Experiment: MFC

Student Handouts

MFC 1: Starter Experiment

Getting Started

When was the last time you took a walk in the park, in your neighborhood, out in a field, or in the woods? Did you consider what might be living right under your feet? The ground you walk on is teeming with activity!

Throughout this unit, you will explore the electrifying properties of dirt, also known as soil, within a "MudWatt" vessel.

Learning Goals

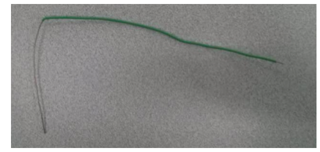
- ✓ Follow directions to assemble the MFC experiment which includes a "MudWatt" vessel and sensors to monitor internal and external temperatures.
- ✓ Describe how the MFC experiment components and BasicBoard system work together to gather power and temperature information.
- ✓ Understand how Logo collects and displays measurements from the MFC experiment.
- ✓ Describe any patterns you see in playback data from the MFC experiment.

Instructions

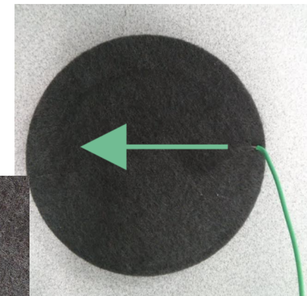
1. Gather the following materials:
   - ☐ BasicBoard and HP Stream
   - ☐ Wire as needed
   - ☐ 2 Leashed and wrapped temperature sensors

     (Calibration numbers must be known)
   - ☐ Hookup wire
   - ☐ Needle nose pliers
   - ☐ Wire stripper
   - ☐ Anode pad (thin) + green titanium wire + nylon bolt, nut, and washer
   - ☐ Cathode pad (thick) + orange titanium wire + nylon bolt, nut, and washer
   - ☐ MudWatt vessel from Keego Technologies LLC (lid predrilled)
   - ☐ 2 crimp connectors
   - ☐ Small amount of modeling clay
   - ☐ Pencil
   - ☐ Plastic container
   - ☐ Cup of water
   - ☐ Spoon
   - ☐ Screen or sifting device
   - ☐ Soil (dry)
   - ☐ Additives: pinch of salt, pinch of sugar, and shredded thin paper to add to the soil

2. Assemble the MudWatt vessel, if it is not already assembled. Note that the **Anode** is the **thin pad** with the **green** wire, and the **Cathode** is the **thick pad** with the **orange** wire.

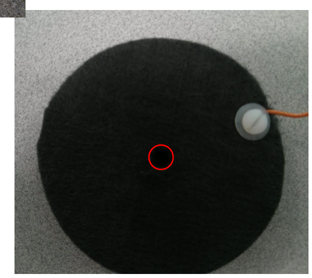


- Bend the **green** anode wire where the **green** and silver wire meet.
- Poke the silver wire into the pad from the side so all of it disappears into the pad.
- Feed the nylon bolt through the washer, then push it into the pad near the **green** wire. *NOTE: Keep the washer completely on the pad.*



- Wrap the **green** wire around the bolt, between the pad and the washer.
- Twist the nut onto the bolt on the other side of the pad.

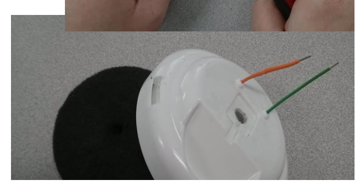
- **Repeat** using the **orange** cathode wire with the cathode thick pad. Replace "**green**" with "**orange,**" "anode" with "cathode", and "thin" with "thick" in the instructions above.



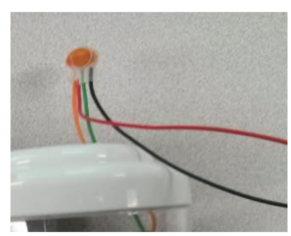
- Make a small hole in the center of each of the two pads.
- If the lid did not arrive pre-drilled, ask your teacher to create a hole in the lid of the MudWatt vessel.

- Using wire strippers, cut off a 30 cm section of both the **red** and **black** wire. Strip both ends of the wire by about 1 cm.

- Get the MudWatt vessel plastic lid. Push the **orange** cathode wire and the **green** anode wire each through one of the small holes in the lid.



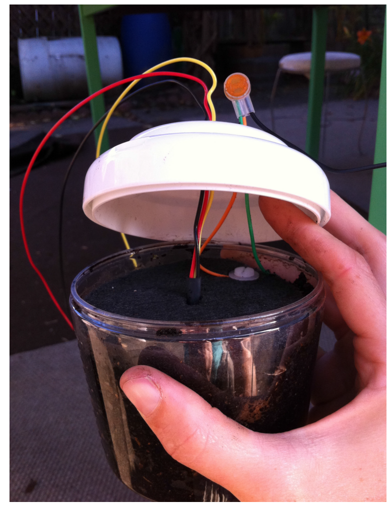
- Find a crimp connector. Firmly push the **green** anode wire in one hole and the **black** wire in the other hole. Then use pliers to squeeze the connector into place, connecting the two wires.
- Repeat the process with the crimp connector using the **orange** cathode wire with the **red** wire.



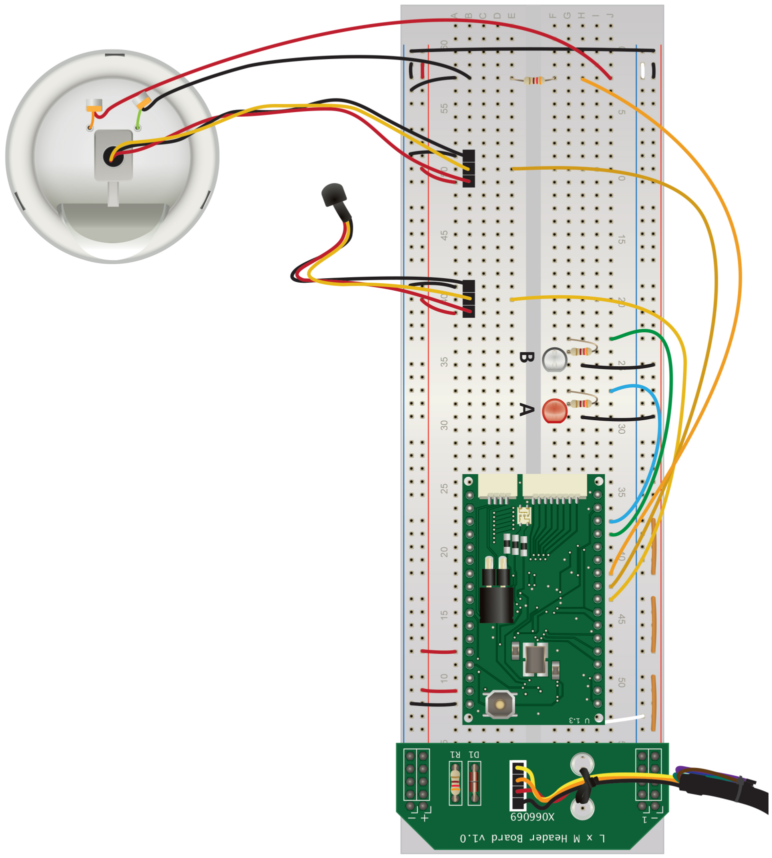
3. Collect, create, and add mud to the **MudWatt vessel.** Save some of this mud in another container for a future lesson.

- Dig up soil, preferably near a creek, pond, or compost pile. *Do not use store-bought soil.*
- Dry the soil in the Sun.
- Strain the dried soil through a screen and discard rocks and small sticks.

- Add clean water to the soil until it is as wet as dough.
- Keego Technologies, the MudWatt inventors, suggests mixing in a pinch of salt, sugar, and several strips of newspaper.
- Add a handful of the mud mixture to a separate container. Cover with plastic wrap, aluminum foil, or a lid. Label this container with your name and set it aside for a future lesson.
- Create a 1 cm layer of the soil mixture at the bottom of the MudWatt vessel
- Put the anode (attached to the **green** wire) on top of the soil mixture layer
- Put a 5 cm layer of soil on top of the anode
- Place the cathode (attached to the **orange** wire) on top of the thick soil mixture layer.
- Thread the leashed and waterproofed **temperature sensor** through the hole in the lid and then the hole in the cathode near the center of the MudWatt vessel.
- Carefully poor out excess water
- Tightly close the lid on the MudWatt vessel
- Use modeling clay to seal around the hole and temperature sensor wires to prevent evaporation.



4. Wire the MFC circuit as shown in the diagram to the right



5. Plug the FTDI cable into your HP Stream.

6. Create your own working copy of the experiment called **`MFC`** by following these steps. If done correctly, a new black terminal window should pop up that says **`Welcome to Logo`**.

