Activity

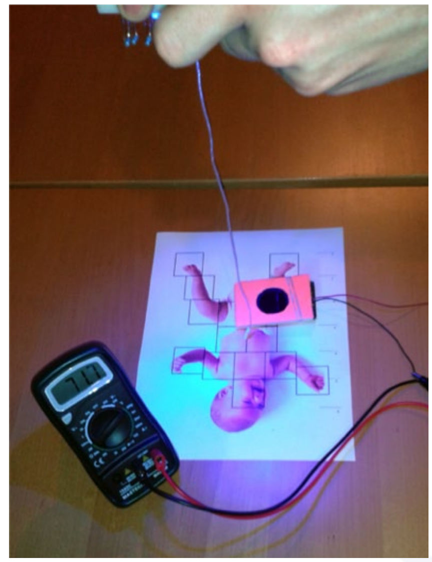
1. Pass out the handouts and materials. Introduce the design challenge, constraints, and material costs.
2. Before students begin building, go over the following warnings:
    - Current will only travel through LEDs in one direction. They will not work if installed backwards.
    - Always have at least one resistor in the circuit between the positive side of the battery and the positive leg of the LED. If there are no resistors, the LED will burn out.
    - NEVER use more than 3 resistors in parallel with a LED. This will cause the LED to burn out.
3. Students should brainstorm within their group several different possible circuit designs and then choose the best one. [*We hope your students come up with several innovative LED layouts. When we tested this activity with a group of middle school youth one group made an LED layout in the shape of a person! Although not a practical solution, it was a great idea!*]
4. Once the students decide on their final layout, they should draw it on the breadboard diagram in the handout. They should also draw any other wires and electrical components needed to set up that circuit.
5. The students will then build a phototherapy unit prototype in their groups. Walk around and assist the students if they are having trouble.

    If an LED does not light up they may have placed a wire in the wrong hole, the LED may be flipped around in the wrong orientation/polarity, or a component may be connected to make a short circuit. [*A short circuit allows the current to bypass the intended path for a path of very low resistance. If a student creates a short circuit, immediately remove the battery as the excessive current can quickly damage the components.*]

    Also, make sure the students understand why the resistor is needed. Explain to them that *the resistor reduces the current going into the LED*. If the resistor were not there, the current would be too high for the LED causing it to burn out.

# Activity 4: Phototherapy Design Challenge

6. IMPORTANT! MAKE SURE TO TURN OFF THE CEILING LIGHTS IN YOUR ROOM BEFORE TAKING ANY MEASUREMENTS! AMBIENT LIGHT WILL PRODUCE HIGHER/INCONSISTENT BILI-METER READINGS.



7. To test their designs, one student will hold the phototherapy unit over the center of the baby. The string taped to the breadboard will allow them to hold the phototherapy unit steady at 12" above the paper.
8. Another student will take bili-meter readings in each grid square. Make sure the student holding the phototherapy unit holds it as steady as possible. They might also want to place a small piece tape on the back of the baby grid so that the paper remains stationary on the table.
9. After taking measurements in all of the squares on their baby grid and recording them in their handout, the students should determine if their phototherapy unit meets the all of the criteria. If not, they should try modifying it. Even if it does meet the minimum criteria, students still may wish to make modifications and try new ideas in order to optimize their design (see example designs on the next page).
10. Once they are satisfied with their design, students should record and calculate the total cost of the unit according to the *Material Cost* chart.
11. They will then use the following formula to calculate each unit's overall performance. The phototherapy unit with the highest performance score is the winner.

$$\text{performance} = \frac{\text{average light intensity}}{\text{total cost}}$$

