Learning by Making

UNIT 2

Going with the Electron Flow

Starting an LEDs Project

Starting a new LEDs project

Answer each question as shown below. If you do not see a black full screen window with questions,
(1) click on the **black icon** at the bottom of your screen,
(2) type `start` and
(3) hit the **enter** key.

Terminal

```
Would you like to load an existing
experiment? (y/n)
> n

Would you like to create a new experiment
(y/n)
> y

Please select an experiment by typing its complete name.
List of experiments
> LEDs.tar

Provide a name for the new experiment folder.
> LEDs-YourName

Please select version by typing its complete name
start
> start
```

At the end of the questions and answers, you should see a new window pop up in the bottom left corner of your computer screen (and the question screen will disappear).

Starting a previously created LEDs project

Answer each question as shown below. If you do not see a black full screen window with questions,
(1) click on the **black icon** at the bottom of your screen,
(2) type `start` and
(3) hit the **enter** key.

Terminal

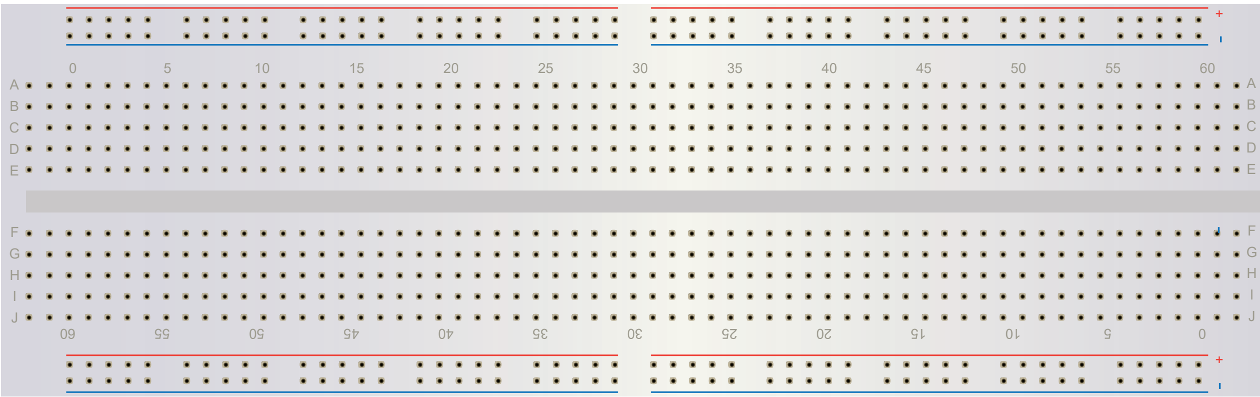
```
Would you like to load an existing experiment? (y/n)
> y

Which experiment would you like to load?
> LEDs-YourName
```

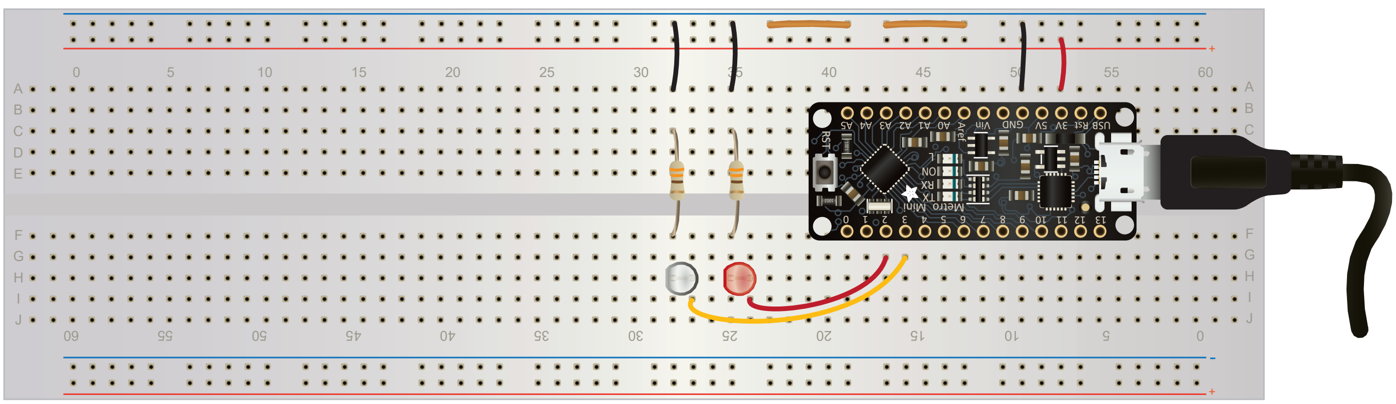
At the end of the questions and answers, you should see a new window pop up in the bottom left corner of your computer screen (and the question screen will disappear).

Components and Material

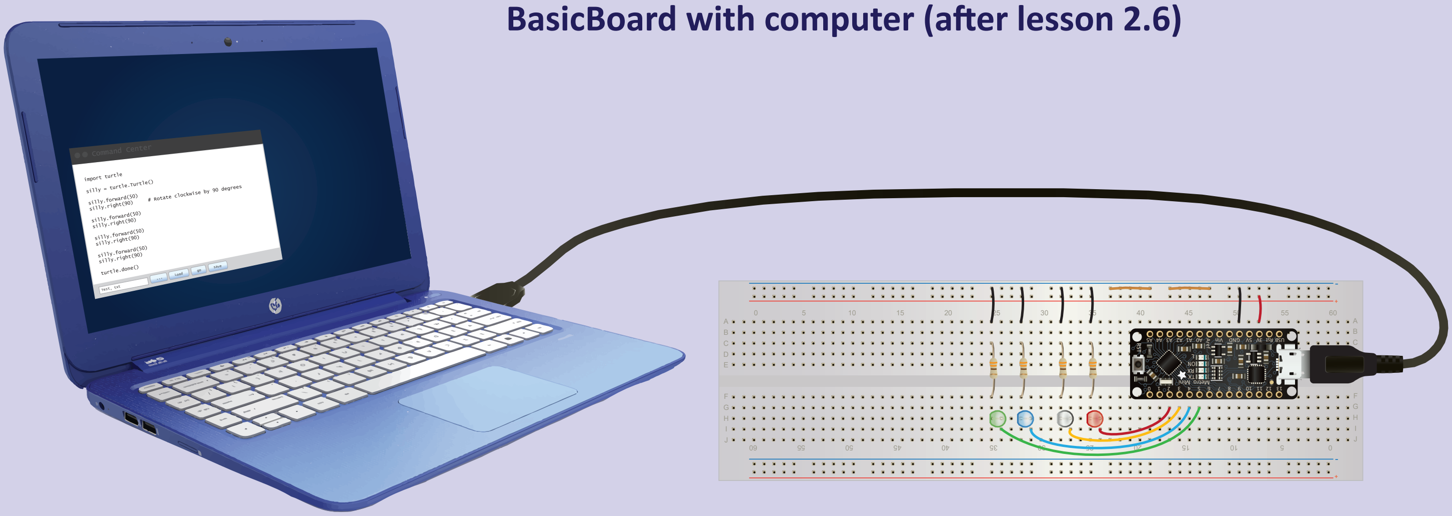
Blank Breadboard



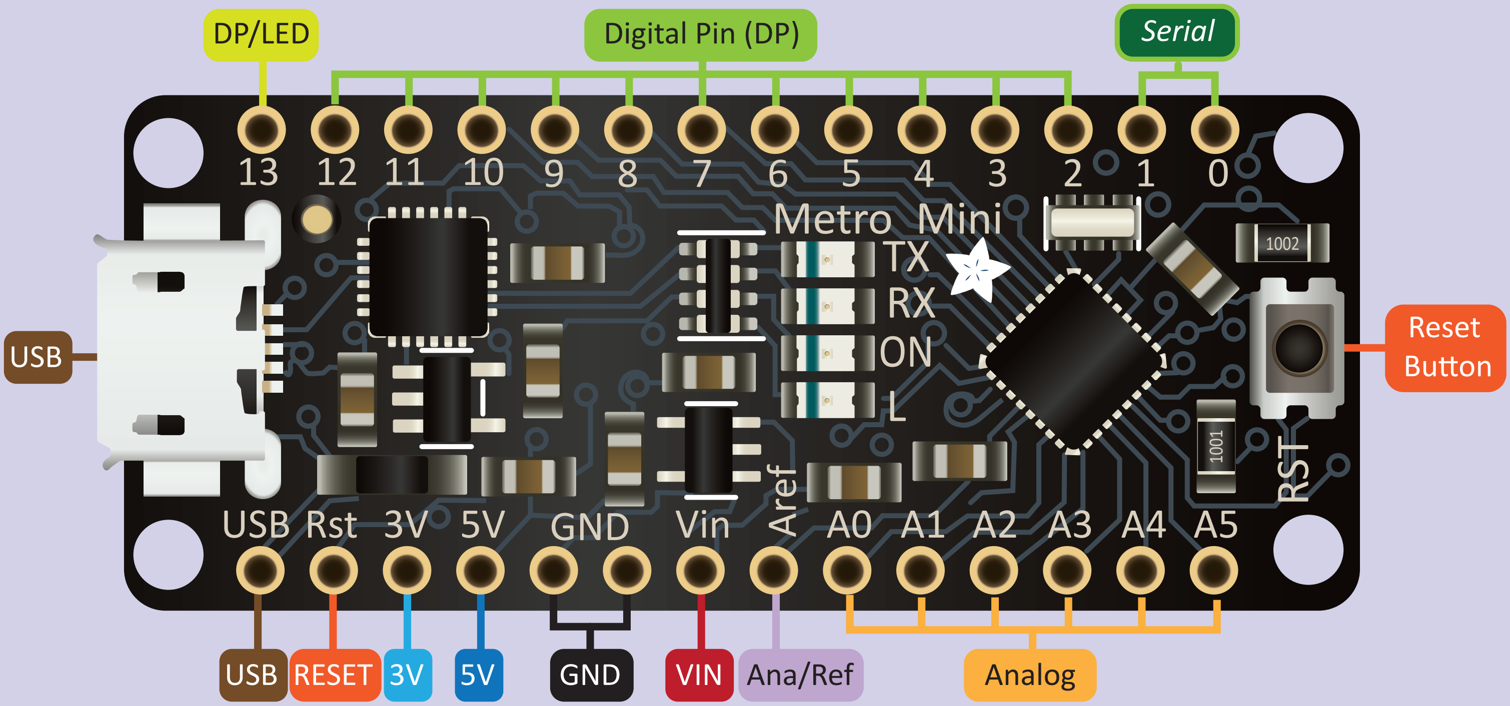
BasicBoard (as delivered)



BasicBoard with computer (after lesson 2.6)

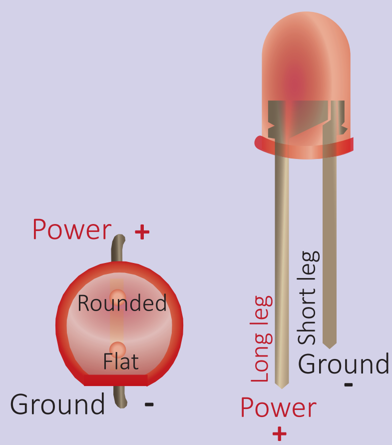


Arduino

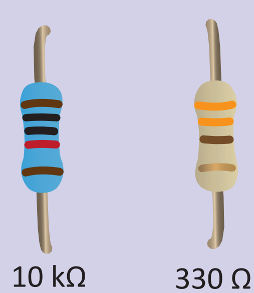


Multimeter

LED (top and side view)



Resistors



Promise to Stay Grounded

Electrostatic discharge can and will damage sensitive electronic compontents like the application board. Simple acts like getting up from a chair, walking around on a carpet, or touching objects can induce a charge on your body.

What can you do to avoid electrostatic discharge?

- **Keep your components in antistatic bags until you are ready to use them**
- **Wear cotton clothing rather than wool or synthetic fibers**
- **Avoid shuffling your feet on carpet**
- **Touch unpainted metal with a clear grounded path**

The threshold for you feeling a small shock is much higher than that of the equipment we will be using in this classroom. It is for this reason that you must shed excess electrons from your body before working with the BasicBoard.

You must **GROUND** yourself.

I, ____________________, hereby promise to ground myself before working with sensitive electronics. I will touch the copper loops on the BasicBoard with both my feet firmly on the floor on a regular basis.

________________________________ ______________

Signature Date

2.1 Introducing the BasicBoard

Learning Objectives:

- Students will investigate the structure and function of the Arduino, BasicBoard, and breadboard.
- Students will learn how to use the Computer to send signals to the BasicBoard.

Materials

For each group of 2 students

- Basicboard
- Computer

For each student

- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

- Arduino
- BasicBoard
- Breadboard
- LED
- Microprocessor
- Programming word
- Sensor
- USB Cable

Tasks you need to perform

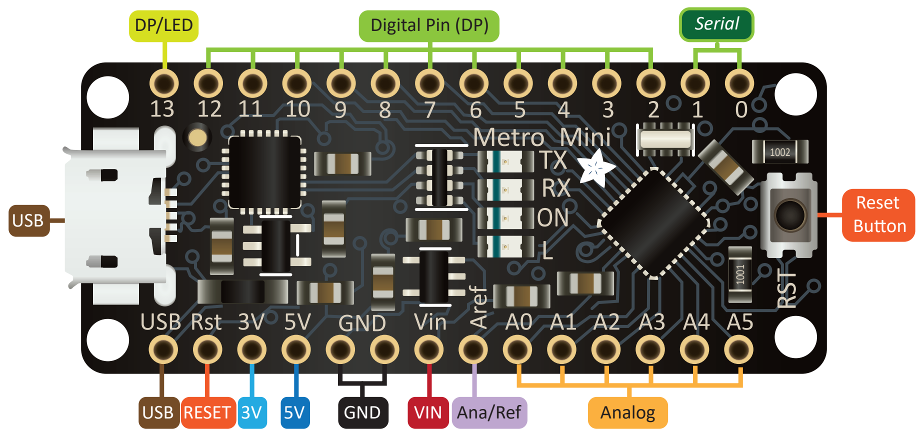
Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

In this class, you will be running experiments using your computer and various electronic **sensors**.