- Answer **`n`** to would you like to load an existing experiment.
- Answer **`y`** to create a new experiment
- Select **`MFC.tar`**
- Give your experiment a descriptive name. **Record this name in your notebook.**
- Select the version **`target`**

7. Use the command **`.edit-project`** to open the `uLogo` and `jLogo` program files.

8. Open the `jLogo` file for this experiment. This file ends with the extension **`.logo`**

9. Locate the word `init-calibration`. Enter the calibration values **for the sensor that you are using**. Recall, the format is `[ADCReading1 Temperature1 ADCReading2  Temperature2]`

```
to init-Calibration
     make "temp1_cal [6000 4 14000 70]
     make "temp2_cal [6000 4 14000 70]
end
```

10. Save the `jLogo` file.

11. Reload the experiment with the command **`.reload`**

12. Compile and download the code to the AppBoard with **`.compile`** and **`.download`**.

13. Run the program with **`.run-forever`** and confirm that you see packets printed to the terminal window. A separate graph should pop up and refresh each time a new data point is added.

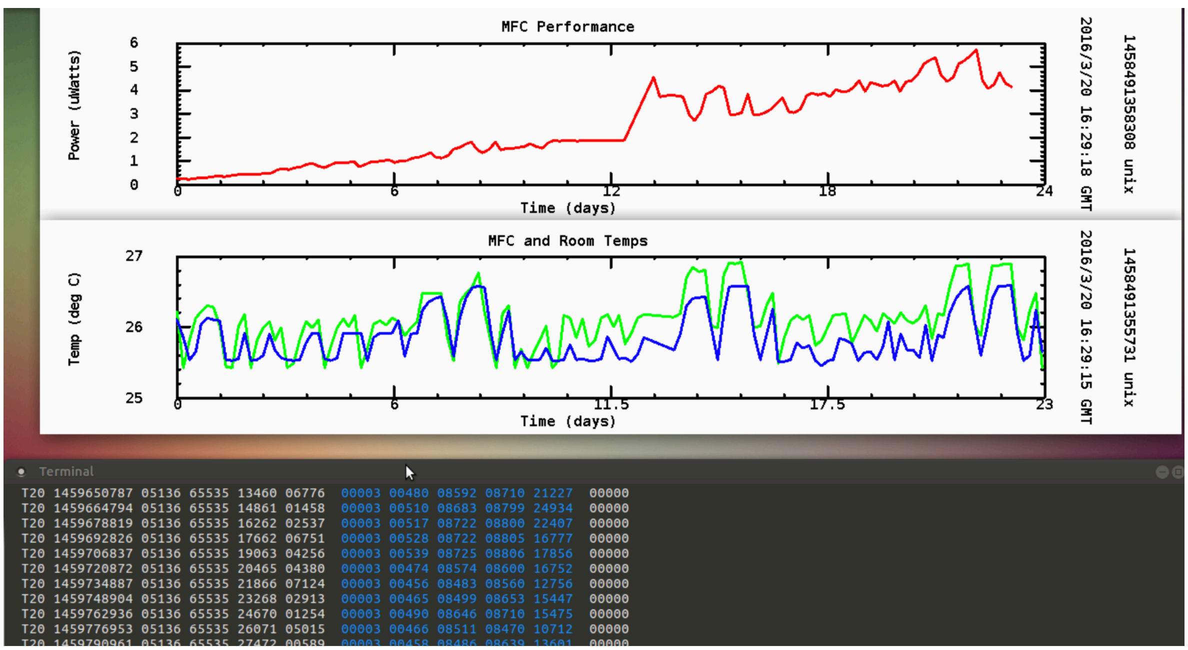
14. Stop the experiment with the command `..` (two dots)

15. Your MFC can't generate any electricity just yet. It needs to sit for a few weeks. For now, we will take a look at sample MFC data collected by another teacher on the Learning by Making team.

16. Use the command **`.edit-project`** to re-open the jLogo file, **`MFC.logo`**.
- Locate the word **`run-playback`**
- Locate and use a semi-colon (`;`) to comment out the line beginning with **`playback-default`**
- Add new line beneath it with the following text:
  `playback-special "data/sampleData.pac 0 0 false 0 false`
- Add a new line beneath that with the following text:
  `process-data-packet`
- Save and exit Pluma

17. Reload the experiment with the command **`.reload`**

18. Enter **`.run-playback`** to start replay of the sample MFC experiment run. Your screen should look similar to this figure:



19. Complete the Starter Experiment challenges.

Challenges

	Credit	Task
1	◆	Draw a simple diagram of your experimental setup. Make sure to indicate the pins on the BasicBoard to which the sensors, cathode, and anode are attached. Label each component, interaction, and mechanism of this starter experiment.
2	◆◆	In your notebook, describe any patterns you see in the sample packets or the graph. What are the units?
3	◆	Identify the independent (manipulated) and dependent (respondent) variables in this experiment. What can be changed or controlled? What can be tested?
4	◆	Restart the program with **`.run-forever`** to begin collecting MFC data. Leave your computer open and powered to monitor your MFC for the next few weeks.

Helpful Hints

If you need to start over, hold down the **`ctrl`** key and **`c`** at the same time. Next, type the command **`start`** and hit the **`enter`** key.
If you already created the MCF experiment, answer **`y`** for **`Would you like to load an existing experiment?`**
If you see **`chip not found`**, call the teacher over.
If you see _____ **`undefined`**, you are trying to run a uLogo word on the AppBoard that it doesn't understand.
If you see **`I don't know how to`** _______, you are trying to run a jLogo word on the HP Stream that it doesn't understand.
If you get an error message, see if you can figure out what you did wrong by asking a classmate for help. If all else fails, ask your teacher.
Watch the FTDI cable <u>during</u> download. If it blinks fast, the AppBoard is working.
Watch the FTDI cable <u>after</u> download. If it slowly blinks red and green, the AppBoard is working.
It is ok to pause the experiment with **`..`** and disconnect the MFC. Warning, there will be a power surge when you first plug it back in.

Going Further

Extra Credit	Task
◆◆	**1.** Use **`.edit-project`** to open the jLogo file for this project. **2.** Locate the **`process-data-packet`** word. **3.** Locate the line **`convert-list “days :time-list ”SecondsToDays`** **4.** Add a new line below it with the following text: **`convert-list “hours :time-list ”SecondsToHours`** **5.** Locate the word **`SecondsToDays`** **6.** Beneath this word (after the **`end`** statement) create the structure for a new word called **`SecondsToHours`** with the following text: **`to SecondsToHours :seconds`** **`end`** **7.** Using **`SecondsToDays`** as a reference, write code inside your **`SecondsToHours`** word that will convert **`:seconds`** into **`:days`**. **8.** Save and exit Pluma. **9.** Use **`.reload`** to load this new code. **10.** Test your code by running the **`.run-playback`** command. After the data has loaded, enter **`.print :hours`** in the terminal window to see if your list was generated and if the numbers inside make sense. In your notebook, record a few of your new readings. Check your math. Do the numbers make sense? Why or why not?

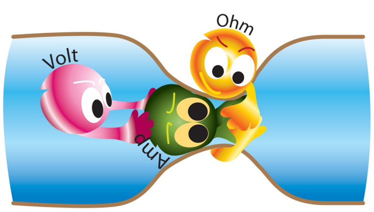
MFC 2: Models and Questions A

Modeling the MFC Circuit

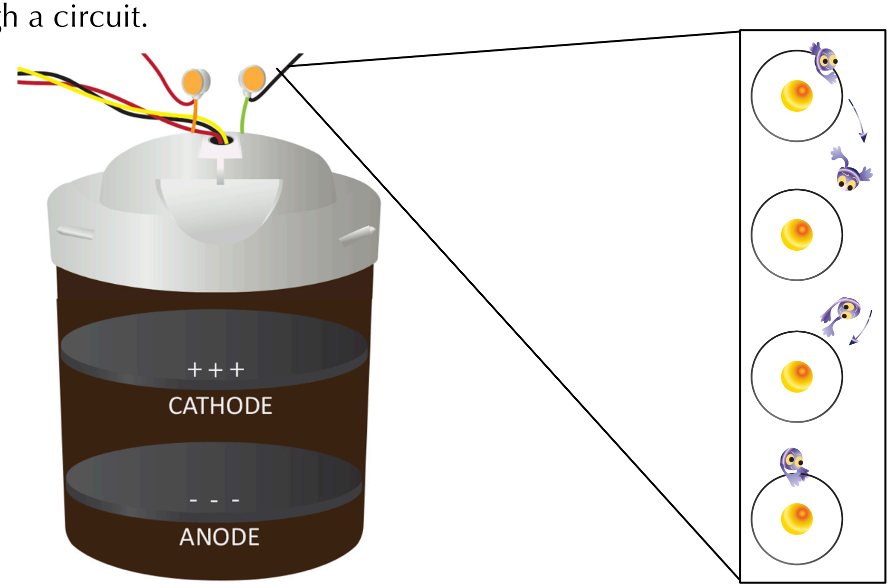
Getting Started

Your MFC acts somewhat like a battery!