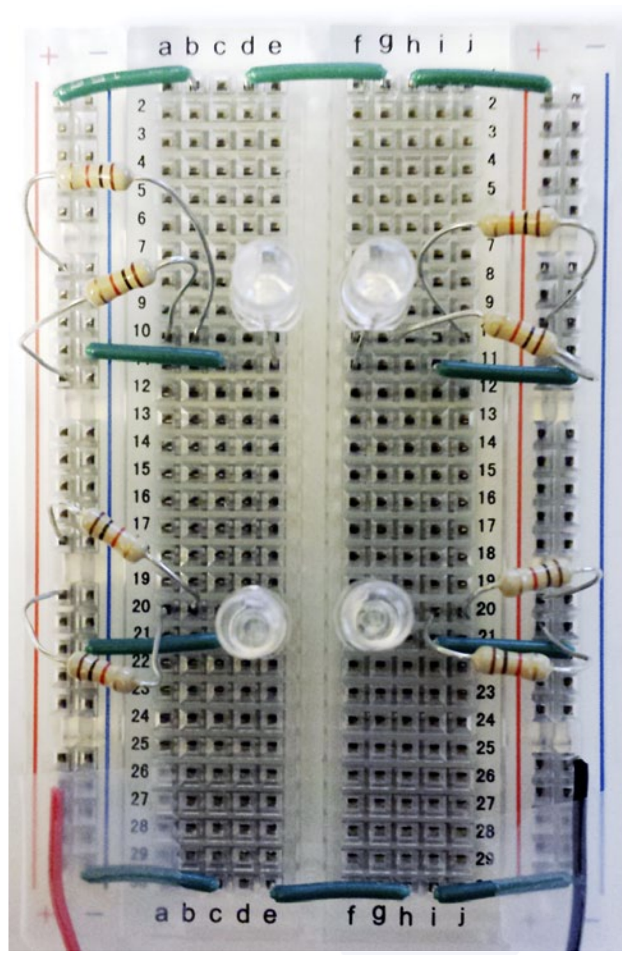
# Activity 4: Phototherapy Design Challenge

## Example Design #1: Optimizing Cost

Total Cost: $29.60
Average Light Intensity: 115.9 µA (Jameco LEDs)

Performance Score: 3.9

| Component | Start | End |
|---|---|---|
| Resistor 1A | TRL | A20 |
| Resistor 1B | TRL | B20 |
| LED 1 | Pos to E20 | Neg to E21 |
| Wire 1 | C21 | TBL |
| Resistor 2A | TRL | A10 |
| Resistor 2B | TRL | B10 |
| LED 2 | Pos to E10 | Neg to E11 |
| Wire 2 | C11 | TBL |
| Resistor 3A | BRL | J20 |
| Resistor 3B | BRL | I20 |
| LED 3 | Pos to F20 | Neg to F21 |
| Wire 3 | I21 | BBL |
| Resistor 4A | BRL | J10 |
| Resistor 4B | BRL | I10 |
| LED 4 | Pos to F10 | Neg to F11 |
| Wire 4 | I11 | BBL |
| Wire 5 | TRL | B1 |
| Wire 6 | D1 | G1 |
| Wire 7 | H1 | BRL |
| Wire 8 | TBL | C30 |
| Wire 9 | E30 | H30 |
| Wire 10 | I30 | BBL |
| Battery Snap | Red to TRL | Black to BBL |



LED Pos = Long Leg
LED Neg = Short Leg
TRL = Top Red Line
BRL = Bottom Red Line
TBL = Top Blue Line
BBL = Bottom Blue Line

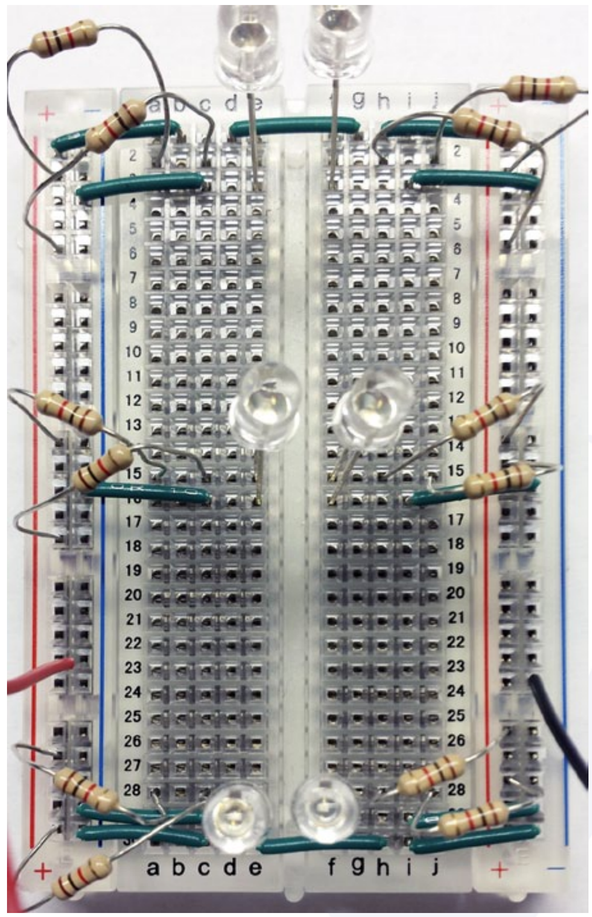
# Activity 4: Phototherapy Design Challenge

