MESA USA
National Engineering Arduino Challenge
Instructor Manual 1.1

TEMPLE UNIVERSITY®
COLLEGE OF ENGINERING

MESA Mathematics Engineering Science Achievement
PENNSYLVANIA

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Module 1: The Engineering Design Notebook and the Engineering Design Process

The Engineering Design Notebook

Section 1.1: Purpose

An Engineering Design Notebook (EDN) documents the sequence of steps you used in designing a solution to a problem. An Engineering Design Notebook is a clear and detailed description of your team's design process so that someone unfamiliar with your work can understand it.

Section 1.2: Content

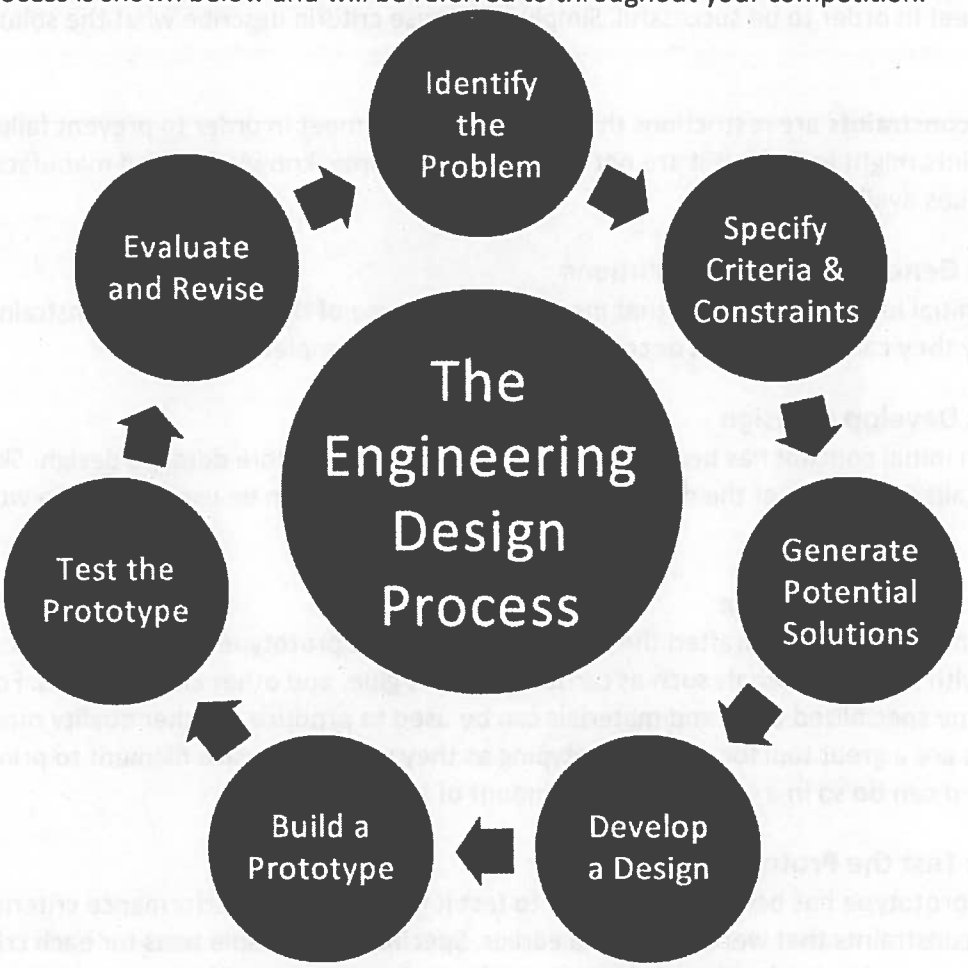
You use the EDN to record your ideas, research, observations, sketches, comments, and new questions throughout the design process. It can be used as a reference document for new ideas, or to communicate your steps to others who want to continue your original project.

Section 1.3: Your Engineering Notebook Should Include

- Notes on background research
- Problem definition
- Lists of criteria and constraints
- Information received from experts
- Drawings, sketches, and photos
- Questions or issues
- Mathematical calculations
- Data tables, charts, and graphs

Section 1.4: MESA Engineering Design Process

The engineering design process is a series of steps that engineers use to create functional products and processes that solve problems. While the engineering design process can be defined in multiple ways, all versions of it have the same general structure. MESA's engineering design process is shown below and will be referred to throughout your competition.



Step 1: Identify the Problem

The Engineering Design Process begins with the identification of the problem that must be solved. By defining the problem an engineer can ensure that the functions, features, and requirements of the solution properly address all aspects of the problem.

Step 2: Specify Performance Criteria and Design Constraints

Performance criteria are statements that define what specifications and standards the design must meet in order to be successful. Simply put, these criteria describe what the solution must do.

Design constraints are restrictions that the design must meet in order to prevent failure. These constraints might include, but are not limited to, cost, time, knowledge, and manufacturing techniques available.

Step 3: Generate Potential Solutions

These initial ideas are concepts that may only meet some of the criteria and constraints, but possibly they can be modified or combined to provide a complete solution.

Step 4: Develop a Design

Once an initial concept has been chosen it is time to create a more detailed design. Sketches and detailed drawings of the design provide a blueprint that can be used to build a working model.

Step 5: Build a Prototype

Once a design has been drafted the next step is to build a prototype. Initial prototypes are made with simple materials such as cardboard, tape, glue, and other craft supplies. For later prototype specialized parts and materials can be used to produce a higher quality model. 3D printers are a great tool for rapid prototyping as they use inexpensive filament to print the parts and can do so in a relatively short amount of time.

Step 6: Test the Prototype

Once a prototype has been built it is time to test it relative to the performance criteria and design constraints that were developed earlier. Specific, quantifiable tests for each criteria and constraint need to be developed. Multiple trials can be run to provide more accurate data on the prototypes performance.

Step 7: Evaluate and Revise

After the prototype has been tested it is time to evaluate the data gathered to determine the success of the device. Analyze what aspects of the design failed to meet the necessary performance criteria and design constraints. Learning from the failures of early prototypes is the greatest way to improve future prototypes.

Module 2: Build a Rover

Section 2.1: Prototype

A prototype is classified as a model of a product used to explore test concepts and ensures that the product is safe and user-friendly. It is important to realize that the goal of building a prototype is to work through the design flaws. Prototyping allows you to fix any flaws or imperfections with the design. In this module, you and your team will build a low-cost rover that will provide a solution to a problem your team will identify.

Section 2.2: Activity - Identify the problem

Read the MESA Arduino STEM Solutions (NEDC/PA MESA) to familiarize yourself with the performance tasks. Based on the performance tasks, your team will develop a problem. The first step into developing a problem is to identify the industry that your teams Human centered design rover will solve. Human centered design means you develop a solution to a problem by integrating the human perspective in every step of the problem-solving process.

Section 2.3: Potential Industries

There are three potential industries that your team can focus on: Aerospace industry, Natural Disaster Search and Recovery, or Agriculture Automation. Your teams Natural Disaster Rover can assist in mining accidents, nuclear hazard investigations, or search and rescue during a natural disaster. You can develop a Mars Rover that searches for life on Mars taking soil samples! Agriculture Automation is another exciting industry where you can develop a rover that search the optimal soil moisture to plant crops.

Section 2.4: Performance Criteria and Design Constraints

Once you have picked an industry that your team wants to focus on, now you have to consider the performance criteria and design constraints when developing designs for your rover. This is important to understand the PA MESA performance rules. For example, your rover needs to be programmed by Ardiuno and have at least three wheels.

Section 2.5: Generate Potential Solutions/Develop a Design

When you and your team are sketching out your designs for your rover make sure you keep in the performance criteria and design constraints that your team have identified. It is recommended that you divide up your class into groups or your team to sketch out some potential solutions for your rover. After you are done with your sketches go over each one as a class. It is also recommended to utilize the Elegoo UNO Project Smart Robot Car Kit V2.0 if your team wants to go that route. Once your team has picked the optimal design, go more into detail with your design. For example, where are you going to put your sensors and which sensors are

you going to use. Are you going to use three wheels or four wheels? What is the base of your rover going to be made out of? Is it going to be 3-D printed or laser cut? These are all questions that need to be considered be developing your final design.

Section 2.6: Build Prototype/ Testing

When building your prototype always keep in mind your main goal for the performance piece. If your team it utilizing the Elegoo UNO Project Smart Robot Car Kit V2.0 there is step-by-step instructions in that kit.

Module 3: Using Arduino Microcontrollers

In this module you will learn the basics of wiring and coding an Arduino. This will allow you to create the electronic system that will power your Arduino device for the competition.

Section 3.1: Terminology

What is Arduino?

Arduino is an open-source family of **microcontroller** boards used to easily design, prototype, and experiment with automating basic electronic devices. Arduino consists of both a **hardware** and a **software** component.