Something in the mud creates a **negative charge** on the buried **anode** while a **positive charge** collects on the **cathode**. This separation of positive and negative charge creates a **voltage** difference. A voltage pushes **current** through a circuit.



A voltage difference drives a current.



Electrons flow along wires between the cathode, anode, and BasicBoard.

Recall from Unit 2, an electric current will only flow through a complete loop – a **circuit**. In this lesson, you will follow electrons on their journey through the MFC circuit.

There are 3 independent circuits in the MFC experiment. Can you identify each one?

Learning Goals

✓ Create a diagram that traces the flow of electrons within the MFC experiment circuits.

✓ Explain the structure and function of the MFC experiment circuits.

Instructions

1. Gather the following materials:
   - ☐ Worksheet: Experiment Plan - Models and Questions
   - ☐ Assembled MFC experiment
   - ☐ *Optional* additional paper, whiteboard space, or poster paper
   - ☐ *Optional* notes from Unit 2 Lesson 3

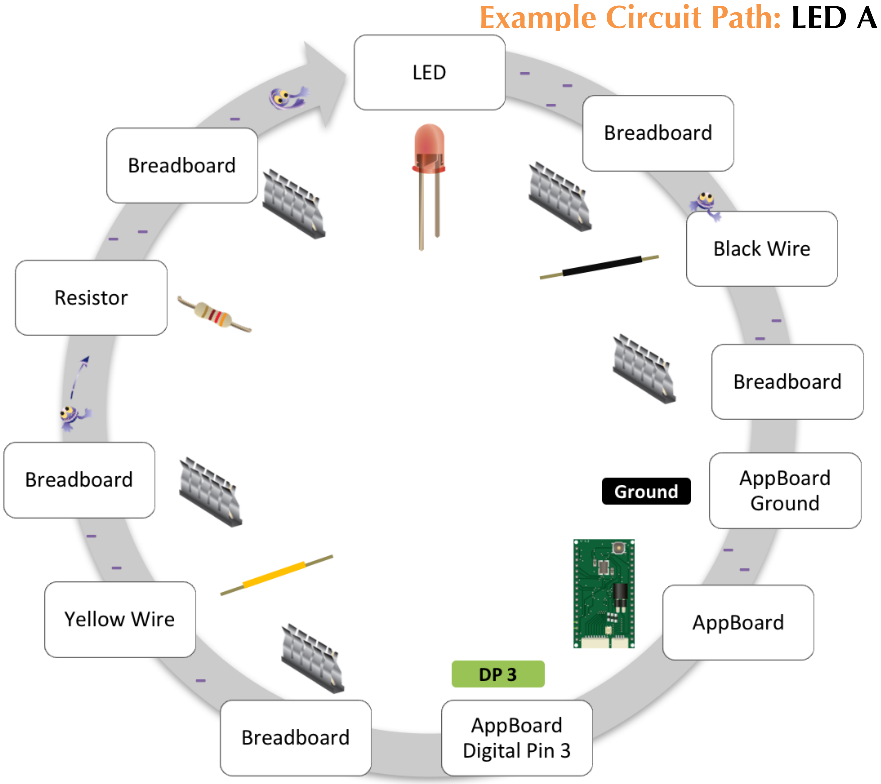
2. In the **Experiment Description** box of your Experiment Plan worksheet, write 1-2 sentences to describe how you connected the MFC to the BasicBoard.

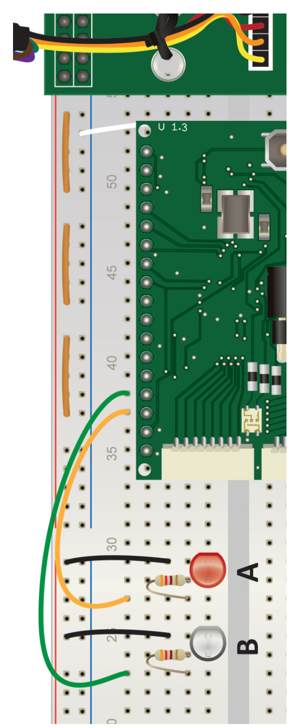
3. In the **My Model** box, propose a circuit path for each of the three MFC circuits. Follow the path that a charged particle would take as it travels through each circuit. Use locations from the provided list.

Green MudWatt Wire	Orange MudWatt Wire	Red Wire
Black Wire	________ Wire	Anode
Cathode	Orange Crimp Connector	Breadboard Hole
Resistor	AppBoard	ADC Pin # ____
Digital Pin # ____	Computer	Temperature Sensor
Mud	Bacteria	Air

note: *Items may be used more than once or not at all. Some locations may not be listed.*

Example Circuit Path: LED A





4. Complete the MFC Circuit Challenges.

Challenges

	Credit	Task
1	◆◆◆	• Swap your Experiment Plan worksheet with that of another group. If you drew your model on something else, attach this worksheet to your model. • Without talking to the other group, fill out the **Peer Feedback** box on their worksheet. Provide at least one suggestion for improving the circuit path and one question you have about the model. • Once you are finished, return the worksheet and model to the other group.
2	◆◆	How can you test if your circuit model is correct? What electrical properties can you measure? • Design a digital multimeter investigation to evaluate the accuracy of each circuit model. • In your laboratory notebook, record and organize your measurements. Write 2-5 sentences explaining the accuracy of your circuit models.
3	◆	• What questions do you still have about how electricity flows through your MFC circuit? In the **Scientific Question** box, write down a scientific question that is: ✓ Answerable ✓ Testable ✓ Specific • In your notebook, write 2-5 sentences to explain how your question is answerable, testable, and specific.

Helpful Hints

Drawing a model may take many iterations. Use an erasable surface to sketch out your ideas.
Show time passing in models by using three panels: before, during, and after.
Use symbols to represent objects that are either too complicated to draw (like a circuit board) or don't have a known form (like an unknown microbe). Label or explain any symbols in your drawings. As a class, you may decide on standard symbols for certain objects.

Going Further

Extra Credit	Task
◆	Your digital multimeters combine many useful electrical measurement devices. Research **voltmeters**, **ammeters**, and **ohmmeters**. Create a handbook for the proper use of each device to measure voltage, current, and resistance.
◆◆	A microbial fuel cell is, essentially, an organic battery. You can wire up multiple MFCs in series and in parallel to change the voltage and current output. Which setup would increase the overall voltage produced? Which setup would increase the overall current?

Models and Questions

Experiment Description

Briefly describe this starter experiment.

My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

This model shows:

I do not understand or/and have questions about:

Scientific Question

What questions do you still have about the process that you modeled?
Generate a testable scientific question.

Name:

Experiment:

Models and Questions

Experiment Description

Briefly describe this starter experiment.

My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

This model shows:

I do not understand or/and have questions about:

Scientific Question

What questions do you still have about the process that you modeled?
Generate a testable scientific question.

Name:

Experiment:

MFC 2: Models and Questions B

Soil and Bacteria

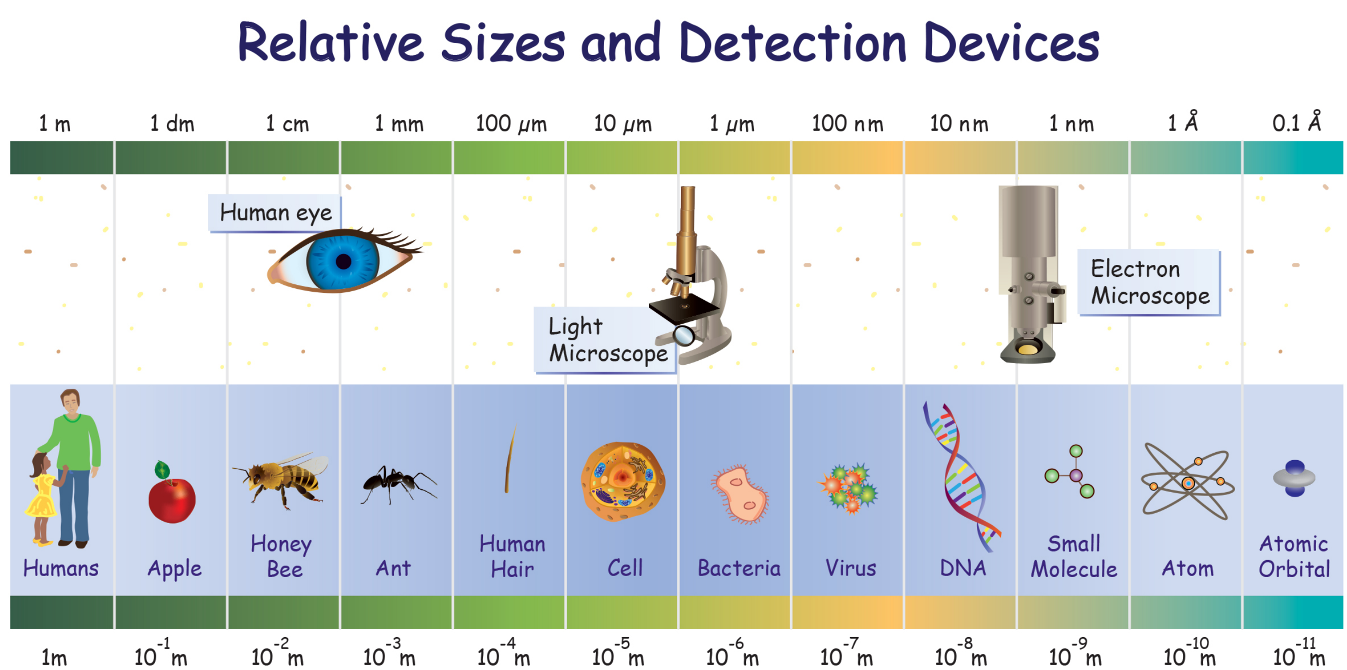
Getting Started

Ever wonder what lives in soil?