Electronic sensors can't talk directly to your computer. There needs to be a connector of some sort - a smart linking device that is able to understand and control these sensors.

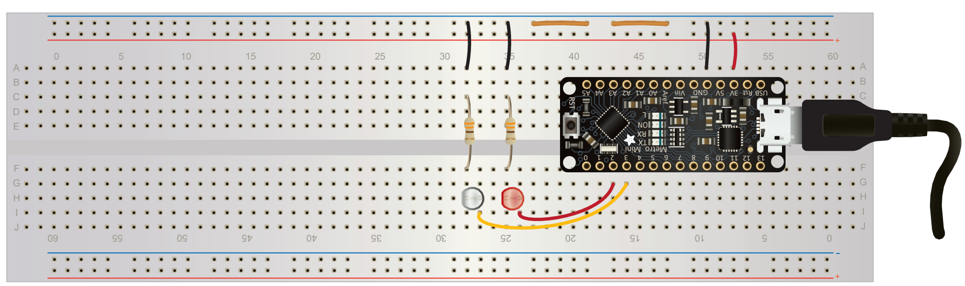
We call this device the ***Arduino****.*



The **Arduino** can store programs in its own built-in memory, and it has a **microprocessor** that can run these programs by sending and receiving signals through 28 metal pins on its perimeter.

The Arduino is connected to a special white plastic **breadboard** with additional wires and components. You will build your experiments on the breadboard. A **USB cable** connects the breadboard to the computer.

We call the Arduino and breadboard combination the ***BasicBoard****.*



We will be typing commands in a computer terminal window. Some commands will be executed by the computer, while others will be run by the microprocessor in the Arduino. To start a new experiment, follow the instructions in this lesson. After the experiment is started, you can always get back to it by remembering the name that you gave it.

Experiment names will always start with the name of the experiment, then a dash, and then YourName. In this lesson, we are running the experiment called "LEDs." If your name is Rey, then your experiment name would be LEDs-Rey.

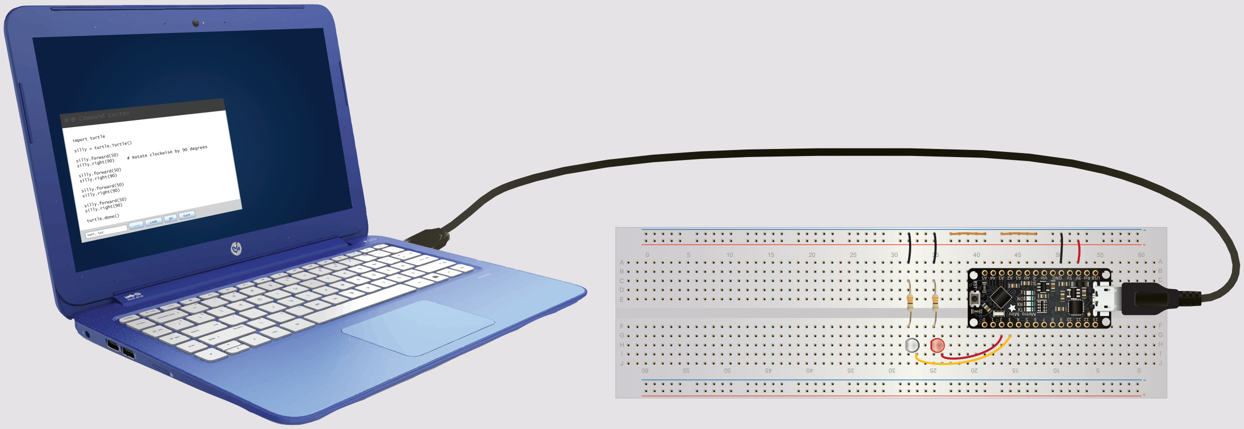
A new window will appear once you start your experiment. If you need to start over because this window disappeared, type **Ctrl-Alt-T** to bring up a new terminal window, and then type `start` and hit the **enter** key. This will bring up the question screen shown in Step 2.

Instructions

STEP 1. Connect the BasicBoard

Turn on your computer and plug in the USB cable from the BasicBoard.

On the worksheet, draw a diagram of the entire system. Label the Arduino, BasicBoard, breadboard, computer, and cable.



STEP 2. Starting a new LEDs experiment

Your computer should now be showing a full screen black window with the first question in purple. Follow the instructions on the top of page 3: *Starting a new LED experiment.*

At the end of the questions and answers, you should see a new window pop up in the bottom left corner of your computer screen (and the question screen will disappear).

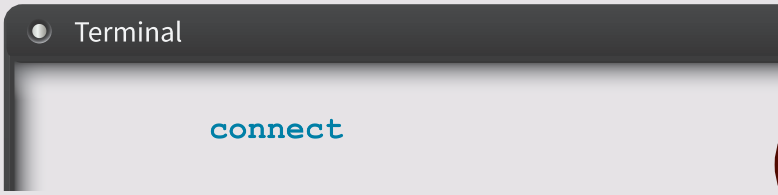
On your worksheet, write down the words that you see in the new black terminal window after you answered all the questions above.

H

If you need to start over, hold down the **ctrl-Alt-T** all at once. Next, type the command start and hit the **enter** key. If the new window does not open, reset or reconnect your BasicBoard.

STEP 3. Connect the Arduino processor with the Computer

Type `connect` in the experiment window. Hit enter. This command will connect the computer to the Arduino, allowing communications through the USB cable. You will start all future experiments with this command.



H

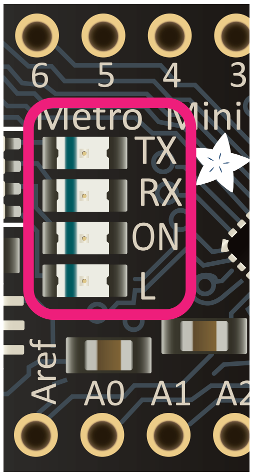
Watch the Arduino during `connect`. If a green light is on, the Arduino has power. If a dim red light blinks quickly, the Arduino is working.

On your worksheet, write the **programming word** that you will always use to start an experiment and the message that is displayed on the terminal after you type it.

STEP 4. Communicate with the Arduino processor to turn on and off the on-board LED light

The Arduino has 4 on-board LED lights:

- Two (Tx and Rx) will blink yellow when data flow to and from the computer.
- A third light (ON) turns green when the Arduino has power.
- The fourth light (L) flashes red when you connect the Arduino and it also can be controlled by the user. We call this light the “on-board” LED , or “OB1”.



Type in the words as shown below in bold. Hit the **enter** key after typing in each word.

Terminal

```
OB1on
OB1off
```

On your worksheet, write down what happened after you type the words:

OB1on
OB1off

If you get an error message, see if you can figure out what you did wrong by asking a classmate for help. If that classmate cannot help you, ask another one.

STEP 5. Complete the challenges

Congratulations! You have successfully connected the Arduino and the Basic Board to the computer, and you have commanded the Arduino to turn on and off its on-board LED. You are now ready for the challenges for this lesson.

Name:____

STEP 1 Sketch a diagram of the entire system. Label the Arduino, BasicBoard, breadboard, computer, and cable.

STEP 2 Write down the words that you see in the new black terminal window after you answered all the questions above.

STEP 3 Write the programming word that you will always use to start an experiment and the message that is displayed on the terminal after you type it

STEP 4 Write down what happened after you type the words: `OB1on` and `OB1off`.

When you type	What happens?
`OB1on`	
`OB1off`	

Name:____

C-1

The Arduino contains a single controllable, onboard red LED. To turn on or off this LED, we type special words into the computer. These words are sent to the Arduino through a USB cable. For example, we used the words `OB1on` and `OB1off` to turn the onboard light on and off, respectively.

Explain how communicating with a computer is similar to or different than trying to communicate in English with someone who is not a native English speaker.

C-2

The Arduino understands more than just the words `OB1on` and `OB1off`. It also knows the word `OB1-blink`. But this word needs a number as input in order to run. Type `OB1-blink 1` to test the word and record what happens.

C-3

Tell the on-board LED to blink on and off using five different input numbers. List the numbers that you used, and record what happens for each.

Number used as input	What happened?

C-4

Based on your observations in C-3, what is the function of the input number (that you typed following the `OB1-blink` command)?

Name:____

D-1

Investigate one or more of the following and write a summary of your findings:

- Microprocessor
- LED
- USB cable

D-2

In this class, we are using a specific Arduino called a "Metro-Mini." Find at least one other style of Arduino and compare it to the Metro-Mini. How are they the same and how are they different? Explain.

Learning Objectives:

- Students will learn how to use a digital multimeter to measure connectivity between different holes in the breadboard.
- Students will learn how to cut and strip wires
- Students will gather evidence to determine the underlying structure of the breadboard.
- Students will learn how to measure resistance using a digital multimeter.

Materials

For each group of 2 students

- Blank breadboard
- BasicBoard
- Needle-nose pliers
- 1 digital multimeter
- 1 red multimeter probe
- 1 black multimeter probe
- wire as needed (approximately 10 cm)
- 1 wire stripper
- Ruler
- Variety of resistors

For each student

- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

- Connectivity
- Current
- Digital Multimeter
- Electron
- Resistance

Tasks you need to perform

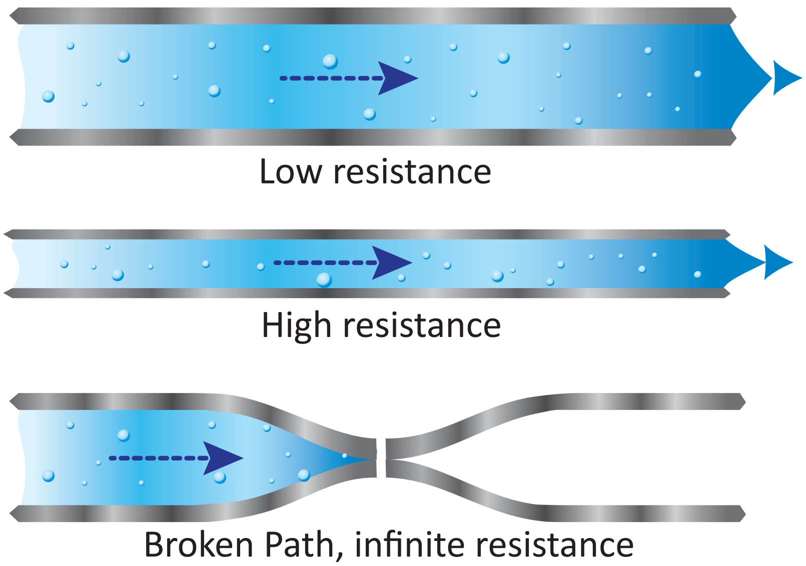
Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

Current is the flow of **electrons** (negatively charged parts of atoms). In order to flow from one place to another, electrons need a path that does not offer much **resistance**.

The images below show cartoons of electrons flowing like water through various tubes. When the tube is really wide, the electrons do not meet much resistance, and can flow more easily, producing a higher current. In a narrow tube, electrons can flow, but they meet with greater resistance, and the current is lower. Electrons cannot flow if the tube is broken, and no current will result due to infinite resistance.

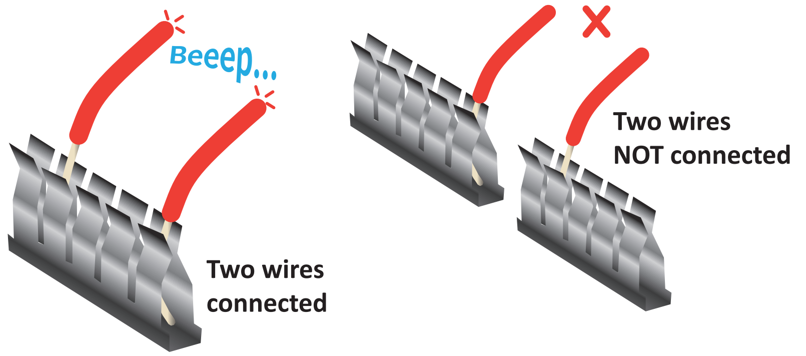
Resistance



Recall the BasicBoard is a specially wired breadboard that houses the Arduino. Without the wires, USB cable and breadboard, there is no way for current to flow from the computer to the Arduino or to any sensors used in future experiments.

Breadboards allow you to make solid electrical connections by plugging wires into holes. Just beneath the plastic coating are rows of metal clips. Current can flow along these small channels of metal, as though they were wires connecting other wires.

In this lesson, we will explore the underlying structure of the metal clips inside the breadboard. Metal allows electricity to flow, but air does not. The metal clips that connect two wires provide an electrical connection between the wires. If wires are connected, then electricity will flow with little resistance. If wires are not connected, the resistance will be infinite (“OL”), and electricity will not flow.



Instructions

STEP 1. Take stock of the materials you have gathered

Gather the materials in the materials list.

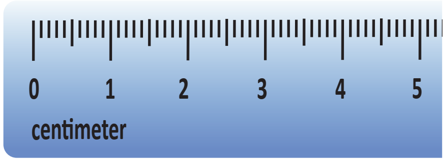
On your worksheet, write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2. Learn how to cut and strip wires using the wire stripper

Using the straight edge of the wire stripper, cut a small piece of wire, about 3 cm long. Look at the size of the insulation on the wire and guess which notch in the wire stripper opening might work best to strip off insulation. Strip about 0.3 cm from each end of your wire

> H
>
> Use needle nose pliers to hold small wires while you cut and strip them.

On your worksheet, put an arrow on the diagram of the wire stripper indicating which notch worked best to strip the wires of insulation.



STEP 3. Connect wires to the breadboard

> H
>
> If you do not strip off enough of the insulation, the wire may not fit properly.
>
> Avoid stripping off too much insulation. Exposed wires may damage circuits or send electrical signals to unintended places.

Plug some wire pieces with stripped ends into various holes on the breadboard to see how well they fit into the holes. Discover the best length to strip off a wire, by creating four new stripped 3 cm wire pieces with more and less insulation stripped off the ends.

On your worksheet, make a table with the first column listing the length of the stripped ends of wires, starting with 0.3 cm and following with your other four lengths. In the 2nd column write one sentence describing how the wire fit into the breadboard hole.