Software: the programs used to direct the operation of a computer and perform certain functions

Hardware: the machines, wiring, and other physical components of a computer or other electronic system

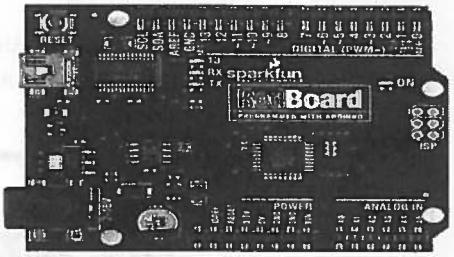
Open-Source: denoting a product or system whose origins, formula, and design are freely accessible to the public to modify and use

Microcontroller: a smaller computer consisting of one circuit

Output: power leaving the system

Circuit: a path where a current source flows through

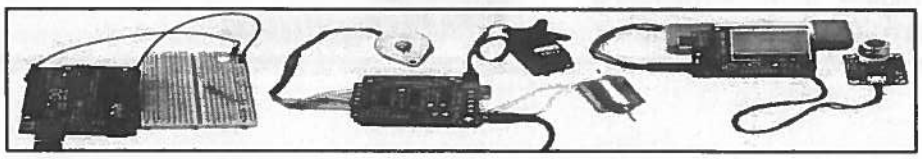
Schematic: a diagram that shows how an electronic circuit is wired



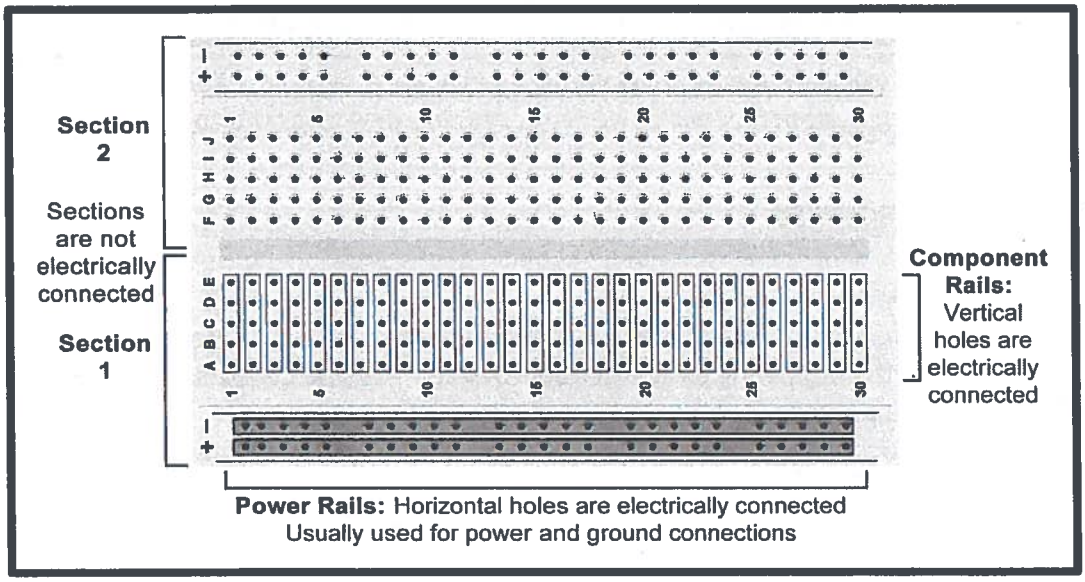
What does Arduino do?

The Arduino hardware and software work together to create electronic projects that are capable of interacting with the world through the use of sensors, lights, motors, and other devices. It does this through the use of its input and output pins. Input pins receive information from hardware components that can include: cameras, buttons, switches, motion sensors, light sensors, proximity sensors, etc. Output pins send signals from the Arduino to hardware components that can include: motors, LEDs, speakers, solenoids, relays, etc.

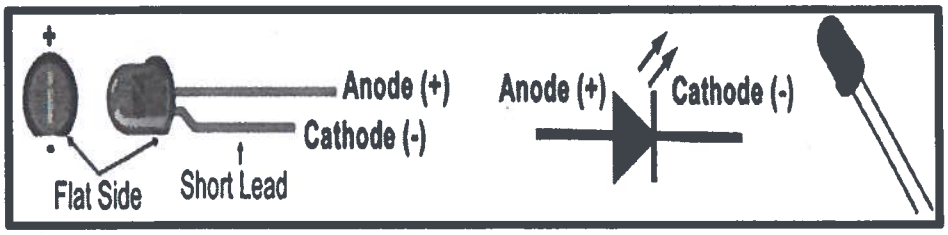
Section 3.2: Electrical Components



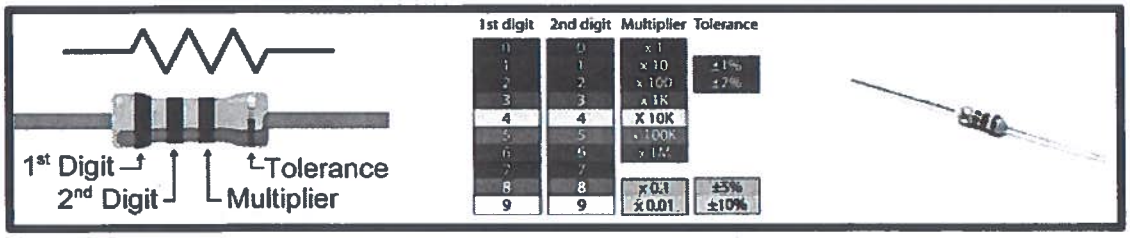
Breadboards are perforated plastic blocks that allow of solderless prototyping of electrical circuits. The holes in the breadboard contain metal contact points that can hold electronic components and connect them with an underlying strip of metal.



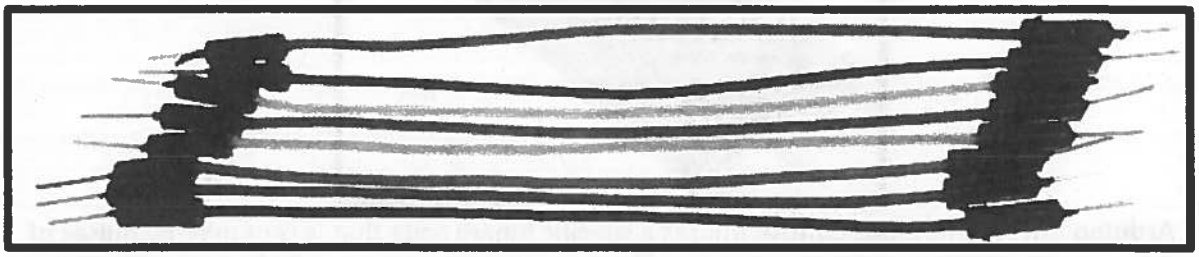
LED: A light emitting diode (LED), is a semiconductor light source. LEDs can produce light of multiple wavelengths: visible, ultraviolet, and infrared.



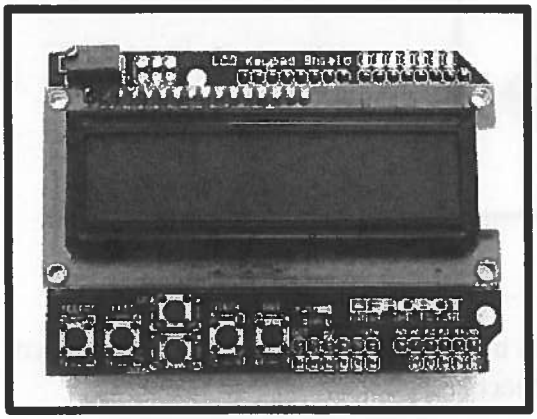
Resistor is an electrical component that limits or regulates the flow of electricity, which can be for the purpose of reducing current in a circuit or lowering voltage levels.

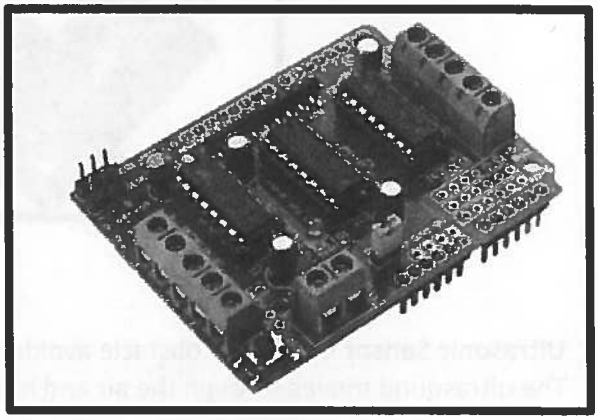


Jumper Wires are short wires that are used for prototyping circuits in combination with breadboard.

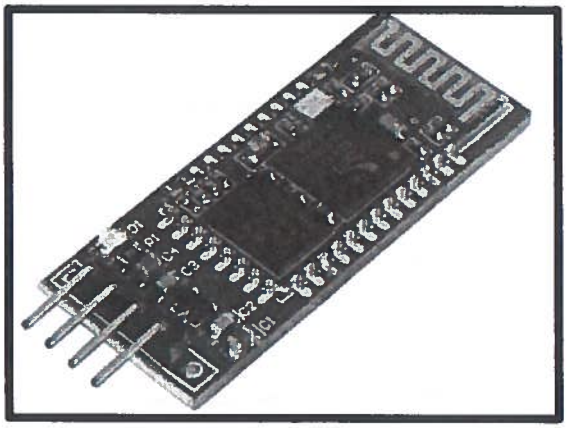


Arduino Shields are placed on top of your Arduino to extend its capabilities. The main function of the shield is a cheap and easy way to connect any external components that are needed. For example, some shields are used to connect to the Internet or a capacitive touchpad.