Soils contain a huge number of organisms of all different types and sizes. The number of different organisms that live in a particular area is referred to as **biodiversity**. The degree of biodiversity is an indicator of how healthy the soil is.

If your soil has a high biodiversity, there tends to be better soil formation, better cycling of nutrients, and greater energy production in the food web. Some of the organisms are big enough for you to see. These are **macroscopic** organisms. Others are so small they require a microscope. These are **microscopic**.

Living organisms are the reason your MFC, which stands for Microbial Fuel Cell, will produce electricity.



Learning Goals

- ✓ Describe, quantify, and categorize organisms in soil samples.
- ✓ After reading *Shewy The Electric Microbe*, investigate how various microbes may interact within soil samples.
- ✓ Create a model that depicts how electrogenic bacteria interact with their environment in a microbial fuel cell.
- ✓ Use graphical representations of MFC data to infer details about microbe populations and soil conditions.

Instructions

1. Gather the following materials:
- ☐ Worksheet: Experiment Plan - Models and Questions
- ☐ Comic Book: Shewy the Electric Microbe
- ☐ A soil sample matching that used in your MudWatt vessel
- ☐ A magnifying glass
- ☐ A sorting tray or large sheet of paper
- ☐ *Optional* additional paper, whiteboard space, or poster paper

2. Pour a small amount of your soil sample out onto a sorting tray or large sheet of paper. You will need enough space to sift through your sample without making a mess of your table.

3. Using a magnifying glass, locate and separate out various organisms within your soil.

4. In your notebook, create and fill out the following table based on your observations. Once done, put away your soil sample.

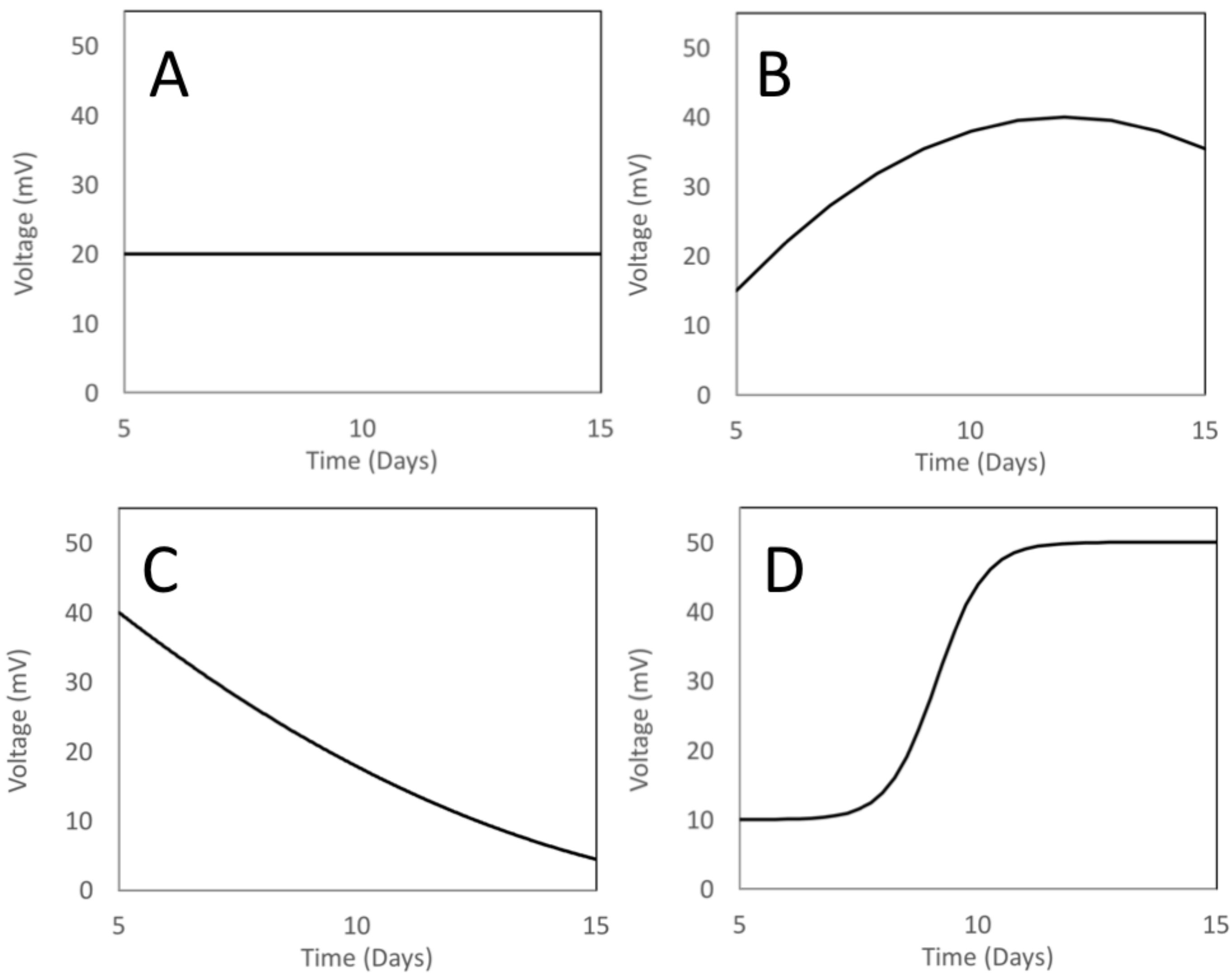
	Organism 1	Organism 2	Organism 3	Organism 4
Type				
Sketch				
Color				
Description				
Quantity				

5. In the **Experiment Description** box of your Experiment Plan worksheet, write 1-2 sentences to describe the organisms found in the soil of your MudWatt vessel.

6. Complete the Soil and Bacteria Challenges.

Challenges

	Credit	Task
1	◆◆	Your table contains organism that are big enough for you to see. There is much more going on in your soil sample. It is full of microbes! • Read the comic book, **Shewy the Electric Microbe**. • How might microscopic organisms, like Shewy, interact with the macroscopic organisms you listed in your table? Do any of them help each other? Do any of them harm each other? In your notebook, write 3-5 sentences about these possible interactions.
2	◆◆	• In the **My Model** box, depict how electrogenic bacteria, like Shewy, interact with other things within the MudWatt vessel. Your model must depict the following: o Where the bacteria live o What the bacteria consume and produce o How the bacteria interact with other organisms o How the bacteria interact with the MudWatt equipment (container, anode/cathode, wires) • Swap your model with that of another group and provide feedback as you did in previous lessons. Use your feedback to improve your own model.
3	◆◆◆	***Population growth leads to more electricity*** Organisms find and consume food. Energy from food is converted into energy that the organism uses to grow, heal, and reproduce. ***Population decay leads to less electricity*** Organisms have an unsafe environment. Too many predators, toxic conditions, or a lack of nutrients will kill organisms. On the next page, examine the MFC electricity output graphs (A-D). They show the amount of electricity generated by 4 different MFCs over a 10-day period. Is there enough food? Is food running out? Is something killing off the microbes? Are the microbes reproducing? What is your evidence? • Address these questions by writing a 1-2 paragraph description of the soil conditions and microbe populations for each MFC.
4	◆◆	• What questions do you still have about soil and the organisms that live within? In the **Scientific Question** box, write down a scientific question that is: ✓ Answerable ✓ Testable ✓ Specific


A
B
C
D
Voltage (mV)
Time (Days)
0
10
20
30
40
50
5
10
15

Helpful Hints

Drawing a model may take many iterations. Use an erasable surface to sketch out your ideas.
Show time passing in models by using three panels: before, during, and after.
Use symbols to represent objects that are either too complicated to draw (like a circuit board) or don't have a known form (like an unknown microbe). Label or explain any symbols in your drawings. As a class, you may decide on standard symbols for certain objects.

Going Further

Extra Credit	Task
◆	There are three main types of microbes: **bacteria**, **viruses**, and **fungi**. Create a poster or presentation that shows what each of these organisms look like under a microscope, how tiny they really are, and where they live.
◆◆	Create a glossary for terms found in the Shewy comic book.