STEP 4. Use a Digital Multimeter to test the connections between holes in the breadboard

A **digital multimeter** is a device that can be used to measure different physical properties of circuits, including resistance and **connectivity**. In this step, you will be testing connectivity. It does not matter which color lead (red or black) you use to touch each wire in the pair that you are testing.

Place four 3 cm wires with stripped ends in any four holes on the breadboard. Pick up your multimeter and set the knob to the →|•)). Push the button that is labeled FUNC.. The screen should now show the))) icon above the OL readout. Touch one lead of the multimeter to one wire sticking out of the breadboard and the other lead to a different breadboard wire. When the two leads are connected by metal, you will hear a beeping sound. Try to make the multimeter beep by placing two wires in holes that are connected by wire under the surface of the breadboard. Move the wires around the board and keep testing until you have done at least 10 tests of holes in different regions.

H

In this lesson, make sure the red lead and black lead touch two different wires.

Your bodies conduct electricity. Make sure you don’t insert yourself into a circuit by touching the metal portion of any probe.

On your worksheet, draw double-headed arrows pointing to pairs of holes on the breadboard that you tested. Label each arrow to indicate whether or not this pair of holes was connected (made the meter beep).

STEP 5. Use a Multimeter to measure resistance of breadboard and resistors

Get at least three different resistors from your instructor. Switch the multimeter so that the dial points to the Ω symbol. The physical unit for Resistance is called Ohm, so the Greek letter Omega (Ω) is used to represent resistance.

In the multimeter display window, you will see numbers or letters. When measuring resistance, OL means "overload" or an extremely large resistance. The resistors in this class vary from 10 Ω to 10 kΩ where k = kilo or 1,000. Therefore 10 kΩ = 10,000 Ω. Another unit you may see is MΩ where M = Mega or 1,000,000.

Put one lead of the multimeter on each end of the resistor. (It does not matter which color lead touches each end.)

On your worksheet, write down the three resistor values that you measured.

H

Check that the multimeter knob is set to measure resistance. You cannot measure resistance for any components within a powered circuit. Unplug all power sources.

Look carefully at the meter readout to see kΩ or MΩ on the bottom right of the display, and include these units in the values you record on your worksheet.

STEP 6. Use a digital multimeter to measure resistance of air and yourself

With the meter set to measure Ω, measure the resistance of air between the two leads. Then hold one lead between the thumb and fingers of one hand, and the other lead in a similar manner in the other hand, to measure your resistance.

H

When you measure the resistance of air make sure the leads are only touching air (and nothing else).

On your worksheet, write down the values that you measured for air and for yourself.

W

Keep leads on the surface of your skin.
Do **NOT** pierce your skin with the leads.

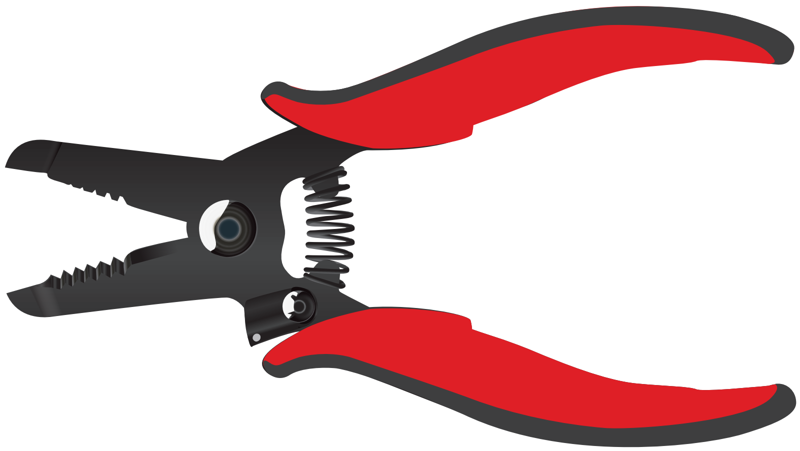
STEP 7. Complete the challenges

Now that you have learned how to measure resistance, please continue with the challenges.

Name:____

STEP 1 Write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2 Put an arrow on the diagram of the wire stripper indicating which notch worked best to strip the wires of insulation.

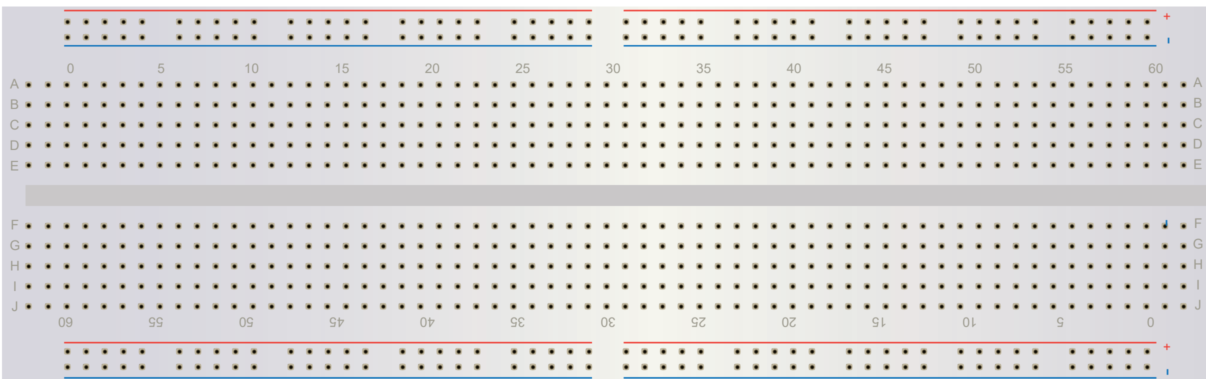


STEP 3 Make a table with the first column listing the length of the stripped ends of wires, starting with 0.3 cm and following with your other four lengths. In the 2nd column write one sentence describing how the wire fit into the breadboard hole.

Length of stripped end	How did the wire fit in the breadboard hole?
0.3 cm	

Name:____

STEP 4 Draw double-headed arrows pointing to pairs of holes on the breadboard that you tested. Label each arrow to indicate whether or not this pair of holes was connected (made the meter beep).



STEP 5 Write down the three resistor values that you measured.

Resistors	Resistance measurement?
R1	
R2	
R3	

STEP 6 Write down the values that you measured for air and for yourself.

Resistors	Resistance measurement?
Air	
Yourself	

2.2 Challenges

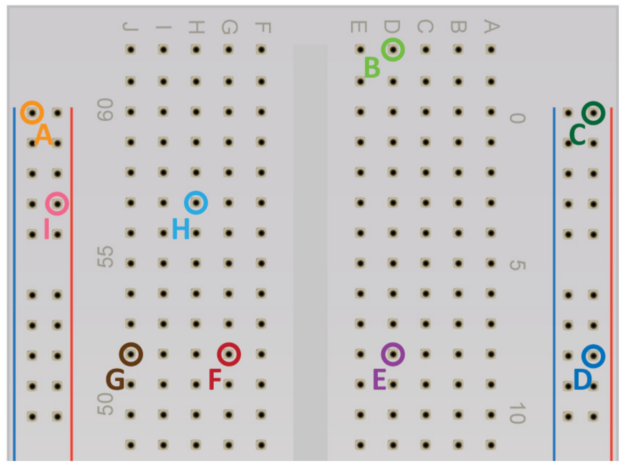
BasicBoard Anatomy

Name:____

C-1

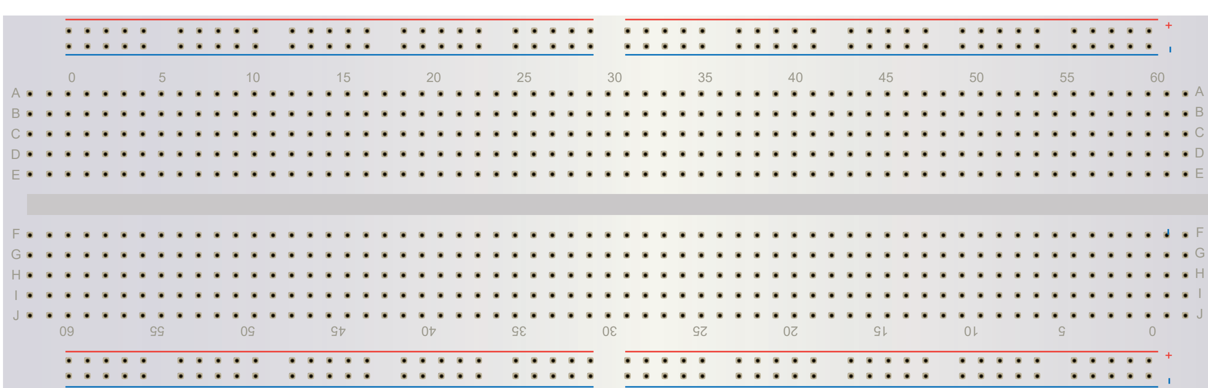
Using a blank breadboard, determine if each pair of holes listed in the following table share an electrical connection or do not share an electrical connection. Fill out the table with “Yes” or “No.”

HOLE 1	HOLE 2	Connected?
A	C	
G	F	
B	E	
E	F	
C	E	
F	H	
B	C	
I	A	
C	D	
D	F	



C-2

Sketch a model of what you think the inside of the breadboard may look like, by using the image below. Draw lines that connect the holes that your measurements indicated were connected. Compare your results to the drawings from at least two of your classmates. If you disagree, make additional measurements to resolve the situation.



Names:____

C-3

Repeat the resistance measurement between your two hands. Then measure resistance for at least 3 other pathways through your body.

Record the results and compare to measurements taken by other students.

Do your measurements agree with others?

Pathways	Resistance measurement?
Between 2 hands	

Observations:____

____

____

____

____

____

____

____

____

Names:____

D-1

Create a YouTube video tutorial for cutting and stripping wires.

D-2

Create a poster which explains the structure and function of breadboard. Your poster must include labeled diagrams of the inside and outside of a breadboard. Your poster must include a discussion of current and resistance.

D-3

Use the digital multimeter to measure resistance across different objects found in your classroom. Are there any similarities between objects that have high resistance? Are there any similarities between objects that have low resistance? Write about your investigation below.

D-4

Find online articles that discuss the use of resistance to measure body mass index (BMI). Discuss the advantages and difficulties using this method to determine BMI.

2.3 Powering the BasicBoard

Learning Objectives:

- Students will use a digital multimeter to measure voltage differences.
- Students will explore the precision and accuracy limits of digital multimeter measurements due to human error and mechanical uncertainty.

Materials

For each group of 2 students

- BasicBoard
- 1 digital multimeter
- Multimeter probes
- Several 3cm wires pieces with stripped ends
- CR 2032 battery
- 1.5V & 9V batteries

For each student

- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

- Circuit
- Digital pin
- Electric potential difference
- Ground rail
- Power rail
- Terminal
- Voltage (source)
- Volts

Tasks you need to perform

Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

In the previous lesson, you investigated the inner workings of the breadboard. Armed with a digital multimeter you mapped out the paths of least resistance.

However, in order for current to flow, the charges must move around at least one closed circular path, called a **circuit**. The circuit provides the energy needed to move the charges, and also tells them which direction to move.

The component of the circuit that provides both energy and direction is called a **voltage source**. Batteries are one example: they have both positive and negative **terminals**. If you put the red lead of your multimeter on the positive terminal and the black lead on the negative terminal (and set the multimeter to measure ⎓V), the readout will display the **electric potential difference** (in volts) between these two terminals. This voltage difference causes the charges to move around a circuit. Negative charges, like electrons, will be pushed away from the positive terminal and attracted to the positive terminal of the battery.

In this lesson, you will learn how to measure voltage at different places on the Basic Board.

Instructions

STEP 1. Set up the computer & BasicBoard

Gather the materials in the materials list. Turn on your Computer and plug in the USB cable to the computer and the BasicBoard.

On your worksheet, write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2. Restart your LEDs experiment using the name you chose in *Lesson 2.1*

Your computer should be showing a full screen black window with the first question in purple. Follow the instructions on the bottom of page 3: *Starting a Previously Created LEDs Experiment.*

At the end of the questions and answers, you should see a new window pop up in the bottom left corner of your computer screen (and the question screen will disappear).

H

If you need to start over, hold down the **ctrl-Alt-T** at the same time. Next, type the command **`start`** and hit the enter key. If the new window does not open, reset or reconnect your BasicBoard.

On your worksheet, write down the words in the new black terminal window that popped up after you typed in your experiment name and hit the enter key.

STEP 3. Connect the Arduino processor with the Computer

Connect your LEDs project. Remember, to do this, you type `connect`.

Terminal

```
connect
```

H

Watch the Arduino during **`connect`**. If a green light is on, the Arduino has power. If a dim red light blinks quickly, the Arduino is working.

On your worksheet, write the programming word that you will always use to start an experiment and the message that is displayed on the terminal after you type it.