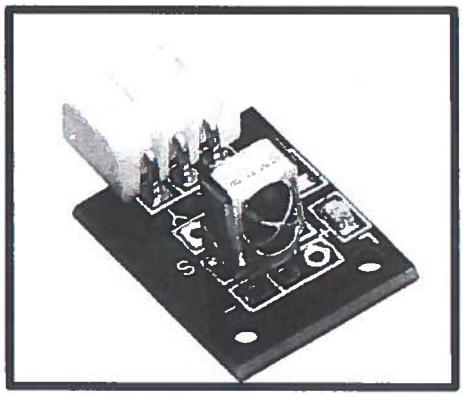




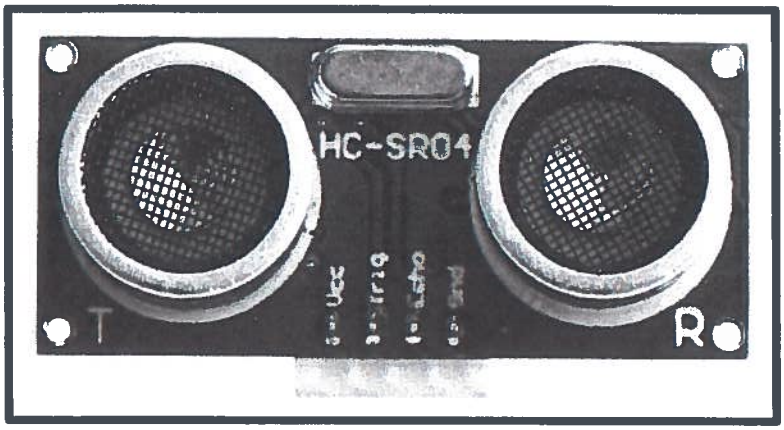
Arduino Bluetooth utilizes a module called Bluegiga WT11, which allows for the Arduino software to transfer textual data from the board to the Bluetooth connection. The Bluetooth connection can either be a computer, phone, or other devices.



Arduino Infrared Remote Control utilizes a specific binary code that is sent over by pulses of infrared light. The binary code corresponds to a specific set of commands like On, Off, Back, or Forward.



Ultrasonic Sensor is used for obstacle avoidance tasks by emitting ultrasound to detect objects. The ultrasound moves through the air and hits the object and bounces back to the sensor.

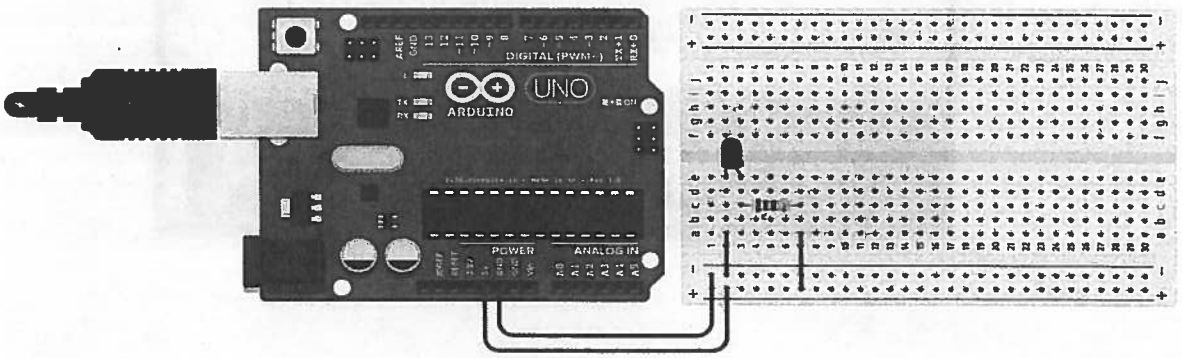


Activity 3.3 Turning on an LED

The objective of this first activity is to understand how to source power from the Arduino board. Follow the procedure on the next page to properly setup the circuit.

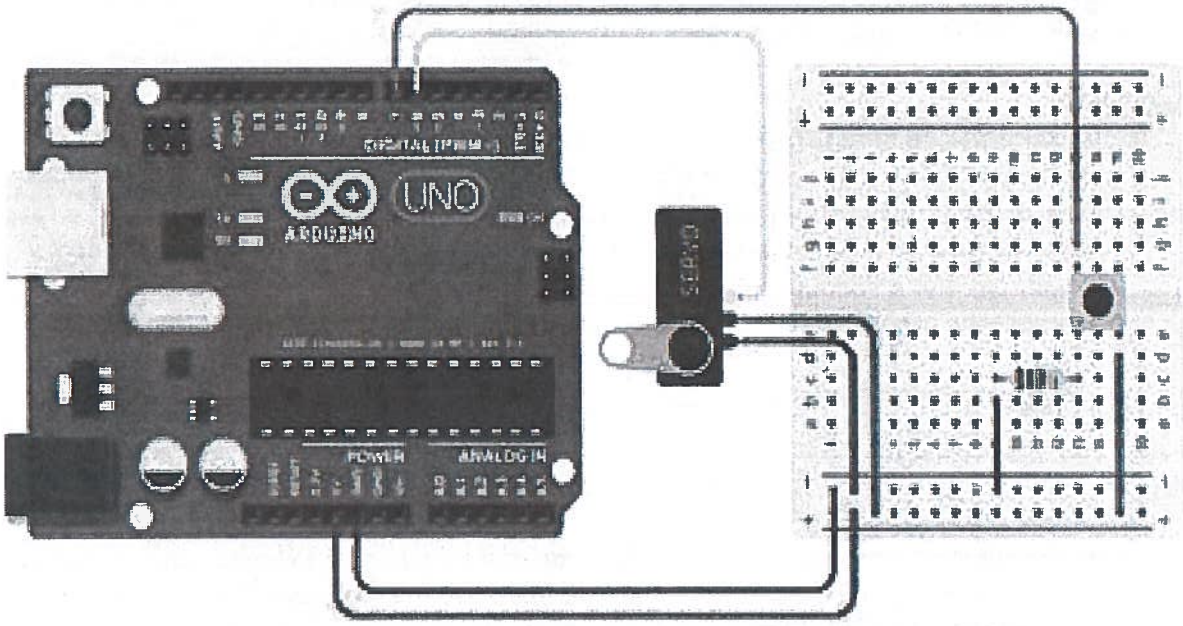
Procedure:

1. Select the components button in the upper right corner of the screen
2. In the search box type 'Arduino' and then click the component labeled 'Arduino Uno R3'
3. Click in the workspace to place the Arduino board next to the breadboard.
4. Click the first dot in the bottom left of the breadboard to place a wire in the positive power rail that is labeled with a red plus sign
5. Connect the other end of that wire to the 5V input pin on the bottom of the Arduino board
6. Create another wire that connects the negative power rail (the row of dots directly above the positive power rail) to the GND pin on the Arduino
7. Create a wire that connects the negative power rail to the 2nd component rail
8. Create a wire that connects the positive power rail to the 7th component rail
9. In the components panel search for 'Resistor' and then click the resistor part
10. Hover the mouse over the breadboard and press the 'R' key three times to rotate the resistor so that it is horizontal
11. Place the resistor so that one end connects to the 3rd component rail and the other end connects to the 7th component rail
12. In the components panel search for 'LED', and place the LED so that the straight terminal (cathode) connects to the 2nd component rail and the bent terminal (anode) connects to the 3rd component rail.
13. Click the 'Start Simulation' in the top right of the screen. If you wired the circuit properly the LED should appear to turn on.
14. If the LED failed to turn on then the circuit is not wired properly. Check to see that your circuit matches the wiring diagram shown below.
15. *Below is an example of the wiring diagram for applying power to an LED*



Activity 3.4: Controlling an LED with a Button

In this activity you will learn how to turn an LED on or off with the press of a button. You will need to declare three variables: the pin the LED is attached to, the pin the button is attached to, and the state of the button (either pressed or un-pressed).



File Edit Sketch Tools Help

LED_Button

```
int led = 7; // create variable for digital pin LED is attached to
int buttonPin = 8; // create variable for digital pin button is attached to
int buttonState = 0; //create variable to store the state of the button

void setup() { // this code runs once
  pinMode(buttonPin, INPUT); // initialize the button pin as an input
  digitalWrite(buttonPin, LOW); // pull the button pin to a low voltage
  pinMode(led, OUTPUT); // initalize the LED pin as an output
}

void loop() { // this code runs continuously
  buttonState = digitalRead(buttonPin);
  // * reads whether the button is pressed and sets the button state variable
  if(buttonState == HIGH){ // if the button is pressed
    digitalWrite(led,HIGH); // then turn the LED on
  }

  else{
    digitalWrite(led,LOW); // otherwise the LED is off
    }
}
```

24 Arduino Uno on COM1

Section 3.5: Activity - Programming Basics:

For any additional help that is needed your team should attend the given build days that are provided by Temple University or go to Code Academy.

The first thing to learn in programming is what is variable. A variable is any particular value that is assigned to a known and/or unknown quantity that contains information. It is made to reference a particular value and it is also classified as a storage location or "Symbolic Names".
Examples:
Number = a + b;
x= 3 + 4
myFavoriteNumber=28

In the first example, both "a" and "b" are variables that represent any number. The variable "a" could be 7 and the variable "b" could be 8. The result would be 15. For this example the numbers can be someone's height or weight. These variables can be arbitrary. In the second example, the variable x is equal to 3 + 4. The result would be that x = 7. In algebra the statements x= 17 and x= 7 + 3 cannot be the same, however in programming "=" is not a truth statement it assigns a specific value to a given variable. First x will equal 17 then afterwards it will equal 10 instead for 17. In programming "=" is identified as an assignment. In the third example, the numerical value 28 is being assigned to the variable, myFavoriteNumber.

There are two different variable properties that are very important to know: The Name, and A Value. A name is unique in the fact that this is how a value is accessed and assigned. When a variable is stored the name represents the title of the variable. The value can be assigned to any variable. For example, flower can be assigned to the value of 28 (flower= 28) and then later on can be changed to 18 (flower= 18). The value can change over any specific time.