Models and Questions

Experiment Description

Briefly describe this starter experiment.

My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

This model shows:

I do not understand or/and have questions about:

Scientific Question

What questions do you still have about the process that you modeled?
Generate a testable scientific question.

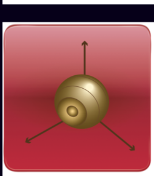
Name:

Experiment:

Models and Questions

Experiment Description

Briefly describe this starter experiment.



My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

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Scientific Question

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Name:

Experiment:

MFC 2: Models and Questions C

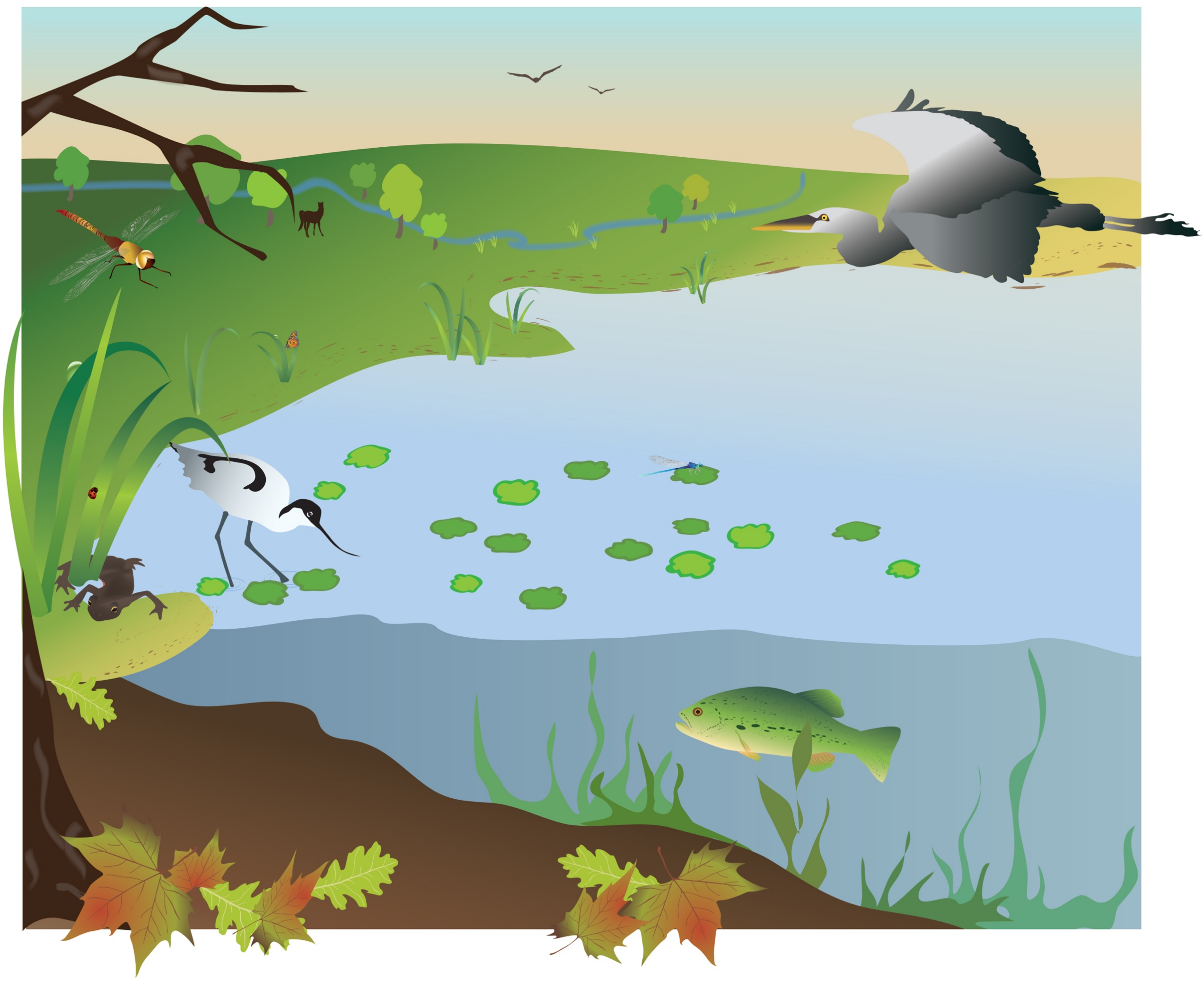
Ecosystems and Energy

Getting Started

Each of your MudWatt vessels contain small ecosystems!

An **ecosystem** includes all the **biotic** (living) and **abiotic** (non-living) things in a particular geographical area. An ecosystem contains a dynamic network of interactions and transformations.

Examine this drawing of a small pond ecosystem:



What things are included in this ecosystem? List 5 biotic and 5 abiotic components.

What interactions may occur in this ecosystem? List two possible interactions between components.

Learning Goals

- ✓ Identify relationships between producers, consumers, and decomposers in ecosystems.
- ✓ Create and refine a model food web of your MudWatt vessel's ecosystem.

Instructions

1. Gather the following materials:
   - ☐ Worksheet: Experiment Plan - Models and Questions
   - ☐ Assembled MFC experiment and/or soil sample (*used as visual reference*)
   - ☐ *Optional* additional paper, whiteboard space, or poster paper

2. Read the following text. In your notebook, record definitions for each of the underlined terms.

> *Life runs on energy. All organisms need to consume or eat some form of energy in order to survive.*
>
> *Energy flows into, out of, and within ecosystems. An example of energy transfer within an ecosystem can be illustrated using a **food web**, which is a graphic representation of the feeding relationships of species within an ecosystem.*
>
> ***Producers** create their own food, usually using the process of photo-synthesis.*
>
> ***Consumers**, which cannot make their own food, eat producers (or other consumers).*
>
> *When a plant or animal dies, **decomposers** (including worms, slugs, snails, bacteria, and fungi) break down the organisms into small and smaller compounds.*
>
> *In this way, matter is continuously recycled through ecosystems.*

3. As a class, gather your lists of biotic things in the small pond ecosystem. Where does each item fit within the food web? Use your laboratory notebook to create and fill out the following table. Record at least **one** producer, **two** consumers, and **three** decomposers.

Producers	Consumers	Decomposers

4. Create a food web poster for your ecosystem.
   a. Write down or draw each biotic thing from your table.
   b. Use arrows and labels to show feeding relationships between items.

5. Complete the Ecosystems and Energy Challenges.

Challenges

	Credit	Task
1	◆	• In the **Experiment Description** box of your Experiment Plan worksheet, write 1-2 sentences to describe ecosystems and what they contain.
2	◆◆	In previous lessons, you explored the contents of your soil samples and learned about the types of microbes that thrive within. • In the **My Model** box, draw a food web of the MudWatt ecosystem. *You may use an additional piece of paper, whiteboard, or poster paper.* Your model must depict the following: o Location of microbes and other biotic organisms o Location of abiotic things o Identification of producers, consumers, and decomposers o Interactions and feeding relationships
3	◆◆	Swap your Experiment Plan worksheet with that of another group. If you drew your model on something else, attach this worksheet to your model. • Provide constructive feedback in their **Peer Feedback** box to help the other group improve their model. • Once your model is returned, use your peer feedback to improve your food web.
4	◆◆	"In ecosystems, energy will dissipate but matter cycles" What does this quote mean? How does energy flow into, out of, and within an ecosystem? How does matter cycle through an ecosystem? • In your notebook, write 2-5 sentences responding to these questions.

Helpful Hints

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Going Further

Extra Credit	Task
◆◆	**Energy** is the ability to do work. In a system with no energy, nothing is happening. Everything stops. Almost every ecosystem on earth is powered by **solar energy**, which is light energy from the Sun. The power to do work contained in solar energy can be harnessed as **electrical energy** by solar panels or as **chemical energy** as plants perform photosynthesis. Chemical energy is the energy stored as chemical bonds are formed and released, as chemical bonds are broken. • Research **Cellular Respiration** and **Photosynthesis** using a biology textbook, the library, or online resources. • Write a 1-2 page paper describing how energy is gathered, stored, and used by organisms that perform each of these processes.

Experiment Plan

Models and Questions

Experiment Description

Briefly describe this starter experiment.

My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

This model shows:

I do not understand or/and have questions about:

Scientific Question

What questions do you still have about the process that you modeled?
Generate a testable scientific question.

Name:

Experiment:

Models and Questions

Experiment Description

Briefly describe this starter experiment.

My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

This model shows:

I do not understand or/and have questions about:

Scientific Question

What questions do you still have about the process that you modeled?
Generate a testable scientific question.