### Example Design #2: Optimizing Light Intensity

Total Cost: $42.00
Average Light Intensity: 161.7 µA (Jameco LEDs)

Performance Score: 3.85

| Component | Start | End |
|---|---|---|
| Resistor 1A | TRL | A28 |
| Resistor 1B | TRL | C28 |
| LED 1 | Pos to E28 | Neg to E29 |
| Wire 1 | C29 | TBL |
| Resistor 2A | TRL | A15 |
| Resistor 2B | TRL | C15 |
| LED 2 | Pos to E15 | Neg to E16 |
| Wire 2 | C16 | TBL |
| Resistor 3A | TRL | A2 |
| Resistor 3B | TRL | C28 |
| LED 3 | Pos to E2 | Neg to E3 |
| Wire 3 | C3 | TBL |
| Resistor 4A | BRL | J28 |
| Resistor 4B | BRL | H28 |
| LED 4 | Pos to F28 | Neg to F29 |
| Wire 4 | I29 | BBL |
| Resistor 5A | BRL | J15 |
| Resistor 5B | BRL | H15 |
| LED 5 | Pos to F15 | Neg to F16 |
| Wire 5 | I16 | BBL |
| Resistor 6A | BRL | J2 |
| Resistor 6B | BRL | H2 |
| LED 6 | Pos to F2 | Neg to F3 |
| Wire 6 | I30 | BBL |
| Wire 7 | TRL | B1 |




| Component | Start | End |
|---|---|---|
| Wire 8 | D1 | G1 |
| Wire 9 | H1 | BRL |
| Wire 10 | TBL | C30 |
| Wire 11 | E30 | H30 |
| Wire 12 | I30 | BBL |
| Battery Snap | Red to TRL | Black to BBL |

# Activity 4: Phototherapy Design Challenge

## Activity Closure

The goal of the Duke-EWH Competition for Underserved Resources and Economies, or CUREs, is to promote the development of new healthcare technologies to aid resource-poor nations across the globe. Through the CUREs program, each year business majors and engineers team up to design new equipment and solutions for developing world problems. In 2006, the prize-winning project was a phototherapy unit designed by Vijay Anand. While typical phototherapy units cost up to $4000 apiece, Anand's LED-based unit only costs about $500--a difference in price that could save the lives of thousands of infants.

After graduating from Duke University with a masters degree in engineering management, Anand used his contest winnings to establish a non-profit company called PhotoGenesis, which uses his design and business plan to commercialize and distribute the units. The final product, BluLine (pictured below), provides a complete phototherapy solution to hospitals in developing countries.

## Exploration Questions

1. You've just learned that a filtered solar panel can be used to test a phototherapy unit and that you can build a phototherapy unit out of basic inexpensive parts. What else would you need for these to be effective devices in a hospital?