There are four different topics for variables programming; Int, Boolean, String, and Float. Int means integer and it is used in many programming languages like C, C++, and C# that holds numerical variables. Just like anything int has limitations where the variables can only be negative and positive whole numbers. For example, 5.6 cannot be used. Boolean can also be referred to as bool or Boolean expression. A Boolean expression essentially means if a statement is true or false. Common expressions that are used are "||" for or and "&&" for and. To fully understand what a Boolean expression is, truth tables can be made.

Examples:

G	M	G AND M
F	F	F
F	T	F
T	F	F
T	T	T

G	M	G OR M
F	F	F

P	Not P
F	T
T	F

As you go through the Boolean examples with your team above think about each statement. Write them down in your engineering notebook. After each team goes through each of the examples, go over them as a class.

The next topic is called a string. A string can be classified as a list of characters, like sentences. This is very important to provide clear communication with the user to the program, " This is a String". The term float means that the variable can contain a decimal point/ fractional value; weight=56.4, gina=349.03, and number= 898.49.

Section 3.5: Activity - Programming Basics- Logic Statements

Basic logic statements are also called conditional statements; if statements, if else statements, and else statements. If statements are used when a situation is true. For example:

```
if ( hour < 19) {
        greeting = " Good Day";
}
```

In this example, if you input an hour that is less than 19:00 then the program will print out "Good Day". From the previous example we know that " Good Day" is a string and greeting is a variable that is assigned a string.

An if-else statement is used when the situation is false. A common "if else" statement is below:

```
If (expression) {
        Statement1
} else {
        Statement2
}
```

An example of this logic statement is below:

```
x <-  -5
if (x > 0) {
        print("Non-negative number")
} else {
        print("Negative number")
}
```

If you input a number that is greater than 0 the output will be "Non- negative number". If you input a number that is less than 0 the output will be "Negative number".

NOTES:

Module 4: Evaluate and Revise the Prototype

After the design has been tested and the performance criteria and design constraints have been verified the engineering design team is tasked with evaluating what changes must be made to the design. The team must analyze the data gathered in any tests to reveal where the prototype failed.

Activity 4.1: Individual Analysis of the Verification and Testing Process

Compare the data gathered directly to the performance criteria and design constraints. Write a statement that records your conclusion on the prototype's ability to meet each criteria/constraint.

Activity 4.2: Group Evaluation of the Testing Process

Selecting one criteria/constraint at a time, each member of the engineering design team should share his/her opinions on how well they felt the prototype met the requirement. The team should discuss how the design failed, why it failed, and possible solutions. Record any additional conclusions gathered through group discussion.

- ➔ What caused the prototype to fail?
- ➔ Where is the prototype surpassing expectations?
- ➔ In which challenge did the arm excel?

Activity 4.3: Redesign and Reiterate the Engineering Design Process

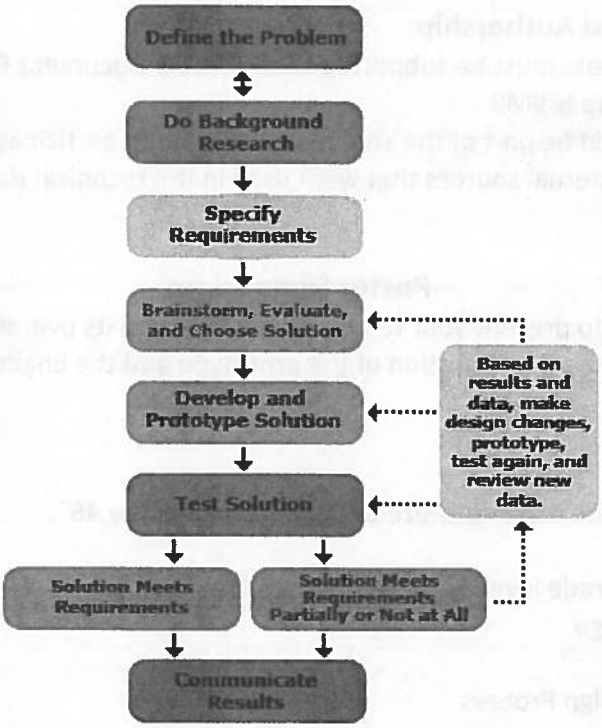
Each team member should develop a new design solution and determine what the next course of action is. Discuss as a group the best solution and next course of action that should be taken by the design team. The goal is to iterate the design process again to either improve an existing prototype or to develop an entirely new solution.

Module 5: Engineering Technical Aspects

There are four different components: Project Report, Poster Symposium, Prototype Pitch, and Presentation and Technical Interview.

Project Report

A technical document that focuses on how well the Engineering Design Process is integrated and implemented throughout your project. A summary of each step of the design process must be provided as well as identifying your objective and client's need (100 points).



Items to include:

- Problem Statement
- Design Process
- Results
- Recommendations
- Data
- Appendix
- Bibliography

Conventions (Format, Language, Grammar):

- The length should be 5 to 10 pages
- Title page should include author's/team members, school, MESA state, and date

- 12 pt. Times New Roman font
- 1" margins and double spaced
- Use Spelling, sentence, paragraphing, and transition conventions
- Readability will increase your score

Written Presentation

- Double-spaced
- Cover sheet
- Graphics should be computer-generated
- Typed

Electronic Format and Authorship:

- All technical papers must be submitted as a Portable Document Format (.PDF)
- Maximum file size is 9MB
- All authors should be part of the student team that are participating in the competition
- Must cite any external sources that were used in the technical document

Poster Symposium

The overall objective is to present your team's final device and its overall functionality. The poster should focus on the final iteration of the prototype and the Engineering Design Process (75 points).

Items to include:

- Size and Type. The maximum size of the poster is 36" by 48".
- Title
- School Name, Grade level, State, Team members' names
- Official MESA logo
- Objective
- Engineering Design Process
- Data
- Conclusions and Recommendations
- Support Materials
- All major sections labeled
- Engineering Design Notebook should be available

Presentation and Technical Interview

The main focus of this presentation is for the team to demonstrate their prototype and interview with the judge panel (75 points).

Overview:

- 5 minute presentation of project summary
- 3.5 minute demonstration of prototype
- 10-12 minutes for technical interview
- Total time 20 minutes

Items to include:

- Project Objective
- Engineering Design Process
- Conclusion and Recommendations for their project
- Prototype Demonstration

Prototype Pitch

Overall objective is to pitch to "investors" and sell your solution. This pitch needs to focus on the client's needs and demonstrate prototype (100 points).

Materials Provided:

- A projector and laptop with PowerPoint and Internet access.
- Wireless Presentation Remote
- Access to electricity for prototypes
- Cafeteria-Style Table (approximately 30" x 72" x 29")
- Special Requests for other materials will be considered but are not guaranteed.

Pitch Rules:

- Teams will have 20 minutes to present.
- Teams will present a prototype pitch to a group of judges, who will act as investors.
- The pitch will be open to the public. States may opt for private sessions at state and local events.
- Teams are allowed to bring additional audio and visual aids to enhance their presentation.
- Teams will be randomly selected to determine the order of presentations.
- Teams must give their pitches in the order drawn. No exceptions or late arrivals.
- Judges will provide time signals to presenters at 1 minute before the 20-minute limit and every minute thereafter. After +5 minutes (a total of 25 minutes), judges will stop the presentation.

Appendix A: Microbes: The Rodney Dangerfield's of the Dirt~ Bert (Optional)

"Saving the Planet" Environmental & Biological Concepts

Overview

Purpose: This unit will explain the different types of microbes, what they eat, the environment they thrive in, their function in the growing process, and how to manipulate the soil environment to promote an increase in numbers and activity.

Grade Level

This unit is intended for students from grades 7 to 12.

Subject Areas

This unit will be aligned with the studies of Environmental Science, Agriculture, and Horticulture.

Rationale

You cannot pick up a newspaper or watch 30 minutes of a news broadcast without reading an article or watching something about nutrition, the health conditions of our citizens, or the quality of food. This phenomenon has caused a resurgence in people growing their own food. In my position as a Master Gardener and an agriculture teacher, I am constantly asked questions about problems gardeners encounter. In the past I would listen to the symptoms and try to diagnose the problem and come up with the solution. Although I never understood the process behind my solutions, I was often successful because I knew the time altered solutions for problems.

This was satisfying for a time, but the compulsive side of me finally broke through and I started to dig deeper into symptoms to find out why the solutions worked. I went to seminars and workshops and bought many books about botany, soil, and gardening. In one seminar I learned about plants sending exudates to the soil and microbes using them for energy and sending the nutrients back up to the plant to use. I did not know that and I had been growing for years! I was floored. That is when I delved whole-hog into the world of microbes. Life on this earth owes its existence to these little creatures and I had to tell the world. I started incorporating this knowledge of microbes into my explanations of solutions to other gardeners and growers. When I would get to the part about microbes the glassed overlook teachers get too often during our lessons would appear. When I would ask about the cause of these expressions, I would get, "they're bugs right?" "Bugs?" I was insulted. My mind immediately went to the comedian, Rodney Dangerfield, whose famous one-liner was "I get no respect!" So I am going to go on this one man crusade to extol the virtues of Microbes; "The Rodney Dangerfield's of the Dirt".

Background Information

In order to have a conversation about microbes we need to learn about the functional environment in which they exist, this is called the Soil Food Web. This is an environment which illustrates the interdependence of creatures to provide food for creatures higher up in the food chain.