Name:

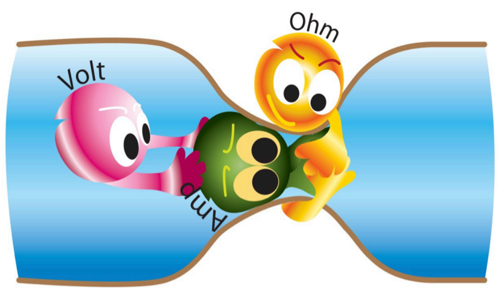
Experiment:

MFC 2: Models and Questions D

Powering the Microbial Fuel Cell

Getting Started

Recall from Unit 2, that Ohm's Law relates voltage, current, and resistance in a circuit. We used a cartoon model to depict the interaction between these three measurements.

<table>
<tr>
<td>Model

</td>
<td>Concept
Ohm's Law:
$Voltage = Current \times Resistance$</td>
</tr>
<tr>
<td colspan="2">This model shows
Current is a flow of electrons within a circuit. Unit: Amp
Voltage pushes electrons around a circuit. Unit: Volt
Resistors reduce the flow of electrons in a circuit. Unit: Ohm</td>
</tr>
</table>

Class Discussion: how might each of these quantities relate to **energy**? If there is more energy in the system, does voltage increase or decrease? What about current? Resistance?

Learning Goals

- ✓ Use Ohm's law to calculate current, voltage, and power for various MFC configurations
- ✓ Estimate the size of an MFC microbe population based on MFC power output

Instructions

1. Gather the following materials:
   - ☐ Worksheet: Experiment Plan - Models and Questions
   - ☐ Assembled MFC experiment
   - ☐ Digital Multimeter
   - ☐ *Optional* additional paper, whiteboard space, or poster paper

2. In the **Experiment Description** box of your Experiment Plan worksheet, write 1-2 sentences to describe Ohm's Law in your own words.

3. Microbes are consuming food inside your MudWatt vessel. They use some food energy to grow/heal/reproduce, and release anything extra as waste. Some of this energy goes into shedding electrons. Some of this energy is escapes as heat. The MFC experiment code calculates the amount of energy released each second and generates a graph of it. This quantity, Energy per unit time has a special name – **Power**.

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} \qquad \text{unit: } Watts$$

There are several ways to calculate power in a circuit if you know at least two of the three quantities: V, R, or I.

$$\boldsymbol{P = V \times I}$$

$$\boldsymbol{P = \frac{V^2}{R}}$$

$$\boldsymbol{P = I^2 R}$$

Use these three equations to fill out the following table in your notebook.

P	V	I	R
	3 V		300 Ω
	1 V	10^{-3} A	
		1 A	200 Ω

4. Your MFC circuit includes a 330 Ω resistor. Use a multimeter to measure the voltage between the red and black wires connected to the anode and cathode of your MFC. Use this voltage measurement and resistor value to calculate the power of your MFC.

5. In the **My Model** box, draw a model to show how you could increase the power output of your Microbial Fuel Cell. *You may use an additional piece of paper, whiteboard, or poster paper.*

6. Complete the Powering the Microbial Fuel Cell Challenges.

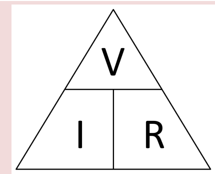
Challenges

	Credit	Task
1	◆◆	• Swap your Experiment Plan worksheet with that of another group. If you drew your model on something else, attach this worksheet to your model. • Without talking to the other group, fill out the **Peer Feedback** box on their worksheet. Write at least <u>two</u> statements for each prompt. • Once you are finished, return the worksheet and model to the other group.
2	◆◆	As a group, reflect on the feedback that you received. What questions do you still have about the power generation? What was unclear in your model? • In the **Scientific Question** box, write a 2-3 sentence reflection.
3	◆◆◆	Throughout the past four Lessons, you created and revised multiple models related to microbial fuel cells. As you expanded your knowledge of MFCs, you may have uncovered more mysteries. It is time to pose a final scientific question. This is your ultimate MFC inquiry. Scientific questions are: ✓ **Answerable**. There is a real answer, often yes or no. ✓ **Testable**. You can design an experiment to find the answer. ✓ **Specific**. The question is focused and unambiguous. The question is not too broad. • As a group, generate a scientific question that will refine, expand, confirm, or refute your current understanding of microbial fuel cells. Write this question in your laboratory notebook. • In your notebook, write 2-5 sentences to explain how your question is answerable, testable, and specific.

Helpful Hints

Drawing a model may take many iterations. Use an erasable surface to sketch out your ideas.
Show time passing in models by using three panels: before, during, and after.
Use symbols to represent objects that are either too complicated to draw (like a circuit board) or don't have a known form (like an unknown microbe). Label or explain any symbols in your drawings. As a class, you may decide on standard symbols for certain objects.

Going Further

Extra Credit	Task
◆◆	The resistors that we use in this class can handle about 0.25 Watts before failure. This experiment uses a 330 Ω resistor. How much voltage would your MFC need to generate to burn out the resistor? Is this voltage possible?
◆	Science classrooms throughout the world have some version of the following figure posted on their walls to help students remember Ohm's Law.  If you want to know one of the three quantities, cover it with your hand and look at what is left. It shows the equation that you need to use. $V = I \times R$ $\quad I = \frac{V}{R}$ $\quad R = \frac{V}{I}$ Make a similar diagram for the power equations. Teach your class how to use the Ohm's Law helpers.

Models and Questions

Experiment Description

Briefly describe this starter experiment.

My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

This model shows:

I do not understand or/and have questions about:

Scientific Question

What questions do you still have about the process that you modeled?
Generate a testable scientific question.

Name:

Experiment:

Models and Questions

Experiment Description

Briefly describe this starter experiment.

My Model

Propose a model to describe what happened.

Peer Feedback

Reviewed by:

This model shows:

I do not understand or/and have questions about:

Scientific Question

What questions do you still have about the process that you modeled?
Generate a testable scientific question.

Name:

Experiment:

MFC 3: Investigation Plan

Getting Started

Huge microbe populations create vast amounts of energy as they decompose organic matter in your MudWatt vessels. Microbes – what they lack in size, they make up for in numbers (and appetite)!

By now, your MFC has been stewing for quite some time. If your microbes thrived and multiplied, you should see some power output.

Now it is time to optimize your muddy microbe powered fuel cells. Reflect on what you've learned about the electronics and soil ecosystem of your MFC. In this lesson, you will design an investigation to figure out what can be done to improve it and generate even more power.

Learning Goals

- ✓ Describe what evidence is needed to answer your scientific question.
- ✓ Design an investigation and explain how this investigation will generate relevant patterns of evidence to answer the scientific question.
- ✓ After peer review of the scientific question and the investigation plan, revise the plan to increase relevance to your question and to generate data that is more accurate and more precise.

Instructions

1. Gather the following materials:
   - ☐ Worksheet: Experiment Plan – Investigation Plan
   - ☐ Assembled MFC experiment
   - ☐ *Optional* additional paper, whiteboard space, or poster paper

2. In your notebook, describe how your MFC has changed since you first built it. Are your microbes thriving or struggling? How do you know? Include a graph or table of power output.

3. In your notebook, write down an investigation plan to address the question you posed at the end of Lesson 2.
   - Describe which variable(s) you plan to change and which variable(s) you plan to measure.
   - Decide on necessary modifications to the startup experiment. Assemble a materials list.
   - Decide on measurement and data collection methods. Does this require software changes? Does this require hardware changes?
   - Identify sources of uncertainty. How will you quantify this uncertainty?
   - Explain how you will process and analyze data.

4. Use the Experiment Plan worksheet to organize the details of your initial plan.
- In the **Variables** box, list the variables you plan to change (independent or manipulated variables) and list the variables you plan to measure (dependent or responding variables).
- In the **Materials** box, list all materials you will need.
- In the **Predicted Result** box, provide an example of the evidence you expect to collect.

5. Modify your MudWatt vessel according to your plan. Since this experiment requires a few weeks of run time, you won't be able to fill in the **Initial Evidence** box like usual. Instead, make a *prediction*. What do you think your power output will be for this new MFC?

6. Complete the Investigation Plan Challenges.

Challenges

	Credit	Task
1	◆◆	Present your experimental design and prediction to the class. For each groups' experiment, provide feedback on the following questions: • Is the investigation relevant to the question posed? • Does the investigation include enough sensors and measurements to address the question posed? • Are there any gaps or weaknesses in the experimental design?
2	◆◆◆	Refine your investigation plan based on peer feedback. In the **Final Investigation Plan** box, describe your revised procedure. • Explain how your plan will improve relevance to your scientific question. • Explain how your plan will improve the reliability of your data collection. Use additional paper as needed.

Helpful Hints

If you already created the Evaporation experiment, answer `y` for `Would you like to load an existing experiment?`
If you see `chip not found`, call the teacher over.
If you see ______ `undefined`, you are trying to run a uLogo word on the AppBoard that it doesn't understand.
If you see `I don't know how to` _______, you are trying to run a jLogo word on the HP Stream that it doesn't understand.
If you get an error message, see if you can figure out what you did wrong by asking a classmate for help. If all else fails, ask your teacher.
Watch the FTDI cable <u>during</u> download. If it blinks fast, the AppBoard is working.
Watch the FTDI cable <u>after</u> download. If it slowly blinks red and green, the AppBoard is working.