STEP 4. Test your board

Make sure your board is working by typing:

`OB1on`

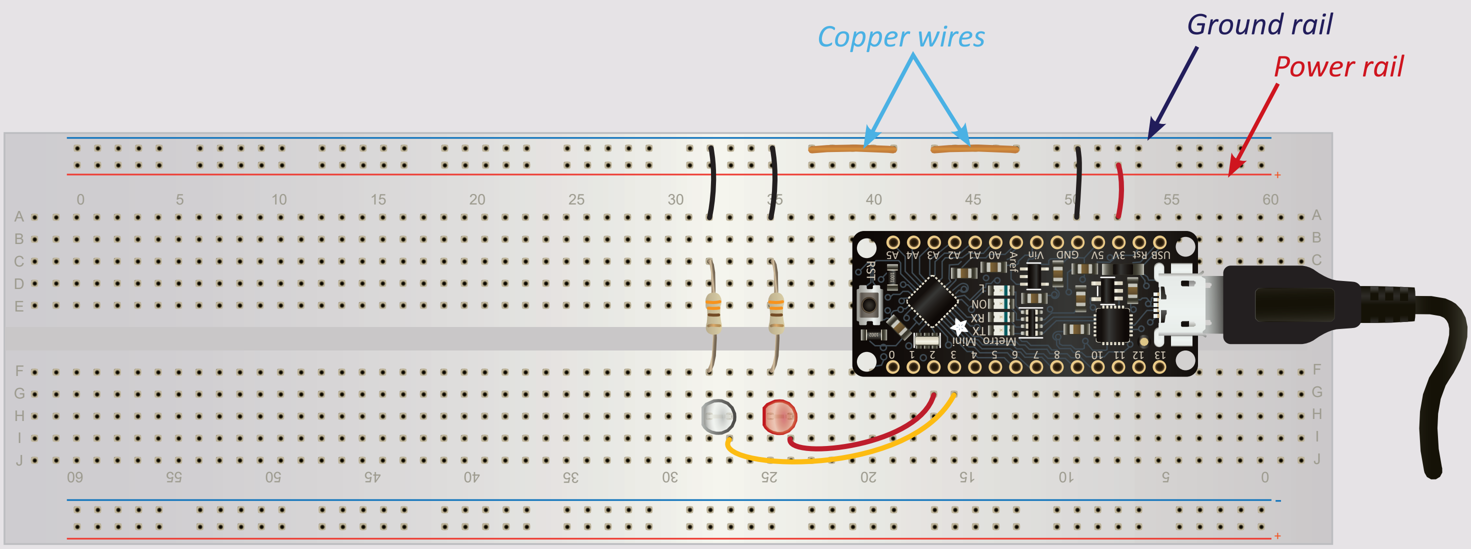
`OB1off`

On your worksheet, write what happened when you used `OB1on` and `OB1off`

> If you get an error message, see if you can figure out what you did wrong by asking a classmate for help.
>
> If nothing happened, hold down the **ctrl-Alt-T** at the same time. Type the command **`start`** and hit the enter key. Repeat Steps 2-4.

STEP 5. Discharge any static electricity that is on your clothes, body or hands.

Mandatory: touch the bare copper wires on the BasicBoard to discharge your static electricity.



On your worksheet, explain why you need to touch the metal wires that are connected through the breadboard to the Arduino, and from the Arduino through the USB cable to the computer. The information in the “Promise to Stay Grounded” on page 6 may help you answer this question.

STEP 6. Explore the Arduino pins.

Examine the Arduino diagram on page 5. This is a blown-up view of the Arduino with all 28 pins labeled. Locate DP 4. All of the pins labeled DP# are **digital pins**. Digital pins can send on/off signals and only on/off signals.

On your worksheet, label the Arduino to help you locate and identify DP 4 in the future.

STEP 7. Measure the voltage of a AA battery

Turn on the multimeter and set the dial to ⎓V. Put the red lead on the positive terminal and the black lead on the negative terminal of the battery.

On your worksheet, record the voltage of the battery using the multimeter. Now interchange the leads, and record the meter reading again. Write a sentence that compares the two readings.

> **H** The red lead should always connect to the higher voltage terminal. If you get a negative reading, interchange the two leads.

STEP 8. Use the multimeter to measure the voltage

Make sure the dial is set to ⎓V.

Take one of the 3 cm wires that you cut and stripped in the previous lesson, and stick it in one of the holes that connects to the **power rail** on the breadboard. This rail is the inner rail near the top edge of the breadboard.

Take another one of the 3 cm wires that you cut and stripped in the previous lesson, and stick it in one of the holes that connects to the **ground rail** on the breadboard. This rail is the outer rail near the top edge of the breadboard.

Now take the red lead from the multimeter and touch it to the wire that is plugged into the power rail, and take the black lead and touch the wire that connects to the ground rail.

On your worksheet. write down the meter reading. Don't forget units!

> **H** Make sure you are making a good connection between the leads and the wires. You might need to wrap the wire around the end of the lead.
>
> Refer to the BasicBoard image on the previous page if you cannot fine the power and ground rails.

STEP 9. Measure the voltage with pin ON

Take another one of the 3 cm wires that you cut and stripped in the previous lesson, and stick it in one of the holes that connects to digital pin 4. Compare your choice to that of your neighbor and make sure you both agree that the wire is connected to digital pin 4.

Turn on digital pin 4 by typing `dp4on` in the terminal window.

Now take the red lead from the multimeter and touch it to the wire that is connected to digital pin 4. Make sure the black lead is touching the wire that connects to the ground rail.

> **H** Check that the multimeter knob is set to measure voltage. Adjust as needed.
>
> Check that only the metal pieces you want to touch are touching, when using the multimeter.

Terminal

```
dp4on
```

On your worksheet, write down the voltage reading for digital pin 4 when it is turned on.

STEP 10. Measure the voltage with pin OFF

Leave the multimeter leads in the same positions (red lead connected to digital pin 4, black lead connected to ground) and then type **dp4off** in the terminal window.

Note: if the units are mV, this is millivolts, where 1 mV = 10^{-3} V. Any reading lower than 50 mV is essentially 0.

> **H:** Make sure to record the units (lower right hand corner of the readout)

Terminal

```
dp4off
```

On your worksheet, write down the voltage reading for digital pin 4 when it is turned off.

> **W:** Your body conducts electricity. Make sure you don't insert yourself into a circuit by touching the metal part of any probe.
>
> If you touch the **reset pin,** it will **turn ALL pins off**. If this happens, type **reload** and then **connect**.

STEP 11. Complete the challenges

Now that you have learned how to measure voltage using the multimeter, please continue on to complete the challenges for this lesson.

Name:____

STEP 1 Write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2 Write down the words in the new black terminal window that popped up after you typed in your experiment name and hit the enter key.

STEP 3 Write the programming word that you will always use to start an experiment and the message that is displayed on the terminal after you type it.

STEP 4 Write what happened when you used `OB1on` and `OB1off`

Command	What happened?
`OB1on`	
`OB1off`	

Name:____

STEP 5 Explain why you need to touch the metal wires that are connected through the breadboard to the Arduino, and from the Arduino through the USB cable to the computer.

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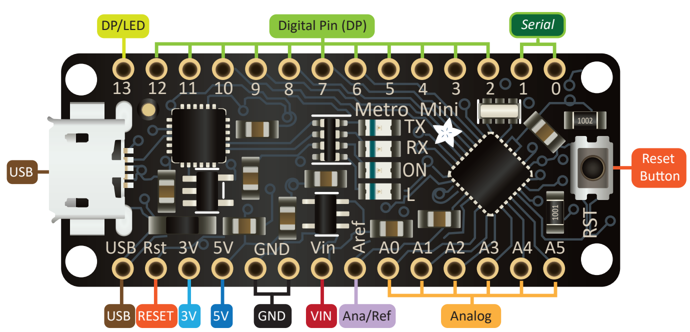
STEP 6 Label the Arduino to help you locate and identify DP 4 in the future.



STEP 7 Record the voltage of the battery using the multimeter. Now interchange the leads, and record the meter reading again. Write a sentence that compares the two readings.

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STEP 8 Write down the meter reading. Don't forget units!

STEP 9 Write down the voltage reading for DP 4 when it is turned on.

STEP 10 Write down the voltage reading for DP 4 when it is turned off.

Name:____

C-1

Voltage differences provide the energy to move electrons around an electrical circuit. One volt provides 1 Joule of energy to 1 Coulomb of charge. But a Coulomb of charge is a very large number of electrons (about 1.6×10^{18})! A nine-volt battery would provide 9 Joules/Coulomb and a 1.5 V battery would provide 1.5 Joules/Coulomb.

Take your multimeter and measure the voltage difference between the terminals of at least two differently-shaped batteries provided by your instructor.

Write down your measurements below. Also write a few sentences to explain the procedure you used to measure this voltage difference.

____

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C-2

Use the Arduino drawing on page 5 to locate DP 5. Perform the following commands and measurements and write the results of each:

Turn off digital pin 4. What command will you use?	
Turn on digital pin 5. What command will you use?	
Voltage difference between two different places on the ground rail.	
Voltage difference between power and ground rails.	
Voltage difference between digital pin 4 and ground.	
Voltage difference between digital pin 5 and ground.	
Voltage difference between the power rail and digital pin 5.	

Write a few sentences explaining the connection between the programming words (`dp4on`, `dp4off`, etc.) and the voltage differences you measured in the circuit.

____

____

____

____

Name:____

C-3

Do all digital pins output the same voltage when activated, meaning turned on? Is there a right way to use the digital multimeters?

As a class, gather all of the voltage measurements on the digital pins. Are any measurements noticeably high or low? If so, ask the group who made those measurements to demonstrate their procedure.

C-4

Find three physical ways to alter the voltage reading on your digital multimeter. Write a few sentences and include sketches to explain each process.

Name:____

D-1

Create a youTube video tutorial for using a multimeter to measure voltage.

D-2

Recall your experiments with differently shaped batteries in C-1. Is there a correlation between physical appearance and the electrical properties of these batteries?

Why might it be useful to have batteries of different sizes and shapes?

Write a summary of your findings.

____

____

____

____

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D-3

The capacity of a battery is measured in Amp-hours, where 1 A-hr will produce a 1 Amp current for 1 hour. Investigate the capacities of batteries with the same voltage rating.
Write a short summary of your findings.

____

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____

D-4

Recall your voltage measurements from C-2. Determine an approximate mathematical relationship between:

a. voltage difference between power and ground rails.
b. voltage difference between digital pin 5 (when turned on) and ground.
c. voltage difference between power rail and digital pin 5.

____

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2.4 Using Digital Pins to Control LEDs

Learning Objectives:

- Students will learn how to turn on and off LEDs using digital pins
- Students will identify the function of resistors and LEDs
- Students will learn how to measure voltage and resistance in a circuit
- Students will recognize the polar nature of LEDs

Materials

For each group of 2 students

- BasicBoard with Arduino and 2 LEDs wired to the Arduino
- Computer
- 4 or more 3 cm wires pieces with stripped ends
- CR 2032 battery
- At least 1 LED that is not connected to the breadboard

For each student

- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

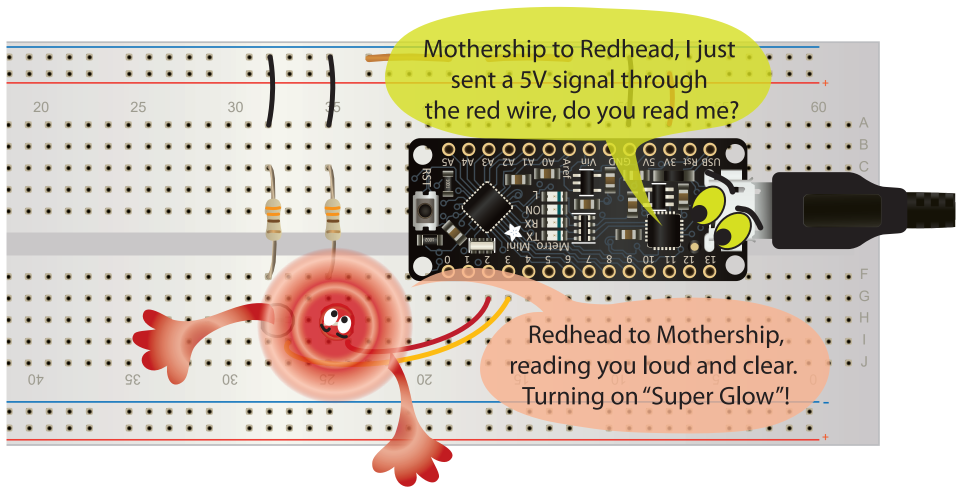
- Polar

Tasks you need to perform

Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

This cartoon shows the Arduino communicating with an LED on the BasicBoard. In this lesson you will explore how the Arduino transfers information and energy using digital pins that are connected to a circuit that includes a resistor and an LED.

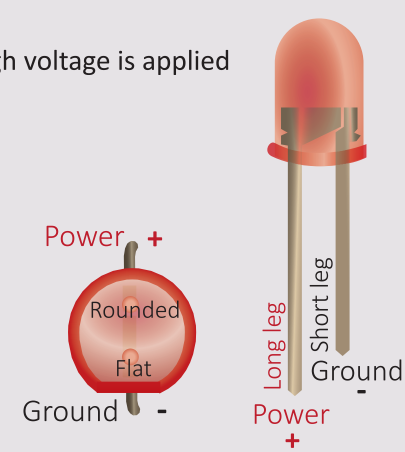


Notice that your BasicBoard has two LEDs already wired (with resistors) to digital pins on the Arduino. We call these the "external LEDs".

Light Emitting Diode (LED) Guide:

LEDs:

- are devices that emit light once enough voltage is applied across their leads.
- may burn out if the voltage is too high
- are *not* incandescent light bulbs
- are **polar**, which means they have a **positive** and a **negative** (ground) side.
- will **not work** if they are plugged in **backwards**!



Instructions

STEP 1. Set up the computer and BasicBoard, and gather materials

Gather the materials in the materials list. Turn on your computer and plug in the USB cable to the computer and the BasicBoard.

On your worksheet, write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2. Restart your LEDs experiment and connect the Arduino to the computer

Use the instructions at the bottom of page 3 to reload your existing project with the name you chose in Lesson 2.1. Connect your project using `connect`.

Terminal

```
connect
```

H

Watch the Arduino after you type connect. If a dim red LED blinks, the Arduino is working

STEP 3. Discharge static electricity and check the connection to the BasicBoard

Discharge any static electricity, then check to make sure everything is working by turning on and off the on-board LED. Remember to touch the ground wires on the breadboard to discharge any static build up.

Then make sure you are connected by testing the on-board LED.

Terminal

```
OB1on
OB1off
```

On your worksheet, record the results of using these two commands.

W

Do NOT remove either LED from your BasicBoard! Use the loose LED for steps 4 and 5.

STEP 4. Examine an LED and light it with coin battery

Take the LED that you gathered (that is not connected to the breadboard) and study it. Consult the LED guide to determine the relationship between the flat side of the LED and the length of the LED's "leg". Now create a circuit that uses the coin battery (CR 2032) to light the LED.

On your worksheet, fill out the table to indicate:

a. Which LED leg (longer or shorter) is connected to power and which is connected to ground?
b. Which LED leg (longer or shorter) should be connected to the + terminal of the battery and which to the – terminal (in order to light the LED)?
c. Which terminal of the battery (+ or -) represents power and which represents ground?