   [*Bili-meter:*
   - *An enclosure to hold it in place*
   - *Calibration so you know what current represents the correct light intensity*
   - *Instructions, potentially in multiple languages*

   *Phototherapy Unit:*
   - *Increased number of LEDs to effectively treat a life-size infant*
   - *Clinical trials*
   - *Design for wall power or higher battery power*
   - *Design a housing/fixture to hold the light's in place*]

2. What needs of a resource-poor setting does the bili-meter meet? What kinds of problems can it detect?

   [*The bili-meter assists hospitals with maintenance on the phototherapy machine, because it quickly tells the technician, nurse, or doctor know if the machine is in working condition. It can detect low power output in the phototherapy unit, use of the wrong kind of bulb in the wrong part of the spectrum, and if the baby is the correct distance away from the light.*]

# Activity 4: Phototherapy Design Challenge

3. Could babies with neonatal jaundice be treated by simply placing them in direct sunlight?

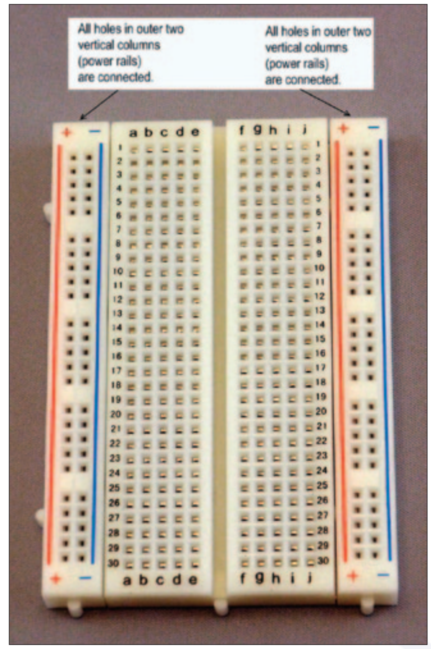
   [*Yes, in some cases sunlight can actually be more effective than using phototherapy units to treat jaundice. However, sunlight also contains damaging UV rays, which can cause sunburns and be harmful to the baby.*]

## Optional Extension

The following video shows another phototherapy unit designed for the developing world by professional engineers at an organization called Design that Matters: vimeo.com/65174744. This video briefly takes students through the design process of the Firefly phototherapy unit and is a perfect example of the real world applications of the activity they just completed.

# Tools Used in this Module

## Electrical Breadboard




Breadboards are used to build and test electrical circuits. Wires can be inserted into the holes to connect components in a circuit.

All holes in each of the outer vertical columns (power rails) are electrically connected inside of the breadboard. There are two power rails on the left side and two power rails on the right side. Generally, the blue power rail is negative and the red power rail is positive.

In the center, there are rows of holes labeled A-J. All five holes in a single row are connected inside the breadboard. Opposite halves of the breadboard are not connected.

Examples:

- A1 is connected to D1
- A1 is NOT connected to A2
- E1 is NOT connected to F1

## Digital Multimeter

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

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

Voltage

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

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

# Tools Used in this Module

Resistance

Resistance is measured in ohms (Ω). To measure a resistor, turn the selection knob to a value slightly higher than the expected resistance. For example, to measure a 100 kΩ resistor, the meter should be set to the "200k" position or higher in the Ω range.

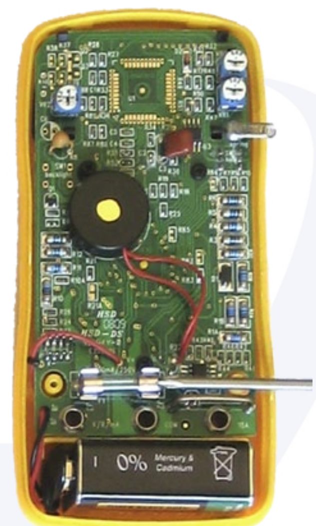
Use your fingers to pinch the meter probes against the metal wires coming out of each side of the resistor. It doesn't matter which way you hook up the meter probes. You will not measure a negative resistance if you swap the probes.

Current

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

Replacing a Fuse or Battery

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



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

# Glossary

### Bili-meter
A biomedical device which measures light intensity levels emitted by phototherapy units to ensure they are working properly.

### Bilirubin
A brownish yellow substance found in bile. The liver of newborn babies sometimes cannot break down bilirubin causing jaundice.

### Consumable
An item that is disposable and gets thrown away after use. Examples include bandages, syringes, tongue depressor, etc.

### ECG Electrode
A small electrically conductive pad that attaches to the skin in order to better measure electrical signals inside the body.