Going Further

Extra Credit	Task
◆	It is important to track how energy flows into, out of, and within a system during an investigation. Explain why it is important to keep track of energy when studying a system, using an example from your investigation.

Experiment Plan

Investigation Plan

Your New Scientific Question

Variables

Manipulated:

Responding:

Materials

Predicted Result

Initial Evidence

Perform a test run of your investigation. Record your observations and data.

Peer Feedback

Reviewed by:

Final Investigation Plan

Revise your initial plan in your notebook. Then, explain below how your plan will improve relevance to your scientific question. Explain how your plan will improve the reliability of your data collection.

Teacher Approval:

Name:

Experiment:

Investigation Plan

Your New Scientific Question

Variables

Manipulated:

Responding:

Materials

Predicted Result

Initial Evidence

Perform a test run of your investigation. Record your observations and data.

Peer Feedback

Reviewed by:

Final Investigation Plan

Revise your initial plan in your notebook. Then, explain below how your plan will improve relevance to your scientific question. Explain how your plan will improve the reliability of your data collection.

Teacher Approval:

Name:

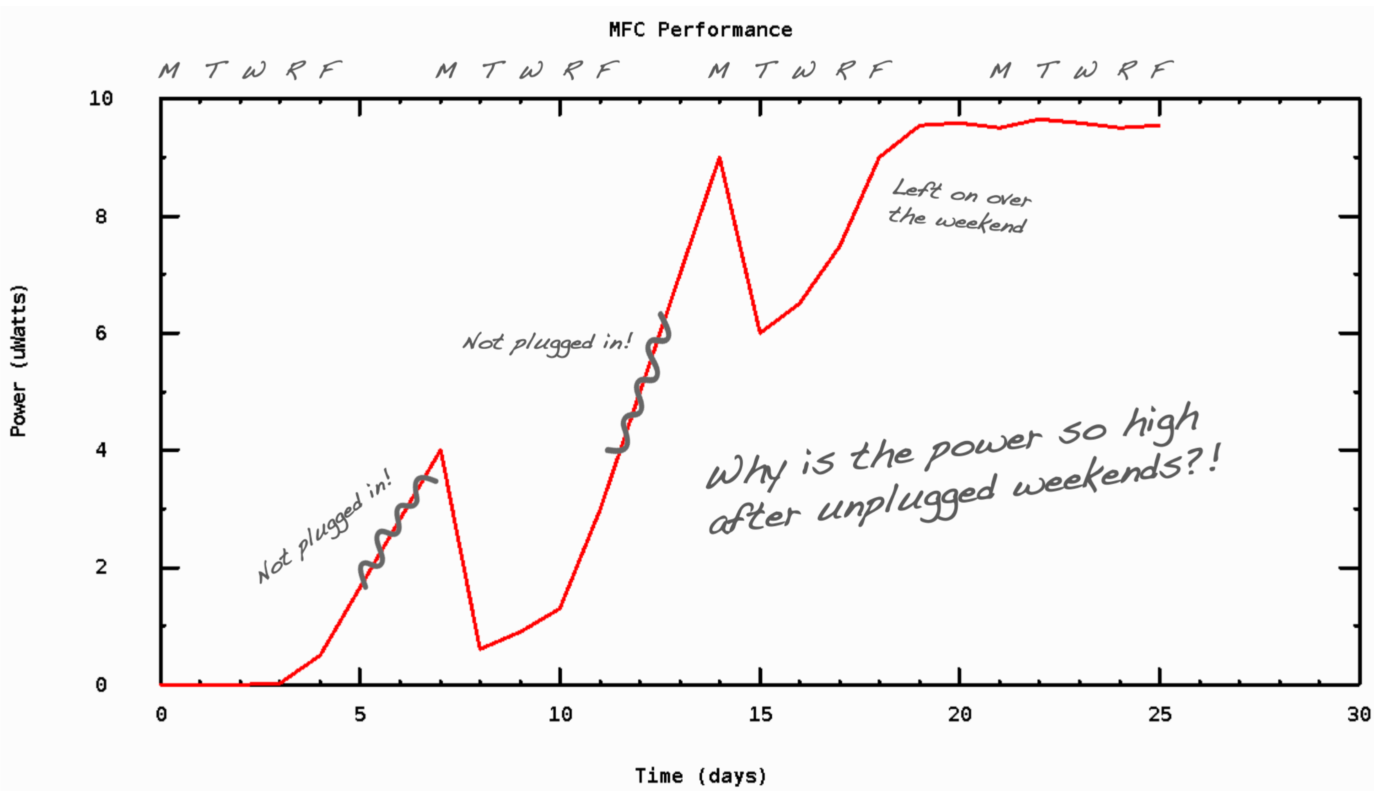
Experiment:

MFC 4: Evidence and Interpretation

Getting Started

A group of three students needs help figuring out how to analyze their MFC experiment data collected over the last four weeks.

Student A	Student B	Student C
Here's the graph. Check out the spikes! What caused the power jumps? Are they mistakes? Should we just ignore them?	We had to unplug our MFC after the first two Fridays. Is there a connection? What are the microbes doing each weekend?	We didn't collect data on four of the days, but the graph shows a line there. Should we graph individual data points instead of connecting the dots?



What would you do? In small groups, take **5 minutes** to draft a response to these student questions. Share your ideas with the rest of the class.

Learning Goals

- ✓ Organize, represent, and analyze data from the investigation.
- ✓ Assess whether or not the data collected is sufficient evidence to answer the scientific question.
- ✓ Revise your microbial fuel cell model and explain how this new model is a better fit for available evidence.

Instructions

1. Gather the following materials:
   - ☐ Worksheet: Experiment Plan – Evidence and Interpretation
   - ☐ Assembled MFC experiment
   - ☐ *Optional* additional paper, whiteboard space, or poster paper

2. If you need to reload data from a previous experiment run, use **`playback-default`** for real time replay or use **`playback-special`** for advanced options. *Remember, you can edit and rename pac files in the data folder of each experiment.*

   Using **`playback-default`**
   - Use the command **`.edit-project`** to re-open the jLogo file**, `MFC.logo`**
   - Locate the word **`run-playback`**
   - Edit the name of the pac file to match the one that you want to analyze
   - Save and exit Pluma
   - Reload the experiment with the command **`.reload`**
   - Replay your experiment with **`.run-playback`**

   Using **`playback-special`**
   - Use the command **`.edit-project`** to re-open the jLogo file**, `MFC.logo`**.
   - Locate the word **`run-playback`**
   - Locate and comment out the line beginning with **`playback-default`**
   - Add new line beneath it with the following text, if it does not already exist:
     `playback-special "data/YourFile.pac 0 0 false 0 false`

pac file	**start time**	**end time**	**speed**	**sample**	**analysis**
`"data/YourFile.pac`	**`0`**	**`0`**	**`false`**	**`0`**	**`false`**
Replace the text `YourFile.pac` with the name of your actual pac file	enter the unix time of the *first* packet you want to load Example: **`1457793122`** is March 12th, 2016 at 2:32:02 PM	enter the unix time of the *last* packet you want to load Example: **`1461486356`** is April 24th, 2016 at 8:25:56 AM	**`true`** – run at normal experimen t speed **`false`** – run as fast as possible	Enter a number that says how many packets to skip **`0`** – use all packets **`5`** – load every 5th packet	**`true`** – plot after each individual packet **`false`** – plot only at the end

   - Add a new line beneath that with the following text, if it does not already exist:
     `process-data-packet`
   - Save and exit Pluma
   - Reload the experiment with the command **`.reload`**
   - Replay your experiment with **`.run-playback`**

3. To create new graphs, edit any of the plotting words in your **`MFC.logo`** file and replay the experiment. Alternatively, you may use the `jLogo` words **`x-data`**, **`y-data`**, **`analyze`**, **`quick-plot`**, and **`display-quick`** to create new graphs. Refer to Lesson 3.7 for a reminder on the function of these words.