STEP 5. Compare the loose LED to the LEDs on the breadboard

Compare the loose LED to the two external LEDs that are wired on the breadboard and connected to the Arduino. One is LED is red and the other one is white.

On your worksheet, fill out the table to indicate the connections (digital pin or resistor) and functions (signal or ground) for each external LED.

W

Do NOT remove or unplug either LED from your BasicBoard! Use the loose LED for steps 4 and 5.

STEP 6. Identify the digital pins that are connected to the two external LEDs

Consult the diagram of the Arduino and look at the BasicBoard to determine which digital pins to activate in order to light up each LED.

On your worksheet, write the digital pin number that is connected to each LED, and the commands you will use to turn it on and off.

H

Refer to previous notes and lessons if you can't remember the commands to use.

STEP 7. Turn on and off the two external LEDs

Use the commands you identified in STEP 6 to turn on and off the two external LEDs.

On your worksheet, record what you typed and the results. Also show at least one classmate that you successfully turned on and off each LED. Ask your classmate to initial your worksheet to verify that you can turn on and off each light.

W

Each LED is connected to a resistor to limit the amount of current that can flow through the LED. **Too much current can burn out the LED.**

STEP 8. Measure the resistance

Turn off both external LEDs.
Switch the dial of your multimeter to measure resistance (Ω). Then measure the resistance of each resistor that is attached to an LED on your board, by placing one multimeter lead on each leg of the resistor.

On your worksheet, record your resistance measurements. Don't forget units!

H

Resistance can only be measured when the circuit is powered off. So, if your LEDs are still turned on, turn each of them off before doing these measurements.

It may be possible to directly touch each meter lead to a leg of the resistor. If not, move the 3 cm wires to holes that are connected to each resistor leg.

Check that the multimeter dial is set to measure resistance.

STEP 9. Measure the voltages with the lights OFF

Take one of the 3 cm wires that you previously cut and stripped, and stick it in one of the holes that connects to the digital pin on the breadboard that is used to control the external red LED.

Take another one of the 3 cm wires and stick it in one of the holes that connects to the digital pin that controls the white LED.

Take a third 3 cm wire and stick it in one of the holes that connects to the ground rail.

Measure the voltage between the red LED's digital pin and the ground rail, and then between the white LED's digital pin and the ground rail.

On your worksheet, record the results of your voltage measurements with LED off. Don't forget units!

H

Check that only the metal pieces you want to touch are touching, when using the multimeter

STEP 10. Measure the voltages with the digital pins ON

With your 3 cm wires in the same locations, type the commands you identified in STEP 6 to turn each of the LEDs on.

Measure the voltage between the red LED's digital pin and the ground rail, and then between the white LED's digital pin and the ground rail.

On the worksheet, write down the voltage readings with LED on. Don't forget units!

H

Make sure you are making a good connection between the leads and the wires. You might need to wrap the wire around the end of the lead

Check that the multimeter dial is set to measure voltage.

STEP 11. Complete the challenges

Now that you have learned how to turn on and off LEDs using digital pins, please continue on to complete the challenges for this lesson.

Name:____

STEP 1 Write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 3 Record the results of using these two commands.

Command	What happened?
OB1on	
OB1off	

STEP 4 Fill out the table.

Which leg?	Connected to power or ground?	Connected to + or - terminal battery?
Long leg		
Short leg		
Which?	**Connected to power or ground?**	
+ Terminal		
- Terminal		

STEP 5 Fill out the table with your observations.

Which?	Connected to digital pin or resistor?	Connected to signal or ground?
Red External LED – flat side		
Red External LED – round side		
White External LED – flat side		
White External LED – round side		

Name:____

STEP 6 Write the digital pin number that is connected to each LED, and the commands you will use to turn it on and off.

Which device?	Which digital pin?	Command used to turn on?	Command used to turn off?
Red LED			
White LED			

STEP 7 Record what you typed and the results. Also show at least one classmate that you successfully turned on and off each LED. Ask your classmate to initial your worksheet to verify that you can turn on and off each light.

When I type...	Which LED? (red or white)	What it did (turn on or off)	Initials

STEP 8 Record your resistance measurements. Don't forget units!

Resistor connected to which LED?	Resistance measurement
Red LED	
White LED	

STEP 9 Record the results of your voltage measurements with the LEDs off. Don't forget units!

Digital pin connected to ?	Voltage measurement
Red LED	
White LED	

STEP 10 Write down the voltage readings with the LEDs on. Don't forget units!

Digital pin connected to ?	Voltage measurement
Red LED	
White LED	

Name:____

C-1

How do the various hardware components interact with each other? How do they communicate? Write a few sentences describing how the computer, Arduino and LED circuits work together in this system. Include measurements to support your claims.

____

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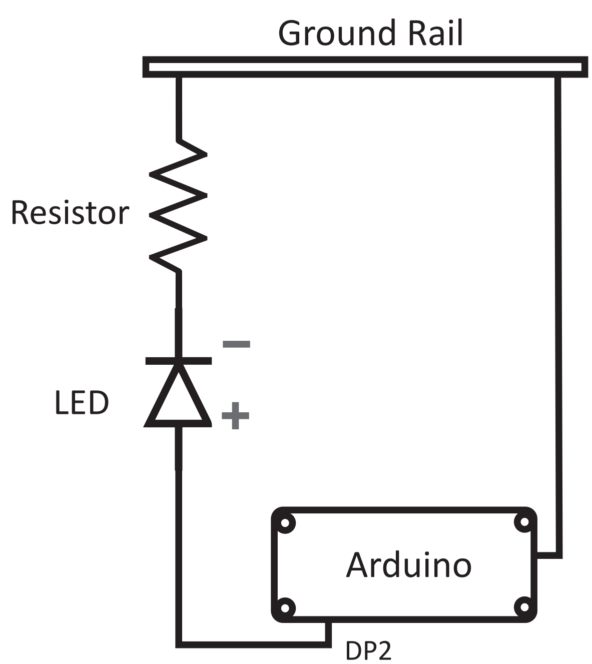
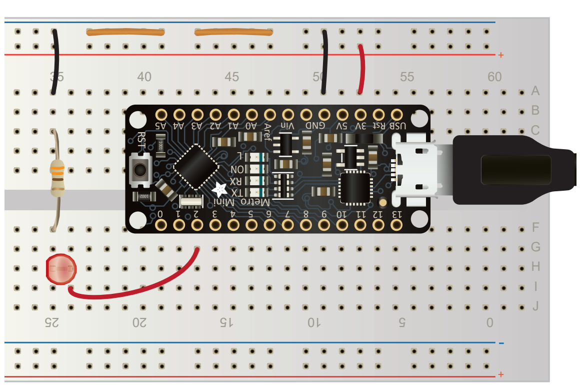
C-2

Circuit 1 is the circuit on the BasicBoard that powers the red LED. It can be represented by a schematic drawing that shows the connections between each circuit element. The schematic emphasizes that the circuit is actually in the shape of a closed loop when you add the connections to ground.
Are the three other circuits wired properly? In other words, will they light up?
Draw a schematic for each circuit as in the example. Be sure to label:

- the positive and negative sides of the LED
- the signal (digital pin) and ground wires
- the resistor



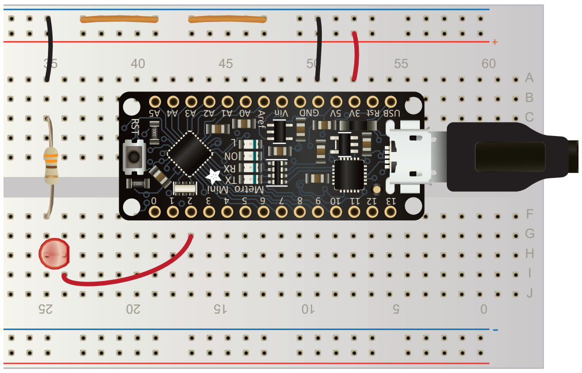
1



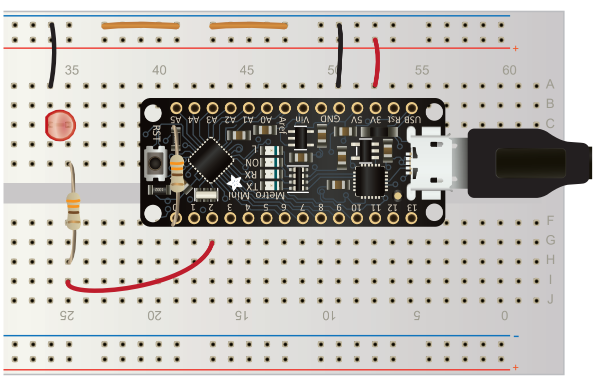
Name:____

C-2 *continued*

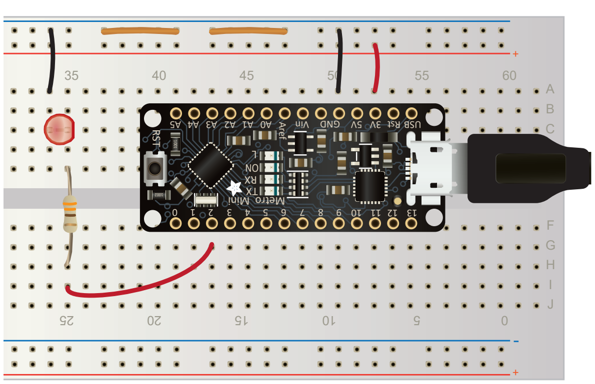
2 Will it work to light the LED? Circle the correct answer: YES NO



3 Will it work to light the LED? Circle the correct answer: YES NO



4 Will it work to light the LED? Circle the correct answer: YES NO



Name:____

C-3

LEDs burn out if too much voltage is applied across the leads, as the current will be too high. These circuits include resistors to lower the voltage (and thereby the current). The function of a resistor is to remove energy from the circuit, usually in the form of heat. Turn on each LED to do the following measurements:

a. Measure the voltage across the two legs of the resistor
b. Measure the voltage across the two legs of each LED
c. Measure the voltage between the digital pin and the ground rail.

Which LED?	Voltage across resistor (a)	Voltage across LED (b)	Voltage between digital pin and ground rail (c)
Red LED			
White LED			

d. For given LED, find a mathematical relationship between these three voltages (a,b and c)?
Hint: The relationship may be more obvious if you round off all the numbers to have only one digit after the decimal place.

Name:____

D-1

Find another way to wire a circuit with an LED and a resistor on the BasicBoard. Connect your new circuit to one of the active digital pins (4,5 or 6) to test it out. Describe your steps.

D-2

An LED only lights up when enough voltage is applied across its leads. What minimum voltage do you need to turn on the red LED and the white LED? Are these minimum voltages the same for each LED? Why or why not?

Hint: Use resistors of different sizes to change the voltage across a given LED.

D-3

Create a graphic that depicts the mathematical relationship you found in C-3 question d. between the voltage across the resistor legs, the voltage across the LED legs and the voltage between a turned on digital pin and ground.

2.5 Ohm's Law

Learning Objectives:

- Students will use Ohm's Law to calculate voltage, current or resistance, given two of these quantities.
- Students will learn that voltage and resistance are directly proportional.
- Students will learn that current and resistance are inversely proportional.

Materials

For each group of 2 students

- BasicBoard with Arduino and 2 LEDs wired to the Arduino
- Computer
- 4 or more 3 cm wire pieces with stripped ends
- 10k Ohm resistor
- Red LED

For each student

- Worksheet
- Challenge sheet
- Ohm's Law Worksheet
- Double Dare Sheet

Vocabulary:

- Directly proportional
- Inversely proportional
- Ohm's Law

Tasks you need to perform

Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

In Lesson 2.2, you learned how to measure resistance in a circuit. In Lesson 2.3, you learned how to measure voltage in a circuit. In lesson 2.4, you measured resistance and voltage in the same circuit. In this lesson, you will explore the relationship between these two quantities, and learn how to calculate the current flowing in a circuit.

Ohm's Law relates the voltage, current and resistance in a circuit. It is written as:

V = I x R where

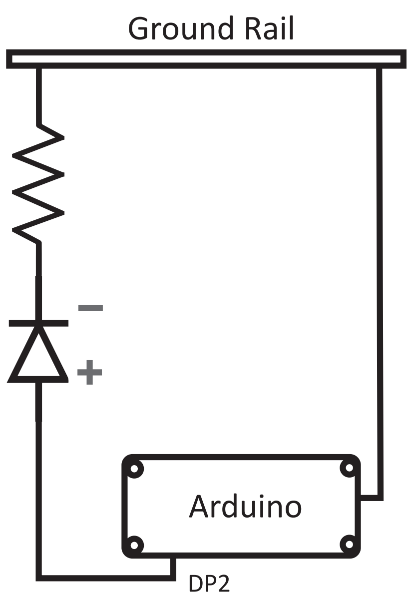
V = voltage (in volts)

I = current (in amps)

R = resistance (in ohms)

When we build circuits in this class, we usually choose the value of the power source (e.g., the 3.3 V power rail or a 1.5 V AA battery), and then adjust the resistance so that the circuit produces enough current to perform some task (e.g. light an LED or turn on/off a switch).

We saw in the previous lesson, that the red external LED circuit can be drawn as a schematic diagram:



In this circuit, the total amount of energy available is given by the voltage measured between the Arduino digital pin and ground. Some of this energy (voltage) is lost when the electrons travel across the LED, and some is lost when they travel across the resistor. The electrons that flow from the Arduino through the LED and resistor are the same electrons all the way around the circuit. They start out with more voltage energy when they leave the Arduino, and run out of voltage energy by the time they reach the ground voltage level.

Instructions

STEP 1. Set up the computer and BasicBoard, and gather materials

Gather the materials in the materials list. Turn on your computer and plug in the USB cable to the computer and the BasicBoard.

On your worksheet, write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2. Restart LEDs experiment and connect Arduino to computer

Use the instructions at the bottom of page 3 to reload your existing project with the name you chose in Lesson 2.1. Connect your project using `connect`.