### Electrocardiogram (ECG)
A graph of the heart's electrical signal pattern (displayed on the screen of the electrocardio*graph* machine).

### Jaundice
A yellow-orange discoloration of the skin, whites of the eyes, etc. due to an increase of bilirubin in the blood.

### Parallel circuit
A circuit with more than one path for current to flow.

### Phototherapy
The use of light in the treatment of disease.

### Pulse
The rhythmic contraction and expansion of the arteries with each beat of the heart.

### Series circuit
A circuit with only one path for current to flow.

### Stethoscope
An instrument used by doctors to amplify sounds inside the body, such as the heartbeat.

# Acknowledgements


## Authorship Team

Dr. Ed Maxa, Associate Professor (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Kate Guerdat, Former 4-H Extension Associate, Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University

Amy Chilcote, 4-H Extension Associate, Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University

Dr. Mitzi Downing, Department of 4-H Youth Development Cooperative Extension Service, North Carolina State University.

Kristy Oosterhouse, 4-H Program Coordinator, Children and Youth Institute, Michigan State University Extension

Dr. Jacob DeDecker, Program Leader, Children and Youth Institute, Michigan State University Extension

Steven Worker, 4-H SET Coordinator, University of California Agriculture and Natural Resources, Youth, Family and Communities, 4-H Youth Development Program

Lynn Schmitt-McQuitty, County Director & Science Literacy Youth Development Advisor, University of California Agriculture and Natural Resources

Dr. Matthew T. Portillo, 4-H Youth Development Program Advisor, Academic Assembly Council President, University of California, Butte County

Amanda Meek, 4-H SET Educator, University of Missouri Extension

Dr. Jeff Sallee, Assistant Professor and Extension Specialist 4-H Youth Development, Oklahoma State University

Dr. Gary A. Ybarra, Professor of Electrical and Computer Engineering, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Dr. Paul Klenk, Research Scientist, Duke University

Wendy Candler, Curriculum Development / Graphic Design, Techsplorers

## Curriculum Developers

Dr. Paul Klenk, Research Scientist, Duke University

Alexander Dahinten, Duke University Developing World Healthcare Technology Laboratory Technical Coordinator

John Sanderson, EWH Student Programs Coordinator

Carlos Amaral, EWH Student Programs Coordinator

Alex Chan, Curriculum Development, Techsplorers

Wendy Candler, Curriculum Development / Graphic Design, Techsplorers

Dr. Gary A. Ybarra, TechXcite Principal Investigator, Duke University

## Collaborative Contributors

Donna Patton, Extension Specialist, West Virginia University Extension Service

Sherry Swint, Extension Agent, West Virginia University Extension Service

Lynna Lawson, 4-H Youth Development Specialist, University of Missouri Extension

Robert B. Furr, County Extension Director, North Carolina Cooperative Extension

Carla Burgess, Youth Curriculum Reviewer, Duke University

# Acknowledgements


## Layout, Graphics, & Design

Jenny McAllister, Adobe InDesign Layout, Techsplorers

Wendy Candler, Illustration / Graphic Design, Techsplorers

Illustration / Graphic Design / Website Design – Cuberis Design + Web Solutions

## Leadership Team

Dr. Ed Maxa, Professor Emeritus (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Allen O'Hara, Grant Manager, National 4-H Council

Gregg Tabbachow, Grant Manager, National 4-H Council

Dr. Gary A. Ybarra, Professor of Electrical and Computer Engineering, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

## Research Team

Dr. Ed Maxa, Professor Emeritus (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Dr. Mitzi Downing, Department of 4-H Youth Development Cooperative Extension Service, North Carolina State University.

Dr. Eddie Locklear, Director of National 4-H Afterschool Program (retired 2012)

Dr. Gary A. Ybarra, TechXcite Principal Investigator, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Dr. Anne D'Agostino, TechXcite Program Evaluator, Compass Evaluation and Research Inc.

## Program Management

Rodger Dalton, TechXcite Program Manager (2012-2014), Duke University

Dr. Paul Klenk, TechXcite Program Manager (2007-2012), Duke University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### Youth Handouts

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