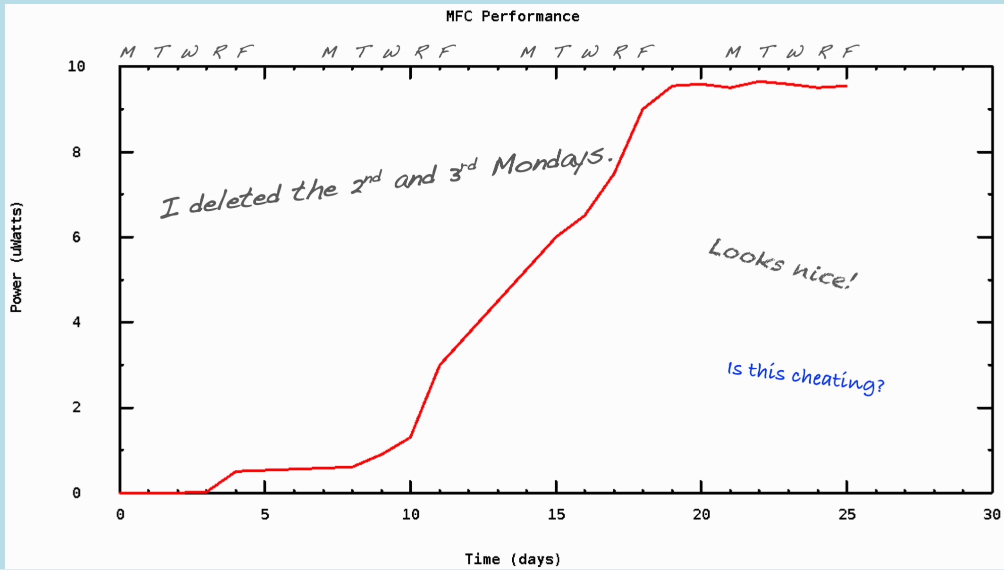
4. Identify features of the dataset that should be analyzed in order to answer your scientific question. Use statistical analysis to identify and quantify sources of error or uncertainty.

5. Complete the MFC Challenges.

Challenges

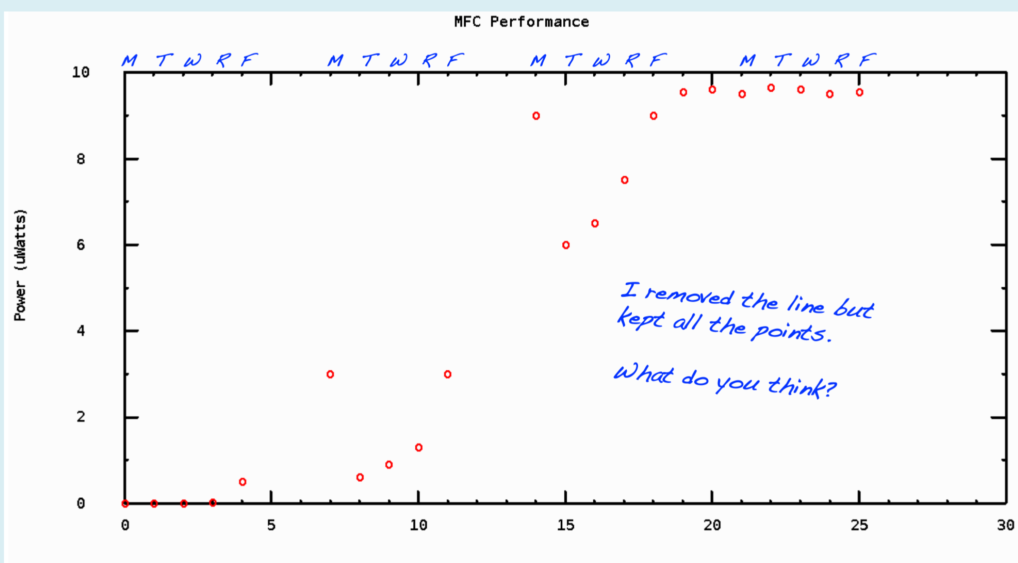
<table>
<tr><th></th><th>Credit</th><th>Task</th></tr>
<tr><td>1</td><td>◆◆</td><td>
One of the students from the earlier discussion decided that the two Monday data points were outliers and should be excluded from analysis.

How was this done? Write down a procedure for either removing or skipping specific data points from an experiment.
How could you focus analysis on the last two weeks? Write down a procedure for only loading the last two weeks of an MFC experiment run.



</td></tr>
<tr><td>2</td><td>◆◆</td><td>
One of the students from the earlier discussion decided that they should plot individual points rather than connecting each one.

How was this done? Write down a procedure for changing the way something in graphed in the MFC experiment.
What would be your next analysis step? Should this group keep those Mondays or throw them out? Explain your reasoning.



</td></tr>
</table>

3	◆	Data **tables** provide an organized way of viewing information. **Graphs** are visual representations of information from a data table. Organize data from your experiment into tables or graphs. Gather evidence by describing patterns and relationships between variables. • Fill out the **Data** box of the Experiment Plan worksheet. Include a table, graph, or written summary of your results. Recall, graphs must include the following features: ☐ A descriptive title ☐ x-axis label with units ☐ y-axis label with unites ☐ Numbered Axes ☐ Data
4	◆◆	Draw conclusions based on your gathered evidence. Is this the only way to interpret the results of your analysis? How do you know that your interpretation is appropriate? How confident are you that your group's claim is valid? • Answer your scientific question using the three parts within the **Interpretation** box. • In your notebook, write a 2-5 sentence reflection on the questions listed above
5	◆◆◆	On a piece of paper, whiteboard, or poster, draw a revised model about the generation of power in an MFC. Your model must depict the following: • Experiment components • How matter moves within the system • How energy flows within the system In the **Revised Model** box, briefly sketch your new model and explain why this model is a better fit for the evidence that you gathered.

Helpful Hints

If you need to start over, hold down the **`ctrl`** key and **`c`** at the same time. Next, type the command **`start`** and hit the **`enter`** key.
If you already created the Evaporation experiment, answer **`y`** for **`Would you like to load an existing experiment?`**
If you see **`chip not found`**, call the teacher over.
If you see _____ **`undefined`**, you are trying to run a uLogo word on the AppBoard that it doesn't understand.
If you see **`I don't know how to`** _______, you are trying to run a jLogo word on the HP Stream that it doesn't understand.
If you get an error message, see if you can figure out what you did wrong by asking a classmate for help. If all else fails, ask your teacher.
Watch the FTDI cable during download. If it blinks fast, the AppBoard is working.
Watch the FTDI cable after download. If it slowly blinks red and green, the AppBoard is working.

Going Further

Extra Credit	Task
◆	Scientists often have to define the boundaries of physical systems and use them to create models to test ideas. Explain why defining systems and models is important in science, using an example from your investigation.
◆◆	Do you agree with the following statements? Write a 1-2 paragraph reflection based on your experiment. "In science, there is no difference between data and evidence." "Observations are facts. Inferences are just guesses."

Evidence and Interpretation

Data

Organize, represent and analyze data from investigations in your notebook.
Then, describe below sources of error or uncertainty.

Interpretation

Claim

Answer your scientific question

Evidence

Provide evidence to support your claim

Justification

Explain why your evidence is relevant and important

Revised Model

Revise your initial model based on these investigation results.

Name:

Experiment:

Evidence and Interpretation

Data

Organize, represent and analyze data from investigations in your notebook.
Then, describe below sources of error or uncertainty.

Interpretation

Claim

Answer your scientific question

Evidence

Provide evidence to support your claim

Justification

Explain why your evidence is relevant and important

Revised Model

Revise your initial model based on these investigation results.

Name:

Experiment:

MFC 5: Presentation

Getting Started

Did you know that microbial fuel cells could help save the world?

- MFCs produce clean energy without burning fossil fuels.
- MFC can decontaminate soil and wastewater.
- MFCs can desalinate ocean water.

Many wineries and breweries are tinkering with their own MFCs to reduce their carbon footprint. A team of UC Berkeley student designed an MFC using a water bottle, aluminum cans, wire, and fish compost to create LED lamps for people in rural Panama.

What impact will your MFC have on the world?

Learning Goals

✓ Create an evidence-based account of the investigation process and the answer to the scientific question.

Instructions

1. Create a group presentation for your experiment. As you write your presentation, remember to do the following:
    - State the explanation you are trying to support.
    - Include genuine evidence (data + analysis + interpretation).
    - Explain why the evidence is important and relevant.
    - Organize your argument in a way that enhances readability.
    - Use a broad range of words including vocabulary that you have learned.
    - Use proper grammar, punctuation, and spelling.

2. Complete the Presentation Challenge.

Challenges

	Credit	Task
1	◆	Present your MFC Experiment to the class. • Connect your HP Stream to the projector and demonstrate your final investigation to the class using the `jLogo` playback feature. • Share your presentation with the class. • Answer questions from the class about your project.

Helpful Hints

If you need to start over, hold down the **`ctrl`** key and **`c`** at the same time. Next, type the command **`start`** and hit the **`enter`** key.
Make sure your HP Stream is set to mirror your screen to the projector.
If you see **`I don't know how to`** _______, you are trying to run a jLogo word on the HP Stream that it doesn't understand.
If you get an error message, see if you can figure out what you did wrong by asking a classmate for help. If all else fails, ask your teacher.

Going Further

Extra Credit	Task
◆	Give a presentation on one of the following topics related to microbial fuel cells: • Desalination • Bioremediation
◆	Science is an ongoing process. What new questions should be investigated to build on your research? What future data should be collected to answer your questions?
◆◆	Communicating scientific results to peers is a valuable part of doing science. Scientists share results with the media, publish scientific papers, give presentations, and attend conferences. Locate a recent example of any of these items on the topic of evaporation. Write a 1-2 page summary and reflection.