Terminal

```
connect
```

H: Watch the Arduino after you type connect. If a dim red LED blinks, the Arduino is working

STEP 3. Discharge static electricity and check the connection to the BasicBoard

Discharge any static electricity, then check to make sure everything is working by turning on and off the on-board LED. Remember to touch the ground wires on the breadboard to discharge any static build up.

Then make sure you are connected by testing the on-board LED.

Terminal

```
OB1on
OB1off
```

On your worksheet, record the results of using these two commands.

H: Make sure the multimeter dial is set to Ω

STEP 4. Change the resistance and the LED in an external circuit

Gather the 10 kΩ resistor and measure it with the multi-meter. Carefully note the location of, and then pull out the 330 Ω resistor in the circuit with the white external LED. Put the new resistor in the exact same holes in the board where the 330 Ω resistor used to be. Carefully note the location of, and then pull out the white LED, and replace it with the extra red LED.

On your worksheet, write down the resistance that you measured for the new resistor.

W: To avoid harming the circuit, turn the LEDs off before moving either the LED or the resistor.

STEP 5. Compare the red LEDs

Turn on both digital pins connected to red LEDs. Observe the brightness of the light from each.

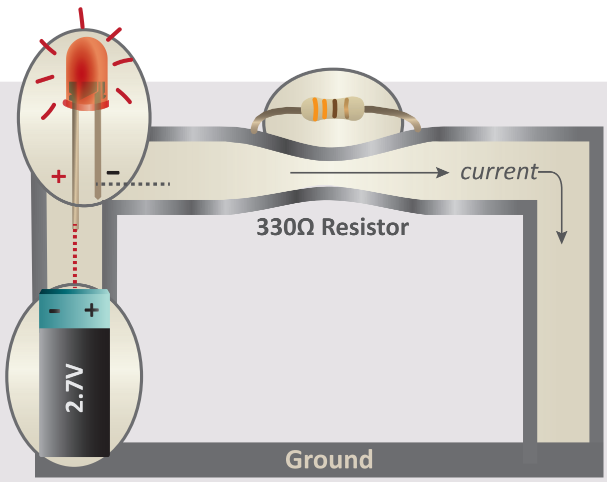
On your worksheet, describe how the brightness of the LED with the 10 kΩ resistor compares to the brightness with the 330 Ω resistor.

STEP 6. Measure the voltage across the resistors

With the red LEDs turned on, measure the voltage across the two legs of the 330 and 10 kΩ resistors.

On your worksheet, write down the voltages that you measured. Which statement most accurately summarizes your observations (circle one)? Write a few sentences using your measurements to support your choice(s).

a. The 10 kΩ resistor had the higher voltage and the LED was brighter
b. The 10 kΩ resistor had the higher voltage and the LED was dimmer
c. The 10 kΩ resistor had the lower voltage and the LED was brighter
d. The 10 kΩ resistor had the lower voltage and the LED was dimmer



STEP 7. Apply Ohm's Law

In a red external LED circuit, the available energy is provided by the voltage difference between the digital pin and the ground. This voltage does not change when the resistors are changed to different values.

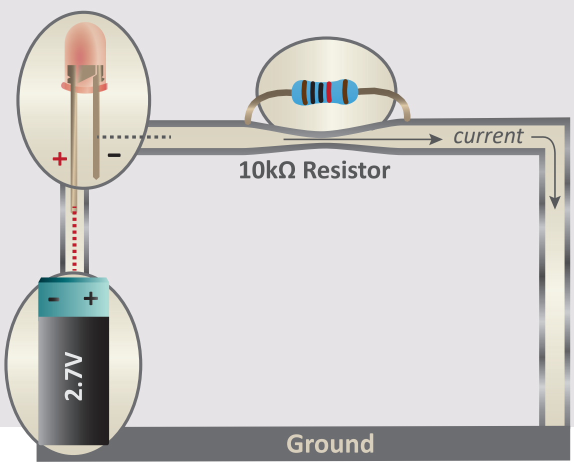
Use your measurements to fill in the table on the worksheet. Follow the example below to use Ohm's Law to calculate the current through the 10 kΩ resistor.

Example:

Given:
V = 2.7 V across resistor
R = 330 Ω

Ohm's Law: V = I x R
Substitute values: 2.7 V = I x (330 Ω)

Solve for I = 2.7 V/ 330 Ω = 8.2 x 10^{-3} = 0.0082 amps



STEP 8. Proportionalities

Two quantities (A and B) are **directly proportional** if when A increases, B also increases. This also means that if A decreases, B also decreases.

Two quantities (C and D) are **inversely proportional** if when C increases, D decreases. This also means that if C decreases, D increases.

Examining the values in your table in STEP 7, circle any and all the statements that you agree describe the red external LED circuit:

a. Voltage across the resistor and its resistance are directly proportional
b. Voltage across the resistor and its resistance are inversely proportional
c. Current through the resistor and its resistance are directly proportional
d. Current through the resistor and its resistance are inversely proportional

Write a few sentences to explain your choices, using your measurements to support your claims.

STEP 9. Relationship between current and brightness

In the past two steps, you have determined the relationship between voltage across the resistor and its resistance, and between current through the resistor and resistance. Reflect on these results, and also on your brightness observations in STEP 6 which related voltage across the resistor to the brightness of the LED.

Examine your results for STEPS 6, 7 and 8 and then circle any and all statements that you agree describe the red external LED circuit:

a. Voltage across the resistor and the brightness of the LED are directly proportional
b. Voltage across the resistor and the brightness of the LED are inversely proportional
c. Current through the resistor and the brightness of the LED are directly proportional
d. Current through the resistor and the brightness of the LED are inversely proportional

Write a few sentences to explain your choices, using your previous measurements to support your claims.

STEP 10. Voltages in circuits

Examining the values in your table in STEP 7, circle any and all the statements that you agree describe the relationship between the 3 different voltages that you measured:

a. Voltage from digital pin to ground = Voltage across LED + Voltage across resistor
b. Voltage across LED = Voltage from digital pin to ground + Voltage across resistor
c. Voltage across resistor = Voltage across LED + Voltage from digital pin to ground

Use measurements from your table to back up your choices.

STEP 11. Return the BasicBoard to its original configuration

Turn off both LEDs. Put the white LED and 330 Ω resistor back in their original locations, removing the 10 kΩ resistor and the second red LED. Turn on the digital pin that runs the white LED and verify its operation.

Did the white LED operate correctly? If so, have your classmate initial your worksheet.

STEP 12. Complete the challenges

If you can use Ohm's Law to correctly calculate voltage, current and resistance, proceed to the challenges.

Name:____

STEP 1 Write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 3 Record the results of using these two commands.

Command	What happened?
`OB1on`	
`OB1off`	

STEP 4 Write down the resistance that you measured for the new resistor.

STEP 5 Describe how the brightness of the LED with the new resistor compares to the brightness with the 330 Ω resistor.

____

____

____

____

____

____

Name:____

STEP 6 Write down the voltages that you measured. Which statement most accurately summarizes your observations (circle one)? Write a few sentences using your measurements to support your choice(s).

a. The 10 kΩ resistor had the higher voltage and the LED was brighter
b. The 10 kΩ resistor had the higher voltage and the LED was dimmer
c. The 10 kΩ resistor had the lower voltage and the LED was brighter
d. The 10 kΩ resistor had the lower voltage and the LED was dimmer

____

____

____

STEP 7 Use your measurements to fill in the table.

Resistor?	Measure: Voltage from digital pin to ground	Measure: Voltage across LED	Measure: Voltage across resistor	Resistance	Calculate: Current through resistor
330 Ω				330 Ω	
10 kΩ				10,000 Ω	

STEP 8 Examining the values in your table in STEP 7, circle any and all the statements that you agree describe the red external LED circuit. Then Write a few sentences to explain your choices, using your measurements to support your claims.

a. Voltage across the resistor and its resistance are directly proportional
b. Voltage across the resistor and its resistance are inversely proportional
c. Current through the resistor and its resistance are directly proportional
d. Current through the resistor and its resistance are inversely proportional

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Name:____

STEP 9 Examine your results for STEPS 6, 7 and 8 and then circle any and all statements that you agree describe the red external LED circuit. Then Write a few sentences to explain your choices, using your measurements to support your claims.

a. Voltage across the resistor and the brightness of the LED are directly proportional
b. Voltage across the resistor and the brightness of the LED are inversely proportional
c. Current through the resistor and the brightness of the LED are directly proportional
d. Current through the resistor and the brightness of the LED are inversely proportional

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STEP 10 Examining the values in your table in STEP 7, circle any and all the statements that you agree describe the relationship between the 3 different voltages that you measured. Then Write a few sentences to explain your choices, using your measurements to support your claims.

a. Voltage from digital pin to ground = Voltage across LED + Voltage across resistor
b. Voltage across LED = Voltage from digital pin to ground + Voltage across resistor
c. Voltage across resistor = Voltage across LED + Voltage from digital pin to ground

____

____

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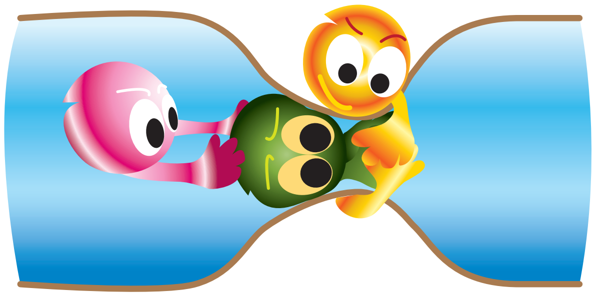
____

STEP 11 Did the white LED operate correctly? If so, have your classmate initial below.

Name:____

C-1

This cartoon illustrates the relationship between voltage, current, and resistance, as summarized by Ohm's Law. Write a few sentences that explain how this cartoon provides a model of the processes that occur within a circuit. Be sure to explain which cartoon character or characters represents electrons.



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C-2

Complete the Ohm's Law worksheet.

2.5 Ohm's Law Worksheet

Name:____

Ohm's law describes the relationship between resistance, current, and voltage in a circuit. A power source provides a voltage that can drive a current. A resistor impedes the current flow by removing energy from electrons. This energy is dissipated as heat, light, or sound.

Voltage is a measure of the difference between high and low electric potential energy.

- Quantity: V
- Unit: Volt, V
- Example: V = 1.5 V

Example: what is the expected current when V= 1.5V and R= 300 Ω?

$V = I \times R$

$1.5V = I\,(300\ \Omega)$

$\frac{1.5}{300}\ \frac{V}{\Omega} = I$

I = 0.005 Amps

Current is the flow of charged particles.

- Quantity: I
- Unit: Amp, A
- Example: I = 20 A

Resistance measure how much a material reduces the flow of electric current.

- Quantity: R
- Unit: Ohm, Ω
- Example: R = 300 Ω

1. Ohm's law is typically written as V = I × R . If you know the current and resistance you can calculate the voltage. Answer a and b then fill out the table to the right.

a. How would you rewrite this equation to solve for current if you know voltage and resistance?

I =

b. How would you rewrite this equation to solve for resistance if you know voltage and current?

R =

V	I	R
120 V	0.5 A	
15 V		200 Ω
	30 A	10,000 Ω
3.0 V	1.2 A	

2. A flashlight runs on 2 D-cell batteries. Each battery provides 1.5 V. The flashlight bulb is rated for 0.7 amps of current. What is the bulb's resistance?

3. A car battery is a 12V source. There is a fuse in the car that trips (breaks) if the current ever rises above 5 A. What is the smallest resistor you need in the circuit to stop the fuse from tripping?

4. Given a 9 volt battery and a 100 Ω resistor, what current must flow through the circuit?

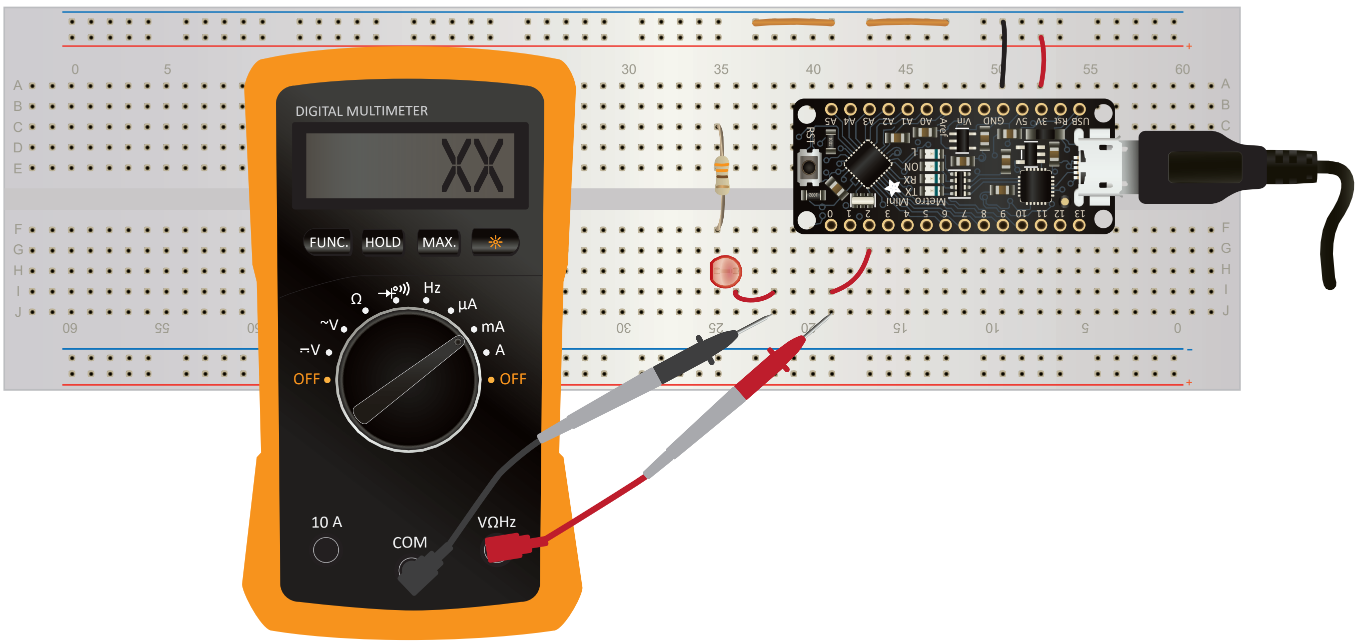
5. A power source is hidden behind a closed panel. Your multimeter measures a current of 0.5 A and you know your light bulb has a resistance of 200 ohms. What is the voltage of the mystery power source?