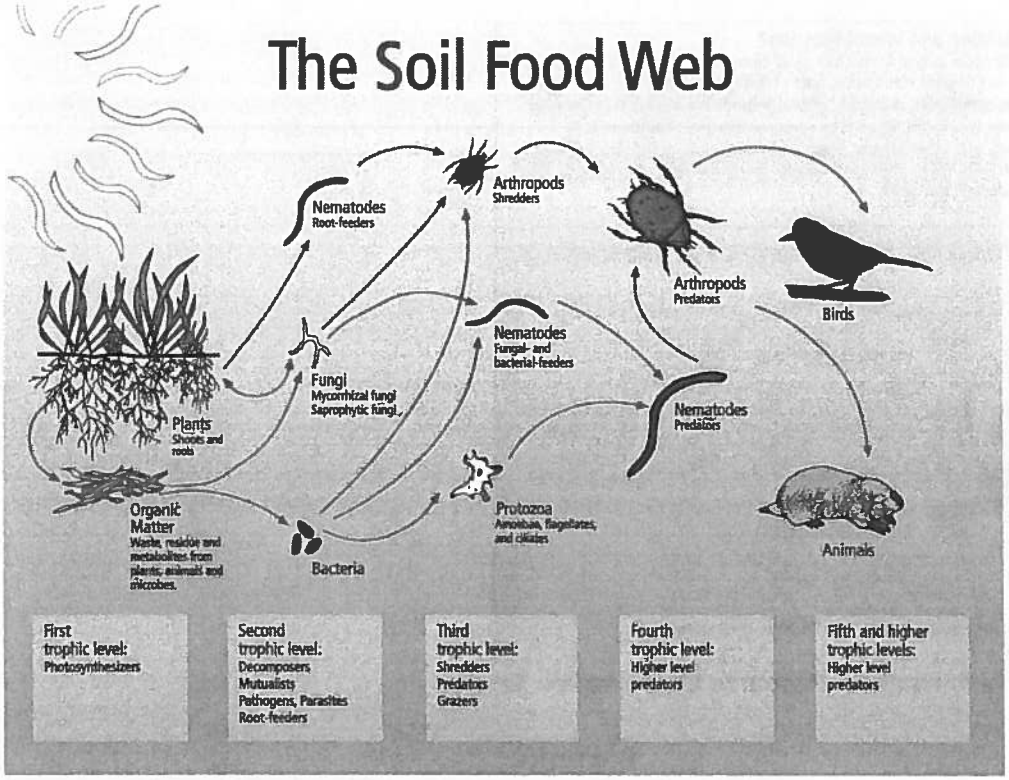


Image courtesy of National Resource Conservation Service

In the Soil Food Web a process takes place in plants called photosynthesis. This is where light works with the plant to split water molecules into hydrogen and oxygen. Oxygen is released to the atmosphere and hydrogen is combined with carbon dioxide to create carbohydrates that the plant uses for food and growth. Any excess carbohydrates the plant can't use gets "sweated" out through the roots to the soil. This "sweat" is called exudates. Exudates consist of other chemicals used for communication and defense but our focus is on the carbohydrates that our microbes will use for food. In this Unit we will talk about some of Second and Third trophic level inhabitants, mainly Bacteria, Archaea, Fungi, and Earthworms. With narrowing down to these four classes of inhabitants there are literally thousands of species in this group but we are only going to explore the beneficial ones, that add to the growing of plants.

There are two processes that occur in the exchange area around the roots of the plant, this area is known as the rhizosphere. The processes are called Immobilization and Mineralization. When the plants release exudates to the soil, microbes capture these substances, convert some of it to use for energy along with inorganic matter in the soil and "house" these nutrients until

they are destroyed or eaten. They unbind nutrients in this process and make these available to plants through the root system. The capture is called the Immobilization process, the release part is the Mineralization Process. Even though the unbinding of nutrients for plant use is very important, equally as important is the trapping of these nutrients in the rhizosphere so they do not get washed away by rain or watering action.

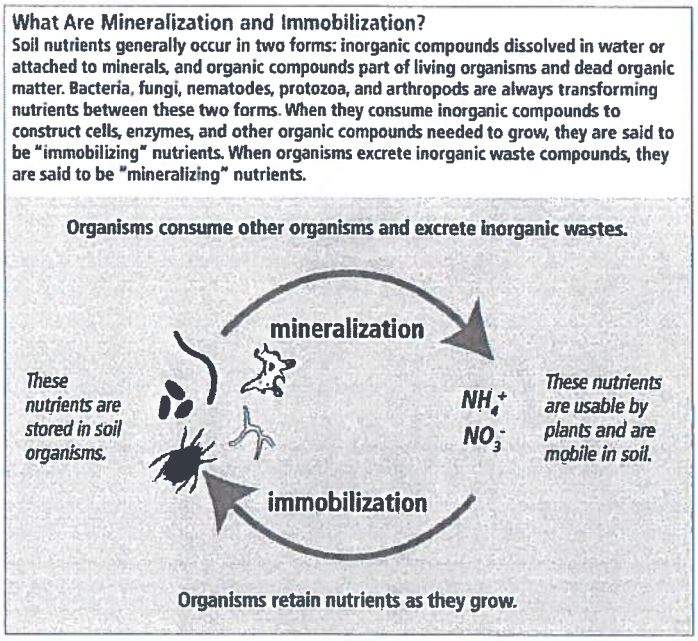


Image courtesy of National Resource Conservation Service

Bacteria

Microscopic Bacteria Image courtesy of National Resource Conservation Service

Jeff Lowenfels writes in, Teaming with Microbes "Bacteria are everywhere. Few gardeners appreciate that they are crucial to the lives of plants, and fewer still have ever taken them into consideration. No other microbe has more members in the soil than bacteria. In part, this is

because these single-celled organisms are so miniscule that anywhere from 250,000 to 5,000,000 of them can fit inside the period at the end of this sentence." (43)
Bacteria are grouped into two major types anaerobic and aerobic. Anaerobic bacteria survive and operate in a low - or no - oxygen environment, whereas Aerobic Bacteria function in an oxygen - rich environment. This is very important because both bacteria are needed for the complete immobilization process.

Physical Description

Bacteria are single - chromosome life forms. They come in 3 shapes, coccus (spherical or oval), bacillus (rod-shaped), and spiral. Bacteria are very small organisms and they do not have mouths. Their cell walls are mainly composed of proteins. These proteins allow nutrients to pass from outside the organism to inside via a diffusion process called osmosis. These proteins act as pumps that suck nutrients from the external environment and also expel "waste" products from inside of the body. Across this cell barrier are different concentrations of fluids that are regulated by the organism and proteins.

Function

Bacteria have two primary functions in the growing environment. They are digesters and suitcases. They employ enzymes to break down organic matter and inorganic matter into nutrients that plant life can use. For example, nitrogen which is essential for plant growth, is normally present in the form of ammonia from waste matter. Bacteria convert this ammonia into nitrites and then convert nitrites into nitrates. These nitrates are in a form that plants can readily use. They use enzymes to unbind other nutrients into forms that plants can use nitrogen as mentioned above and anaerobic bacteria to create sulphates (plant usable nutrients) from sulphur bearing - material.

Environment

Besides the aforementioned oxygen level differences, bacteria need a certain pH level to successfully accomplish their functions. Most bacteria need a neutral pH of 6.5 to 7. Their method of nutrient exchange and enzyme utilization lends itself to a moist environment also. If conditions become too dry the bacteria will go into a suspended animation state until conditions return to normal.

Food Source

Bacteria's favorite foods are the exudates from plants and the dead root tip material sloughed off as the tips grow. Because of bacteria's size digestion takes place outside of the body. The bacteria expel enzymes that break down the food supply into liquid form and the proteins in the cell wall transport the food into the organism's body. The bacteria are very efficient in breaking down "green matter" (cellulose) using enzymes to break the long chains, but they have problems when lignin (the brown fibrous matter), which is impervious to the bacteria's enzymes, is encountered that is left for fungi to decay.

Reproduction

Bacteria reproduce by single cell division; one cell divides into two, etc. ... Under laboratory conditions one solitary bacterium can produce in the vicinity of 5 billion offspring in a mere 12 hours if they have enough food. Fortunately they are held in check by lack of food and conditions. Also bacteria normally do not die of old age. They are either destroyed or killed by environmental means or eaten by other predators and decomposers.

Archaea

Jeff Lowenfels writes in, *Teaming with Microbes* "Just a few years ago, no one would have thought to include archaea in a book on the soil food web. These microorganisms, at first considered a weird and unusual subset of bacteria, were known to live only in extreme environments, such as around geysers or in hot-water ocean vents. Since these spots don't exactly feature in agricultural or horticultural areas, archaea were not considered soil food web members. Then, at the turn of this century, directly as a result of advances in genetic identification of microbes, archaea were found in soil. Moreover, it appears that the role they play in nitrogen fixing - taking atmospheric nitrogen unavailable to plants and converting it into plant-usable form - is a crucial one. Now they have our attention." (52)

Physical Description

Archaea are approximately the same size as bacteria and to the eye (with use of a proper type microscope), they appear to be the same thing. Many types of archaea look a lot like bacteria's three shapes (spherical, rod, and spiral), but they have other shapes too. You can find square shaped, thin needle-like filaments, and rectangular. You can also find lobe-shape, triangular, and teacup shapes. Like bacteria, archaea have cellular walls but unlike bacteria their walls contain lipids, they also contain different amino acids and sugars than bacteria. But there is another distinction between the two, it is genetics. Archaea genes are closer related to eukaryotes (fungi) and they function like eukaryotes in the synthesis of RNA material. Because archaea can be found in various extreme environments they have many modes to utilize the environment to obtain energy. Archaea are also found in the gut of ruminants as well as under the polar ice caps and in the middle of the ocean. There are over 250 types of archaea known so far and because this is a relatively newly discovered organism it is projected that more types will be found since scientists know what to look for.