Name:____

D-1

Measure the current by selecting the setting labeled mA on your multimeter, and inserting the leads into the circuit as shown in the diagram below. You will need to figure out how to rewire your red external LED circuit to be able to do this measurement. Show your plan to your instructor before unplugging or moving any of the wires. Did the current value agree with the that calculated on the worksheet for STEP 7?

Hint: After you turn on the digital pin, the LED will light up when you use the meter to complete the circuit.



D-2

"Measure the resistance across the resistor for the white LED. Use this value to predict the currents. Measure the current and compare to your prediction.

2.6 Let There Be Light!

Learning Objectives:

- Students will use diagrams as visual instructions for adding two additional LED circuits to the BasicBoard.
- Students will write **Logo code** to control the two additional LEDs on the BasicBoard.

Materials

For each group of 2 students

- BasicBoard
- Computer
- 1 blue LED
- 1 green LED
- 2 330 Ω resistors
- Wire
- Wire stripper
- Needle Nose pliers
- Several 3 cm test wires

For each student

- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

- Logo Code

Tasks you need to perform

Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

What good is a BasicBoard if you can't build on it? Let's make your boards bigger and better!

In this lesson, you will add two more circuits to your BasicBoard and write code to make them work.

Instructions

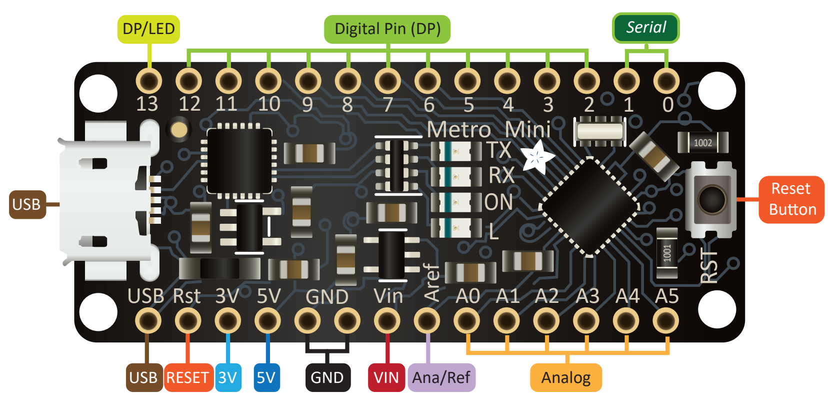
STEP 1. Set up the computer and BasicBoard, and gather materials

Gather the materials in the materials list. Turn on your computer but **DON'T** plug in the USB cable to the BasicBoard.

On your worksheet, write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2. Discharge any static electricity, then wire the blue & green LEDs

Examine the wiring for the circuits that include the red LED and the white LED. Your goal is to copy the wiring design used for these two LEDs, to wire the blue LED to DP 4, and the green LED to DP 5 on the Arduino. Make sure to use one 330 Ohm resistor for each new circuit. Use this diagram of the Arduino to help you identify the correct digital pins.



It may be helpful to use blue wire for the blue LED and green wire for the green LED, and wire the blue LED first.

Measure the wires carefully before cutting them. You goal is to have enough room to strip each end and place them correctly, without having too much extra wire sticking up that can catch on things and come undone.

STEP 2. ***continued***

Draw lines on the image of the BasicBoard on the worksheet that shows the holes you will use and how you have connected the wires for each of the new LEDs.

> **H**
>
> Remember that LEDs are polar and be sure to wire the leg on the flat side to ground, and the round side to the digital pin.

STEP 3. Restart your LEDs experiment, connect the Arduino to the computer and verify that it is operating correctly.

Use the instructions at the bottom of page 3 to reload your existing project with the name you chose in *Lesson 2.1.* Connect your project using `connect`, and test that everything is working by turning on and off the on-board LED, and also the red and white LEDs.

On your worksheet, write the commands that you will type to turn on and off the blue and green LEDs. Then try the commands. Ask your classmate to initial your worksheet to verify that you can turn on and off each of the two new lights.

Terminal

```
connect
OB1on
OB1off
dp2on
dp2off
dp3on
dp3off
```

> **H**
>
> If either of the new LEDs do not turn on or off, check to make sure that the wires are pushed all the way into the holes. You may have cut the wires too short to make a good connection.
>
> If you get an error message or the lights do not turn on or off, see if you can figure out what you did wrong by asking a classmate for help.

STEP 4. Complete the challenges

Now that you have shown that you can turn on and off all four LEDs using commands to digital pins, please continue on to complete the challenges for this lesson.

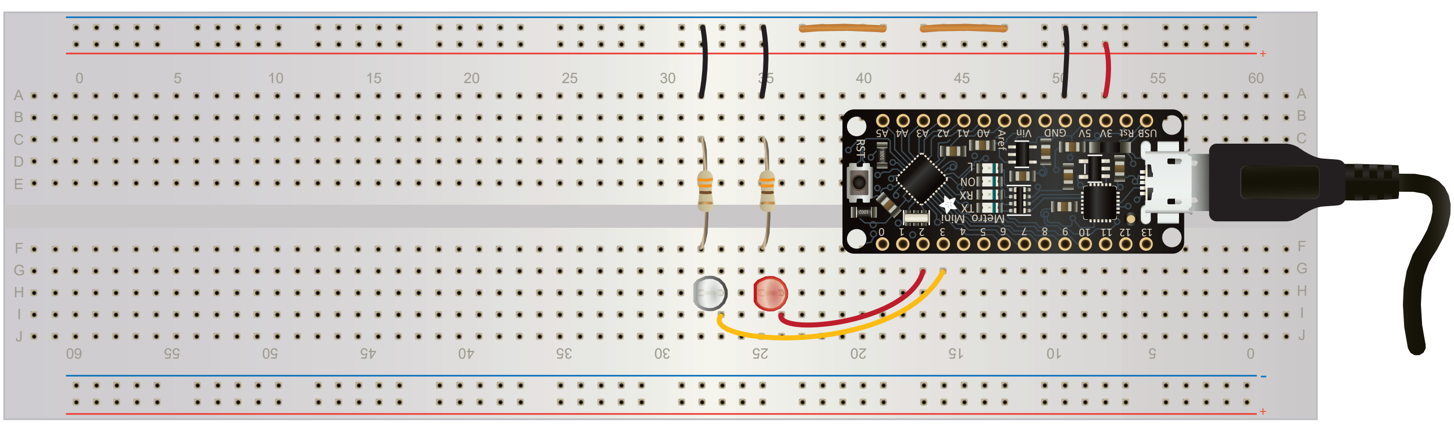
2.6 Worksheet

Let There Be Light!

Name:____

STEP 1 Write down each item on the materials list you have in front of you. If you notice you need to gather more materials, do that now and write them down.

STEP 2 Draw lines on the image of the BasicBoard on the worksheet that shows the holes you will use and how you have connected the wires for each of the new LEDs.



Hints:

It may be helpful to use blue wire for the blue LED and green wire for the green LED, and wire the blue LED first.

Measure the wires carefully before cutting them. You goal is to have enough room to strip each end and place them correctly, without having too much extra wire sticking up that can catch on things and come undone.

Remember that LEDs are polar and be sure to wire the leg on the flat side to ground, and the round side to the digital pin.

Name:____

STEP 3 Write the commands that you will type to turn on and off the blue and green LEDs. Then try the commands. Ask your classmate to initial your worksheet to verify that you can turn on and off each of the two new lights.

When I type...	Which LED? (blue or green)	What it did (turn on or off)	Initials

Hints:

If either of the new LEDs do not turn on or off, check to make sure that the wires are pushed all the way into the holes. You may have cut the wires too short to make a good connection.

If you get an error message or the lights do not turn on or off, see if you can figure out what you did wrong by asking a classmate for help.

Name:____

C-1

Turn on your multimeter and set the dial to ⎓V. Take one of your 3 cm wires and stick it in one of the holes that connects to the ground rail. Take two other wires and stick them in the holes that connect to the digital pins that are controlling the green and blue LEDs. Predict the voltage that you should read when the lights are OFF. Then measure the voltage with the LEDs turned off to test your predictions and record your results in the table below.

Which LED?	Voltage predicted	Voltage measurement
Blue		
Green		

C-2

Type the commands you identified in STEP 3 to turn each of the new (blue and green) LEDs on. Use the multimeter to measure the voltages between the digital pin and ground, and across the resistors that are part of each circuit. Use these measured voltage values to predict the voltages across the two legs of each LED. Then measure the voltages across each LED with the LEDs turned on and record the results.

Which LED?	Voltage between digital pin & ground	Voltage measurement across the resistor	Predicted voltages across the LED	Measured voltages across the LED
Blue				
Green				

Hints:

Recall the relationship between the 3 voltages: digital pin to ground, across the resistor and across the LED.

Name:____

For each Double Dare write the code you used to accomplish the task.

D-1

Swap out the 330 Ohm resistor in one or more of the LED circuits, with a larger value resistor. Predict how the light output will change - will it be brighter or dimmer with the new resistor? Also predict how the voltage across the resistor will change when the LED is turned on. Then make measurements and test your predictions.

____

____

____

____

____

D-2

Investigate how LEDs can emit different colors. What is the difference between the materials used in a red LED and that used in a blue LED?

____

____

____

____

____

D-3

The 2014 physics Nobel prize was awarded to a team of Japanese scientists for the invention of blue LEDs. Why was it so hard to create LEDs that shine blue light? Write an explanation.

____

____

____

____

____

____

2.7 Coding LED Lights

Learning Objectives:

- Students will use the text editor to create words to turn on and off all four LEDs
- Students will learn how to debug simple word definitions

Materials

For each group of 2 students

- BasicBoard with Arduino and 4 LEDs wired to the Arduino
- Computer

For each student

- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

- Debug
- **Logo** words

Tasks you need to perform

Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

In this lesson, you will learn more about creating new **Logo words**, and you will begin to learn how to **debug** your code.

Instructions

STEP 1. Set up computer, BasicBoard, Arduino and verify operation

Set up the computer and BasicBoard, then connect the Arduino to the computer and verify that all LEDs are operating correctly.

Use the instructions at the bottom of page 3 to reload your existing project with the name you chose in Lesson 2.1. Connect your project using `connect`, and test that everything is working by turning on and off the on-board LED, and also all four of your LEDs.

Terminal

```
connect
OB1on
OB1off
dp2on
dp2off
dp3on
dp3off
dp4on
dp4off
dp5on
dp5off
```

On your worksheet, check off the LEDs that function correctly, and indicate which color LED is connected to which digital pin.

STEP 2. Edit the LEDs-YourName.logo file

Open the text editor by typing `edit-project` in the terminal window. This will open a file called LEDs-YourName.logo in a text editor window.

Look in this file, and find the Logo words `a-on`, `a-off`, `b-on` and `b-off`.

Terminal

```
edit-project
```

STEP 2. ***continued***

File Edit View Search Tools Documents Help

Open Save Undo

LEDs-YourName.Logo

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;  words to turn on and off individual LEDs ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
to a-on
   dp2on ;  enter a comment that describes the function of this word
end

to a-off
   dp2off ;  enter a comment that describes the function of this word
end

to b-on
   dp3on ;  enter a comment that describes the function of this word
end

to b-off
   dp3off ;  enter a comment that describes the function of this word
end

```

On your worksheet, predict what you think will happen when you type the Logo words `a-on` and `a-off` as well as `b-on` and `b-off`.

STEP 3. Run words to turn on and off LEDs A and B

In a terminal window, try the words `a-on`, `a-off`, `b-on` and `b-off`.

On your worksheet, describe what happened when you typed the words `a-on` and `a-off` as well as `b-on` and `b-off`.

Terminal

```
a-on
a-off
b-on
b-off
```

STEP 4. Add comments to code

Add comments to the code to describe what happens with each word: `a-on`, `a-off`, `b-on` and `b-off`.

Write down on the worksheet the location of your comments and what you wrote. Include the semi-colon.

STEP 5. Run words to turn on and off LEDs C and D

In a terminal window, try the words `c-on`, `c-off`, `d-on` and `d-off`.

On your worksheet, describe what happened when you typed the words `c-on` and `c-off` as well as `d-on` and `d-off`.

Terminal

```
c-on
c-off
d-on
d-off
```

STEP 6. Hardware or software problem?

When a computer-controlled experiment does not function correctly, the first step is to decide if the problem is due to hardware (wires, connections, circuit design) or software (bad code or instructions). If the hardware works correctly with commands that you previously used, then the problem is with the software.

> To decide whether there is a problem with the wiring or the code, try turning on and off the blue and green LEDs using commands that you verified in STEP 2.

On your worksheet, fill in the table for the blue and green LEDs. Then draw a conclusion: is the problem with the blue and green LEDs due to hardware or software?

STEP 7. Use the text editor to debug the code in LEDs-YourName.logo

What is wrong with the code for `c-on` and `c-off`? Find the code in the `LEDs-YourName.logo` file and discuss it with a classmate. When you think you know what is wrong with `c-on` and `c-off` determine what you need to do to fix the errors. Add comments to your code that explains what is happening. Then save the file and `reload` in a terminal window. This will close your existing terminal window and start up a new window, where you will need to `connect` the Arduino before you can try your new code.

Terminal

```
reload
```

Terminal

```
Welcome to Logo
connect
c-on
```

> If the terminal window does not repoen, type **ctrl-Alt -T** and then start in the new terminal window.
>
> Remember " **;** " are used to create comments in your code.

On your worksheet, write the code that worked to turn LED C on and off. What color is LED C?

STEP 8. Repeat the procedure to debug the code for LED D

What is wrong with the code for `d-on` and `d-off`? Find the code in the `LEDs-YourName.logo` file and discuss it with a classmate. When you think you know what is wrong with `d-on` and `d-off` determine what you need to do to fix the errors. Add comments to your code that explains what is happening. Then save the file and `reload` in a terminal window. This will close your existing terminal window and start up a new window, where you will need to `connect` the Arduino before you can try your new code.

> Remember to use your existing project name to continue your work.
>
> Use `edit-project` to reopen the file for further debugging.

On your worksheet, write the code that worked to turn LED D on and off. What color is LED D?

STEP 9. Complete the challenges

If you can turn all the LEDs on and off individually, proceed to the challenges for this lesson. If not, spend some more time examining the individual words for each LED.

Name:____

STEP 1 Check off the LEDs that function correctly, and indicate which color LED is connected to which digital pin.

Which LED?	Functioned correctly?	Which digital pin?
On Board		
Red		
White		
Blue		
Green		

STEP 2 Predict what you think will happen when you type the Logo words `a-on` and `a-off` as well as `b-on` and `b-off`.

____

____

____

____

____

STEP 3 Describe what happened when you typed the words `a-on` and `a-off` as well as `b-on` and `b-off`.

When I typed....	What happened?
`a-on`	
`a-off`	
`b-on`	
`b-off`	

Name:____

STEP 4 Write down the location of your comments and what you wrote. Include the semi-colon.

Command	Comment you added
`a-on`	
`a-off`	
`b-on`	
`b-off`	

STEP 5 Describe what happened when you typed the words `c-on` and `c-off` as well as `d-on` and `d-off`.

When I typed....	What happened?
`c-on`	
`c-off`	
`d-on`	
`d-off`	

STEP 6 Fill in the table for the blue and green LEDs. Then draw a conclusion: is the problem with the blue and green LEDs due to hardware or software?

Which LED?	Which digital pin	Command to turn on the digital pin	Result?	Command to turn off the digital pin	Result?
Blue					
Green					

Circle your answer: Hardware Software

STEP 7 Write the code that worked to turn LED C on and off. What color is LED C?

STEP 8 Write the code that worked to turn LED D on and off. What color is LED D?

Name:____

For each Challenge, write the code you used to accomplish the task when appropriate.

C-1

Create a word that turns on both LEDs A and B at once. Use **edit-project** to open the **LEDs-YourName**.**logo** file, and think of a name for your new word. Edit the file to insert the code for the new word and comment your code. Save the file, reload the code, reconnect the Arduino and then test your word. Show the results to a classmate to verify the correct operation.

C-2

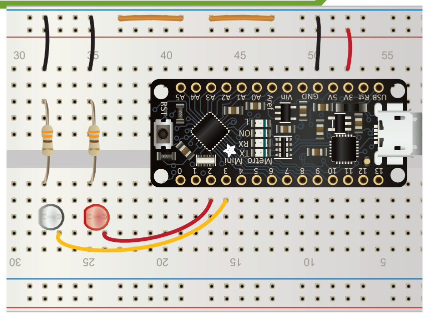
Now create a word that turns off both LEDs A and B at once. Follow the same procedure as in C-1

Name:____

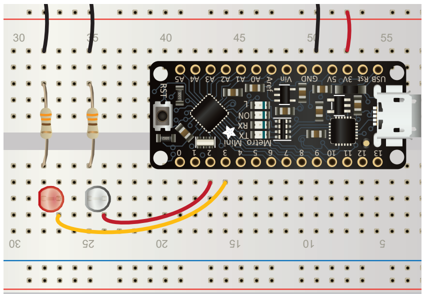
For each Challenge, write the code you used to accomplish the task when appropriate.

C-3

Swap the locations of the red and white LEDs on the breadboard. This will swap their digital pins. What color LED do you expect to turn on when you run the Logo word `a-on`? Run `a-on`. Did you guess correctly? Now swap the red and white LEDs again so they are in their original locations.



Original Configuration



Swapped Configuration

C-4

Reflect on what you have been learning by answering the following questions.

- What two computer commands can you use to turn on the red LED?
- What is the main difference between the two computer commands?
- Why do we have two different ways to turn on the red LED?

Write a few sentences to answer each question.

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2.7 Double Dare Challenges

Name:____

For each Double Dare write the code you used to accomplish the task.

D-1

Modify the Logo code so that you can turn all four LEDs on and off with a single word for all LEDs on and a single word for all LEDs off. Remember to come up with a short and descriptive name for each word. Run your new words.

D-2

The Arduino has 12 digital pins that can be used to send on/off signals (and digital pin 13, which is connected to the on-board LED OB1). Use the Arduino diagram to add more LED circuits to your BasicBoard for any digital pins 6-12. Write code to turn these new LEDs on and off and test your code.

2.8 Blinking LEDs

Learning Objectives:

- Students will use the Logo words `repeat` and `wait` to create blinking light patterns
- Students will create and solve blinking light puzzles with classmates

Materials

For each group of 2 students

- BasicBoard
- Computer

For each student

- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

- blink

Tasks you need to perform

Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

Recall that in TurtleLogo the following word nudged the turtle forward in brief bursts.

```
to turtle-wait
  repeat 10 [ fd 20 wait 10 ]
end
```

Also recall that in TurtleLogo, you had the ability to make your program more flexible using variables. In this example, the variable `:n` will provide the length of the side of the box that the turtle will draw.

```
to draw-box :n
  repeat 4 [ fd :n rt 90 ]
end
```

You ran this word by typing: `draw-box 100` where 100 is the desired length of the side of the box.

In this lesson, you will use Logo's `repeat` and `wait` commands along with variable inputs to build and solve LED puzzles.

Instructions

STEP 1. Set up computer, BasicBoard, Arduino and verify operation

Set up the computer and BasicBoard, then connect the Arduino to the computer and verify that all LEDs are operating correctly.

Use the instructions at the bottom of page 3 to reload your existing project with the name you chose in *Lesson 2.1*. Connect your project using `connect`,and test that everything is working by turning on and off the on-board LED, and also all four of your external LEDs.

Terminal

```
connect
OB1on
OB1off
dp2on
dp2off
dp3on
dp3off
dp4on
dp4off
dp5on
dp5off
```

On your worksheet, check off the LEDs that function correctly.

STEP 2. Edit the LEDs-YourName.logo file

Open the text editor by typing **edit-project** in the terminal window. This will open a file called **LEDs-YourName.logo** in a text editor window.

Look in this file, and find the Logo words **a-blink**, and **a-blink-for**. They should look like this:

Terminal

```
edit-project
```

(LEDs-YourName.logo (~/LEDs-YourName) - Pluma

File Edit View Search Tools Documents Help

Open Save Undo

LEDs-YourName.Logo

```
to a-blink :t
      repeat :t [            ;repeat t times
      a-on                   ;turn on LED a
      wait 10                ;wait 10 deciseconds
      a-off                  ;turn off LED a
      wait 10                ;wait 10 deciseconds
      ]
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;; repeating blink words ;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to a-blink-for :t :n
      repeat :t [            ;repeat t times
      a-on                   ;turn on LED a
      wait :n                ;wait n deciseconds
      a-off                  ;turn off LED a
      wait :n                ;wait n deciseconds
      ]
end
```

On your worksheet, describe the function of the Logo words **a-blink** and **a-blink-for**
For each word, indicate the names of the input variables and the quantities that they represent.

STEP 3. Run words to blink LED A

In a terminal window, run the words **a-blink**, and **a-blink-for** as shown.

Terminal

```
a-blink 5
a-blink-for 10 5
```

On your worksheet, describe what happened when you typed the words as shown. Then try using different numbers as input to each word. Do at least five experiments.

Recall **wait 10** means wait for 10 tenths of a second (10 deciseconds = 1 second)

STEP 4. Complete the challenges

Once you have done a few blinking experiments, please move on to the challenges for this lesson.

Name:____

STEP 1 Check off the LEDs that function correctly.

Which LED?	Functioned correctly?
On Board	
Red	
White	
Blue	
Green	

STEP 2 Describe the function of the Logo words `a-blink` and `a-blink-for`
For each word, indicate the names of the input variables and the quantities that they represent.

STEP 3 Describe what happened when you typed the words as shown. Then try using different numbers as input to each word. Do at least five experiments.

When I typed....	What happened?
`a-blink 5`	
`a-blink-for 10 5`	

Name:____

For each Challenge, write the code you used to accomplish the task when appropriate.

C-1

Create words like `a-blink` for the remaining 3 LEDs and demonstrate that you can run these words from the terminal window. Copy and paste the word `a-blink` and then edit it for the other LEDs. Don't forget to update the in-line comments.

C-2

Create words like `a-blink-for` for the remaining 3 LEDs and demonstrate that you can run these words from the terminal window. Copy and paste the word `a-blink-for` and then edit it for the other LEDs. Don't forget to update the in-line comments.

C-3

Create a new Logo word called `blink-puzzle`. Your word must include code that blinks all 4 LEDs in a unique sequence.

a) Pair up with another group.

b) Without viewing the other groups' code, reproduce their blinking sequence.

In turn, ask the other group to reproduce your sequence.

2.8 Double Dare Challenges

Name:____

For each Double Dare write the code you used to accomplish the task.

D-1

The **`LEDs-YourName.logo`** file also includes a word that will blink the on-board LED. This word is called **`OB1-blink`**. Create additional Logo words for performing complex blinking patterns using a combination of the on-board LED and the four external LEDs.

D-2

How fast does something need to blink to appear continuous rather than discrete? Write Logo code to test this out with your LEDs. You may want to try the word **`mwait`**. Typing **`mwait 1`** tells the microprocessor to wait 1 millisecond. One millisecond equal to 0.001 seconds (= 1/1000 seconds).

2.9 Coded Communications

Learning Objectives:

- Students will use **Logo** to write a Morse Code communication program
- Students will test and refine a **Logo** program based on peer feedback
- Students will demonstrate and explain their Morse Code communication device

Materials

For each group of 2 students
- BasicBoard
- Computer

For each student
- Worksheet
- Challenge sheet
- Double Dare Sheet

Vocabulary:

- Morse code

Tasks you need to perform

Answer questions in your Worksheet, Challenge & Double Dare sheets

Getting Started

Morse code is a method of communicating that uses a series of short and long pulses, which are typically referred to as "dots" and "dashes."

In this lesson we will create words for each Morse code letter using the following rules:

a) The length of a dot is one unit
b) The length of a dash is three units (i.e., three times as long as a dot)
c) The space between dots and dashes within one letter is one unit
d) The space between letters is three units
e) The space between words in a sentence is seven units.

Morse Code Guide:

A • –	J • – – –	S • • •
B – • • •	K – • –	T –
C – • – •	L • – • •	U • • –
D – • •	M – –	V • • • –
E •	N – •	W • – –
F • • – •	O – – –	X – • • –
G – – •	P • – – •	Y – • – –
H • • • •	Q – – • –	Z – – • •
I • •	R • – •	

Instructions

STEP 1. Set up computer, BasicBoard, Arduino and verify operation

Set up the computer and BasicBoard, then connect the Arduino to the computer and verify that all LEDs are operating correctly.

Terminal

```
connect
OB1on
OB1off
dp2on
dp2off
dp3on
dp3off
dp4on
dp4off
dp5on
dp5off
```

Use the instructions at the bottom of page 2 to reload your existing project with the name you chose in *Lesson 2.1*. Connect your project using `connect`, and test that everything is working by turning on and off the on-board LED, and also all four of your external LEDs.

On your worksheet, check off the LEDs that function correctly.

STEP 2. Edit the LEDs-YourName.logo file to create words for a dot and a dash

Open the text editor by typing `edit-project` in the terminal window. This will open a file called `LEDs-YourName.logo` in a text editor window. You will use this file to create all the words needed to implement Morse code.

Your first task is to figure out how to create words to do a single dot and a single dash.

On your worksheet, write the code that will create a single dot (a light that stays on for one unit of time) and a single dash (a light that stays on for three units of time). Run the code and debug if needed. When you think it is working correctly, share your code with a classmate and make sure that you both agree that your code runs correctly.

STEP 3. Create words to represent a few letters of the alphabet

Write code to signal the letters “S” and “O” then test it out on a classmate. Make sure you both agree that the signals being sent are correct.

On your worksheet, write the code for each letter “S” and “O”.

STEP 4. Create a word to send the signal “SOS”

Write code that uses your words for “S” and “O” to create the universal distress signal “SOS”. Send the signal to a classmate.

On your worksheet, write the code that signals “SOS” and get your classmate to initial your worksheet to indicate that the code is working correctly.

STEP 5. Complete the challenges

If you successfully signaled “SOS” please continue with the challenges for this lesson.

Name:____

STEP 1 Check off the LEDs that function correctly.

Which LED?	Functioned correctly?
On Board	
Red	
White	
Blue	
Green	

STEP 2 Write the code that will create a single dot (a light that stays on for one unit of time) and a single dash (a light that stays on for three units of time). Run the code and debug if needed. When you think it is working correctly, share your code with a classmate and make sure that you both agree that your code runs correctly.

Name:____

STEP 3 Write the code for each letter “S” and “O”.

STEP 4 Write the code that signals “SOS” and get your classmate to initial your worksheet to indicate that the code is working correctly.

Name:____

For each Challenge, write the code you used to accomplish the task.

C-1

Create a word that will display "MESSAGE" using Morse code.

C-2

Without sharing your Logo code for letters or dots and dashes, do the following:

a) Send a coded message to another group in your class that has at least 2 words in it.
b) Decipher a coded message from another group in your class.
c) Share your code with the other group and discuss how your implementations differed. Find one way to improve your code based on this experience, and document it here.

C-3

Present your Morse Code words to the class. Be as creative as you'd like with your presentation. Credit will be awarded based on your clarity, effort and creativity. Here are some ideas for the presentation:

- Make a poster
- Make a flyer
- Write an instruction manual
- Demonstrate your code using a computer and a projector
- Make an instructional video

Name:____

For each Double Dare write the code you used to accomplish the task.

D-1

Implement the rest of the letters in the alphabet so you have a complete set. Use the letters to send longer messages.

D-2

Any number can be represented by a sequence of binary digits (zeroes and ones). It only takes four binary digits to count from 0 (0000) to 15 (1111).

a) Research binary numbers and write down all the numbers from 1 to 15 in binary

b) Write code that will turn your 4-LED BasicBoard system into a binary display.