Function

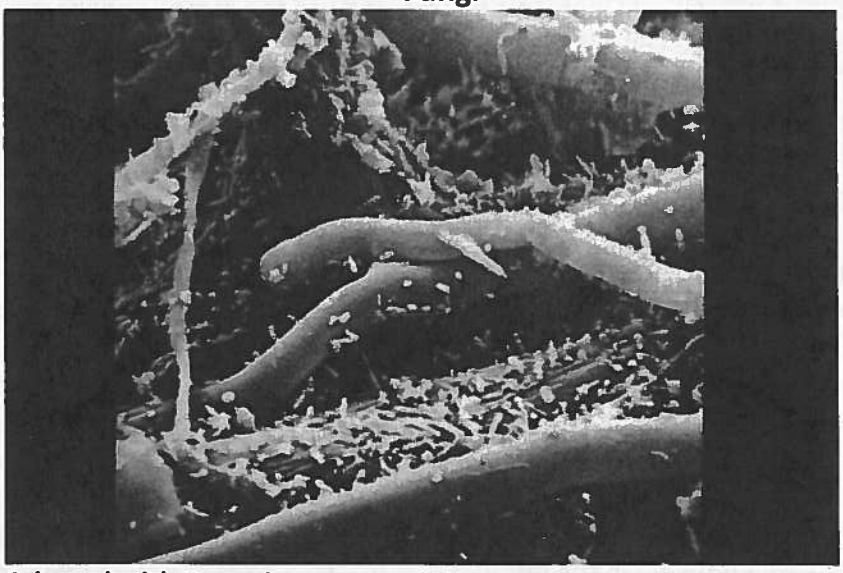
With the newly discovered archaea, scientists have discovered that they are major contributors to the nitrification process, a process once thought to be owned by bacteria. They found the enzyme used for ammonia oxidation in ocean dwelling samples, and found that same enzyme in a huge amount in soil samples (much more than the bacterial gene counterpart). Now because of the greater variety of places archaea are found, more of the oxidation gene has been discovered and archaea are considered to have the greatest number of organisms in the world. Archaea also are great decomposers of sulphur and other organic and inorganic compounds freeing those nutrients for plant life use. Last but not least archaea are responsible for the production of archaeons, a new class of antibiotics. The structure of these antibiotics is

different than those of bacteria so they act in ways existing antibiotics cannot. There is study in using archaea to produce enzymes to treat sewage as well as assisting in the cloning process.

Environment

Archaea are found in almost every environment known to man, from the depths of Mt. St. Helens to beneath the polar ice caps. They are found in the ocean depths around the sea floor vents. There is a salt loving variety of archaea as well as being the responsible party for the production of Methane (previously thought to be the responsibility of bacteria). I am positive we will find them in almost every environment on this earth.

Fungi



Fungi dotted with Bacteria ***Image courtesy of National Resource Conservation Service***

Jeff Lowenfels writes in, *Teaming with Microbes* "Over 100,000 different kinds of fungi are known, and some authorities suggest a million more are out there waiting to be discovered. Say the word, however, and most gardeners immediately think of the familiar white toadstools, bracket, and coral fungi, and puffballs that appear in lawn or on the bark of trees." (61)

Physical Description

Fungi are classified as a eukaryote, an organism that has a distinct cell nucleus which contains all of the DNA material for that organism; they can also have more than one nucleus per cell. Fungi grow from spores in a thread-like fashion. These threads are called hyphae. The hyphal strand consists of walls made of chitin and they are separated by walls called septa but not totally closed off. This configuration allows liquid to pass between cells. The size of these individual strands are too small to see but when you have bundles of them together they become visible and appear as white strands called mycelia. Fungi are much larger than bacteria. Hyphae can grow to the length measured in miles in undisturbed forest. Hyphae display what is

known as apical growth, or growth from the tip. This is different from growth of many organisms like grasses. Grasses grow from the base or root, which is why you can cut a lawn and have it continue to grow. Apical growth has new cells being moved up to the tip and the tip moves forward. Unlike bacteria, fungi do not need water to grow.

Function and Food Source

One of the discoveries I have made in this in depth study has revealed that these "bugs" were thought of being simple in function, dismissing their complicated and complex structure and sophisticated function. Simplified, fungi are major league decomposers and the ultimate delivery system. The aforementioned liquid in the cells is called cytoplasm. This acts as the transport medium to move things throughout the "fungi network". Like bacteria fungi use enzymes to dissolve organic and inorganic matter, and use the osmotic phenomenon to absorb these nutrients through the cell walls into the body. These nutrients are whisked back through the hyphae to the base of the plant where they are made available to the plant. The fungi's favorite food are exudates secreted from plants. Even though fungi like the easier to digest sugars, they also consume the tougher to digest matter, because bacteria are faster to consume the simple sugars. Fungi like bacteria have no mouth but they secrete enzymes to dissolve these tougher to digest materials like lignin, cellulose, and shells of animals. This is also known by many gardeners' fingernails and toenails. One point about exudates is that this secretion is more than food for microbes it is also a communication device. This liquid tells microbes what nutrients they need for growth, because of this ability, fungi can service or deliver the proper nutrients to many plants in the vicinity. Two additional functions fungi provide to the "dirt" kingdom are being a local hideout box and bodyguard services for bacteria. As mentioned before, fungi are much larger than their neighbor bacteria. Bacteria have natural predators known as protozoa. Protozoa are large, much larger than bacteria, but they are also larger than hyphae. When threatened, bacteria can hide in the walls of fungi to elude the protozoa. Nematodes are also a problem in the dirt world, fungi have a novel way of taking care of them, this gets a little graphic (but its nature). The nematode will be cruising along looking for food when it bumps into the tip of the hyphae. Immediately the hypha will coil around the nematode and expand to approx. 3 times its size which effectively strangles the nematode to death, then it proceeds to enter the nematode and consume it as food (gotta love fungi)!

Environment

The operation of secreting enzymes to decompose material causes the environment to become acidic, thus the soils that are heavily populated with fungi tend to have a low pH, i.e. to be acidic.

Reproduction

Fungi reproduction is via spores. That is the main function of the fruiting bodies or mushrooms you see on the surface of the ground. In the gills on the undersides of the mushroom is where the spores are kept. A neat art project done in elementary school is where you take a mushroom and cut off the middle stem portion of the mushroom and then place the cap on a piece of white paper in a few days when you remove the cap there will be a design on the

paper. This design is spores that have fallen out of the drying mushroom cap and have affixed themselves to the white paper in the design of the gills of the mushroom. These tiny spores are carried by the wind so they spread all over the world. A person from Alaska may recognize a native mushroom when visiting Australia.

Earthworms

Jeff Lowenfels writes in, *Teaming with Microbes* "Earthworms are the most recognized inhabitant of the soil food web." (96)

Other than birds, small mammals, and other animals (fish near the shoreline), worms have very few predators. They are one of the most important creatures of the soil but they are also an indication of the health of your soil by their numbers. The soil has to support the other or lower levels of inhabitants in order to support the worm population. They also contribute to the feeding of plants with their manure or castings.

Physical Description

Worms are soft bodied segmented creatures that have a mouth, but no eyes. On their bodies they have sensors along the sides that are light sensitive. Worms also have the ability to expand and contract on demand as well as elongate. They vary in color and size based upon the type, from grayish white and small to red in color, or even black and huge. They move by expanding a section of their body creating a wedge then they narrow down the front part of their body and thrust their head forward chiseling through material. Then they wedge the top into the newly moved material and neck down the rest of their body and pull the rest of their body forward. This action repeats to get where they want to go. Most people would be surprised how quickly these animals move especially when you try to catch them.

Function

Worms are shredders and master decomposers. They open their mouth and pull material inside their bodies. In the digestive tract the food is mixed with saliva where it starts to break down. Then the food travels to a section called a crop which is basically a storage area or stomach. From the crop it travels to a gizzard. This section is just like the gizzards found in chickens and other birds. The gizzard contains little stones or pebbles where the food is ground to a fine paste. This paste is absorbed into the body to be used. Another function of the worm is a burrow maker. The burrows used for transit also serve as passageways for air and water to circulate throughout the soil. Finally the discarded waste is nutrient rich and expelled out of the body into objects called castings. These concentrated objects are gentle time released pockets of fertilizer that are very good for plant life.

Environment

Worms have a skin that is very sensitive to light and to extremes in pH. They prefer a dark, moist, and neutral environment. They are adaptable to temperature conditions by modifying their activity. When it is warm they move lively and decompose more and reproduce with appropriate moisture levels. They die at temps below 40 degrees F and above 90 degrees F.

Food Source

I have been vermicomposting for approximately 7 years successfully maintaining many farms and producing quality compost tea (a manufactured nutrient rich antibacterial product made from compost). I always believed worms major food was the actual food that was placed into the worm bin. But after learning about the other inhabitants of the soil food web, I discovered the main part of the worm's diet consists of the bacteria and other creatures that decompose the food placed in the bin. That revelation is really what drove me to find out more about this unseen world

Reproduction

Worms carry both sets of sexual organs. Each has a tube that holds 15 -20 eggs and when the worms rub up next to each other they fertilize the eggs. The worms are then released in a cocoon where the baby worms will hatch and in 3 - 4 months they will be mature enough to reproduce.

Objectives

Physical Properties
SWBT Identify and compare the relative sizes of 2 microbes (Bacteria and Fungi)
Agricultural Effects
SWBT measure the effect of "microbe enhanced soil" on pea plants in a plant trial setup

Strategies

Students routinely have problems with estimation of object sizes. These microbes are very small and other than earthworms are not visible individually to the naked eye. We will use common objects and math to visualize relative sizes of microbes contained in a teaspoon.

Agricultural Effects

Since these microbes are very small and the equipment needed to observe the quantitative effect they have on plants, we will observe the more general qualitative effect they have on plant growth namely Rhizobium Leguminosarum on pea plants.

Appendix B: Classroom Activities/ Lesson Plans (Optional)

Environmental & Biological Concepts Cont.

How Big is small?

Students have difficulty with estimation and also visualizing size when it comes to objects on the microscopic size. This lesson will help students visualize the size of microbes in a teaspoon using their room and objects in the room as microbes. The first part of this lesson will illustrate the basic math principles used for this activity. We will use the principle of ratios to determine our objects and you will need a ruler or tape measure where the smallest markings are $1/16^{th}$ of an inch (and don't forget the teaspoon).

We will look up or calculate facts needed for this lesson. The facts needed are:

1. Volume of room - Vr
2. Volume of a teaspoon - Vt
3. Volume of bacteria - Vb
4. Volume of fungi - Vf

Once all of the numbers have been obtained, create the ratios of volume of teaspoon to volume of bacteria (Vt/Vb), volume of teaspoon to volume of fungi (Vt/Vf).

Vt = .5 cm3 (from Google calculator)

Vb= 5.24×10^{-12} (assuming spherical bacteria 1 micrometer in diameter)

Vf= 1.57×10^{-10} (assuming 15 micrometer length and 3.5 micrometer diameter)

Now we figure ratios or division factors:

Vt / Vb = $.5 / 5.24 \times 10^{-12} = 95419847328.2$

Vt / Vf = $.5 / 1.57 \times 10^{-10} = 3184713375.8$

Now that we have our factors let's calculate our volume of our room (in inches). Let's assume or room is 20ft (240 inches) x 30ft (360 inches) x 15ft (180 inches). This calculates to 15552000 cubic inches. Now let's divide by our factors. In order to find the comparative size of our bacteria is 15552000 / 95419847328.2 = 0.00163 cubic inches. His corresponds to a box with sides of approximately .05 inches in length. This is about $1/20^{th}$ of an inch, since most rulers have $1/16^{th}$ of an inch as their smallest division, make a mark on your paper that is $1/16^{th}$ x $1/16^{th}$ and compare that to the size of the room. That is the relationship of the average bacteria to a teaspoon!

Next let's do the fungi. We have the math problem of 15552000 / 3184713375.8 that equals approximately .005 cubic inches. This corresponds to a square that has a length equals approximately to .17 inches. This is about $1/5^{th}$ of an inch. Go to your ruler and count 4 of the smallest markings, this is the approx. length. Make a square with this length next to the bacteria square. Compare the size to the room and to the bacteria drawing. It looks huge compared to the bacteria but it is still miniscule compared to the room.

Keep holding up the teaspoon so students will associate the size difference! Now blow their minds with telling them there is about 1 bacteria in the teaspoon and visualize 1 billion dots in the room.

Extra STEM Activity - What's all this fuss about Inoculants?

When you walk into Garden Centers or search the Internet you see all of these products called Rhizobacterial inoculants, Fungal inoculants, and Composite inoculants. What are they and do they really help? We will perform a trial with pea plants and hairy vetch plants subjected to various conditions and enrichments to document growth. We must start with sterile soil and add fertilizer and / or inoculants to specific plants to get the environments we need for comparison.

Material List

20 pea seeds (Pisum sativum L. or another similar strain)
20 hairy vetch seeds (Vicia villosa or another similar strain)
10 - small clay pots
10 – small Dixie cups
Enough potting soil to fill all 10 pots
1 lb - Endomycorrhizal Inoculant (fungi)
1 lb - Rhizobium bacteria
1 lb – 10 – 10 – 10 N-P-K All purpose organic fertilizer
A flat cookie sheet large enough to hold the potting soil at a depth no thicker than 1"
Aluminum Foil to cover and seal the cookie sheet
1 – gallon size ziplock bag

Procedures

We must first soak the pea seeds and the hairy vetch seeds overnight. Place 2 vetch seeds in 5 Dixie cups and put 2 pea seeds in the other 5 Dixie cups. Fill each cup ¼ the way full. Let it sit overnight. While the seeds are soaking we must sterilize the soil. Spread the soil on the cookie sheet and seal it with the aluminum foil. Put it in a 250 degree oven for at least 30 mins (the soil needs to reach a temperature of 180 degrees for over 20 minutes). Label the pots as follows;

Control – V, (control Vetch)
Control – P, (control pea)
Fert. - V, (fertilizer only vetch)
Fert – P, (fertilizer pea)
Fert B – V, (fertilizer + bacteria vetch)
Fert B – P, (fertilizer + bacteria pea)
Fert F – V, (fertilizer + fungi vetch)
Fert F– P, (fertilizer + fungi pea)
Fert BF – V, (fertilizer + bacteria +fungi vetch)
Fert BF – P, (fertilizer + bacteria + fungi pea)
Line up the pots in 2 rows (first row all of the pea labeled pots and the second row all vetch labeled pots)

The next day carefully drain the water off of the seeds. Place a cups with the pea seeds next to the pots labeled pea (first row) and place the cups with vetch seeds next to the pots labeled vetch (second row). Fill the control pots with sterilized soil. In the control pots place the seeds that correspond to the label and then barely cover the seeds with a thin layer of soil . Next fill one fertilizer pot ½ full with soil and then ½ full with fertilizer. Dump the contents into the gallon ziplock bag and shake to thoroughly mix the contents then fill the pot with the soil fertilizer mixture. Do the same procedures for each of the remaining pots. Now place the seeds in the corresponding fertilizer only pots. Take the inoculants and pour enough to thoroughly dust the seeds in the correct cups. After the seeds have been dusted make a small indentation in the middle of the soil and place the seeds in the corresponding cup. Then cover the seeds with a light layer of soil.

Water lightly and put them in a sunny place. Water daily until the seeds germinate and start to grow. Create a chart denoting each pot and measure every other day the height and note the number of leaves opened. Record the readings and compare the results. Does one configuration outperform the others?

After 30 days pull up the plants and notice the bumps called nodules on the roots. This is where nitrogen fixation takes place. Record the number of nodules.

Annotated Bibliography / Resources

Activities:

1) Mathematical problem to help visualize bacteria and fungi size
2) Preparation of bacteria and Fungi enhanced soil
3) Physical comparison of growth of plants under separate conditions

Bibliography

Botany For Gardeners, Brian Capon
Teaming With Microbes, Jeff Lowenfels and Wayne Lewis
Teaming With Nutrients, Jeff Lowenfels
Teaming with Fungi, Jeff Lowenfels

Reading List

Building Soils For Better Crops: Sustainable Soil Management, Fred Magdoff and Harold Van Es
Roots Demystified, Robert Kourik
Crop Rotation, Charles Mohler and Sue Ellen Johnson

Teacher Resources

The Maryland Master Gardener's Manual
Secrets of the Soil
USDA Natural Conservation Service Website
https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/resource/

Student Resources

Excerpts from SARE (Sustainable Agriculture Research and Education) website under Soil Management in the Learning Center Tab;

- Soil Microbiology
- Soil Chemistry
- Soil Quality/Health
- Soil Analysis

The Organic Ring Website - Article - The Effect of Rhizobium Leguminosarum on Pea Plants A Science Fair Research Project – Botany
http://www.oocities.org/rainforest/canopy/3588/legume.html#abstract

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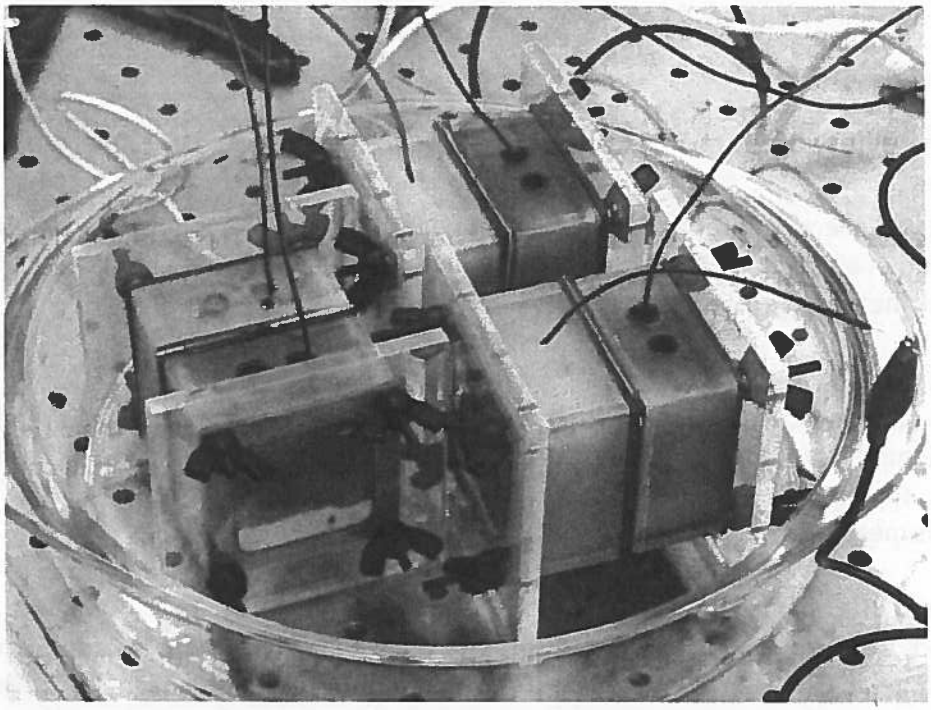
Appendix C: Microbial Fuel Cells (Optional)

Microbial Fuel Cells (MFCs)



Iridescent Lesson Plan

Microbial fuel cells (MFCs) can be used as a tool for multidisciplinary learning for students of all ages. This lesson plan is designed to teach students, ages 9-14, the basic concepts of electricity: voltage, current, and resistance. Through hands-on experimentation, students will see theory in action in a MFC.

This lesson plan was prepared by Andrew Leader (EE '13) and Stefania Samojlik (ME '13) from the Cooper Union.

Iridescent Lesson Plan

Environmental & Biological Concepts Cont.

Objectives

1. Introduce fundamental concepts of electricity: voltage, current, resistance
2. Apply knowledge to understand the basics of microbial fuel cells (MFCs)
3. Experiment with MFC kit

A Quick Review of Electrical Concepts

Voltage

Voltage is the electric potential difference between two points. This potential difference drives the motion of an electrically charged particle.
Voltage is measured in SI units of volts (V).

Current

Current is the flow of electric charge between two points in a conductor. The direction of conventional current follows the flow of positive charge. Thus, the direction of conventional current is the opposite of the flow of negative charge.
Current is measured in SI units of amperes (A).

Resistance

Resistance is the opposition to current. It is also the ratio between voltage and current. This relationship is called **Ohm's Law** which states that V=IR where V is voltage, I is current, and R is resistance.
Resistance is measured in SI units of ohms (Ω).

Introduction TO MFCs

In 1910, M. C. Potter first observed the ability of E. coli to produce electricity [1]. Ever since, scientists have studied the ability of microbes to produce electric potentials in depth, and have incorporated this phenomenon into the design of microbial fuel cells (MFCs), which take advantage of natural biological processes in the microbes to catalyze the conversion of chemical energy in organic fuels into electrical energy. Recently, the search for alternative forms of energy has brought renewed interest to MFCs.

Benefits of MFCs

MFCs offer many potential advantages over other means of localized power generation. In general, since fuel cells do not use combustion, their efficiencies are not limited by the Carnot cycle. The microorganisms in MFCs can derive energy from many different types of fuels [1], making them convenient for situations where refined fuels are not available. While the substrate

molecules are oxidized via microbe metabolism as opposed to combustion, there are no harmful, partially oxidized byproducts such as carbon monoxide. Although different types of MFCs have been designed for various operating conditions, MFCs are generally operated at room temperature and neutral pH, so they can be employed where maintaining harsh conditions is impractical or undesirable, unlike many other types of fuel cells.

Applications

Many potential applications for microbial fuel cells have been described, and some have been implemented with varying degrees of success. Among these applications, methods of wastewater treatment have proven the most successful [1–3], and a small industry of startup companies has already begun efforts to scale up MFC wastewater management processes to municipal levels. MFCs have also been used to power networks of low-power sensors [1, 4]. In at least one case [3], a robot was powered by an MFC. This so-called *gastrobot* was fueled by sugar cubes fed to the MFC anode compartment.

Other attractive applications which have been proposed include MFCs for off-grid power, particularly for use in poor, rural communities. For example, researchers in India have developed an MFC for less than $1, made from commercially available, locally produced earthen pots, for use as a wastewater treatment and local power generation device [5]. The MFC gave a maximum power output of 70 W/m_3, and a Coulombic efficiency of 64.5%.

Groups have also begun proof-of-concept studies on the use of MFCs in vivo to power implanted medical devices such as pacemakers [6, 7]. While many types of bacteria can also produce useful chemicals such as methane and hydrogen, the use of MFCs as sources of these chemicals has also been proposed [2].

Limitations, and how they may be addressed by students

There are still many limitations that impede MFC development for widespread, practical use. Many materials used in state-of-the-art MFCs can be costly, such as custom electrodes and proton exchange membranes. However, some researchers have shown that cheaper alternatives exist, depending on the applications [4, 5].

The types of microbes capable of generating a potential in an MFC are extremely diverse, and each has its own electrical and metabolic properties; full understanding of the electricity generating processes for most microbial species is far away, and optimizing these processes is even further [8].

Most research has been focused on experimenting with different bacteria, mediator molecules, and electrode materials instead of looking directly to applications. A lack of standards between labs hinders their ability to compare results. While the highest power densities are around 4 W/m^2 [9], this remains too low to be a cost effective means of power generation for most applications. Although there has been success for some applications in the lab, no one has demonstrated scalability in any practical sense.

MFCs have already been used as fun, educational tools for young students and scientists. MFCs make good teaching tools because they can be approached from many angles; as an extremely

interdisciplinary subject, the MFC provides strong lessons about many subjects and how they interface in one system.

How MFCs work

Summary of MFC Operation

The operation of the proposed MFC is depicted in Figure 1. In overview, microbes in MFCs break down fuel molecules via their natural catabolic chemical reaction pathways [1, 3]. While some of the energy released from these reactions is used by the organism to power its own functions, some can also be harnessed by introducing electron-mediators into the culture. These electron-mediators reduce chemicals in the catabolic pathways, then diffuse from the cells and deliver electrons to the anode. Meanwhile, protons, another catabolic product, get released and diffuse through a cation specific exchange membrane to react with electrons and oxygen to form water at the cathode. This separation of charge gives rise to an electric potential across the anode and cathode, which is used to power a load.

In Figure 1, the specific sequence of events corresponding to the numbers (1-7) goes as follows:

1. The microbe takes in fuel (glucose) and the mediator molecule (methylene blue, MB), and digests the glucose. During this process, electrons (e-) bind to the mediator molecule.

2. The microbe excretes the negatively-charged MB and protons (H+) into the surrounding fluid.

3. Electrons are transferred from MB to the anode.

4. MB is recycled.

5. Electrons travel from the anode to the cathode across a load.

6. Meanwhile, protons diffuse across the cation exchange membrane to the cathode chamber.

7. Protons, oxygen, electrons and ferricyanide ($[Fe(CN)_6]^{3-}$) react to form water. The ferricyanide, a catalyst, is recycled.

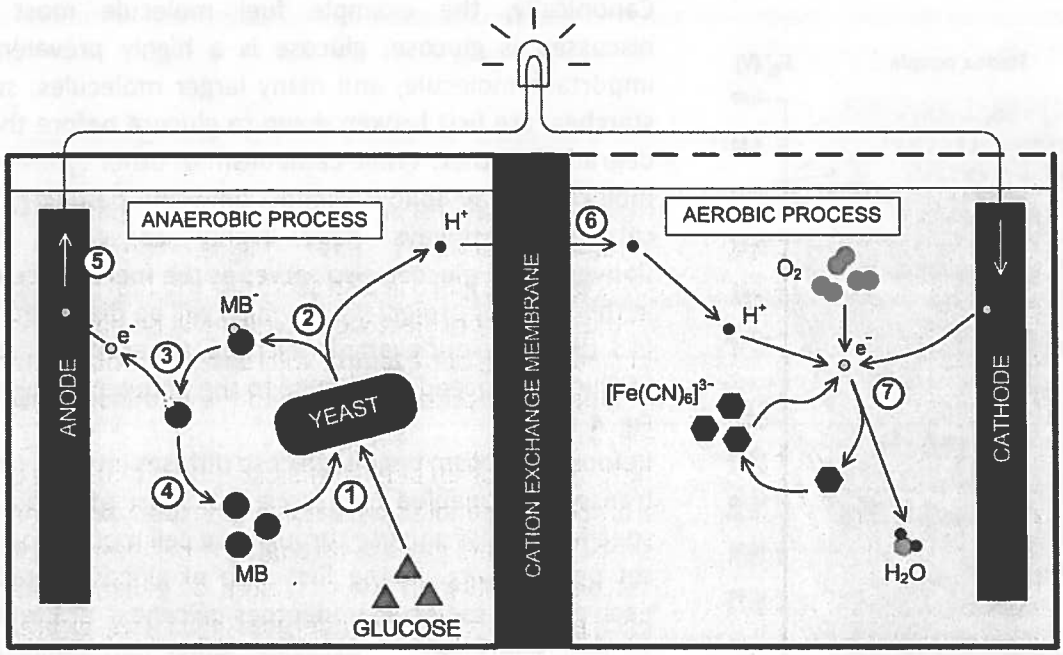


FIGURE 1: DIAGRAM OF MFC PROCESSES

The following subsections describe each of these steps in closer detail. The relevant project work uses *Saccharomyces cerevisiae*, a common species of yeast, as the microbe, methylene blue as the electron mediator, potassium ferricyanide as a cathode catalyst, and glucose as the fuel. Therefore, MFC operation with these components will be explicitly outlined as an example.

MFCs in closer detail

Catabolism and electron transfer

The biological breakdown of complex chemicals in order to release energy is referred to as *catabolism*. During these reactions, the energy-rich fuel molecules are oxidized to simpler molecules. Oxygen has a high reduction potential of 0.82 V, so *aerobic* reactions, or those which require oxygen, tend to be highly favored during catabolism over *anaerobic* reactions, which can proceed without oxygen [11].

In order for power to be transferred to the fuel cell circuit, an intermediate oxidizing agent must be substituted in the anode chamber for oxygen. While oxygen acts as a final oxidizing agent in the cathode chamber, inserting an intermediate step into the overall oxidation of the fuel allows for some of the redox potential to be developed across the MFC electrodes. Many chemicals are capable of serving as this redox intermediate, and some are naturally produced by different kinds of bacteria when oxygen is not present [11]. Fig. 3 shows some of these chemicals in their oxidized and reduced forms, and where they fall in order of reduction potential; such a list of redox couples, ordered by reduction potential, is often referred to as a *redox tower*, and is analogous to vertical steps on a potential energy graph.

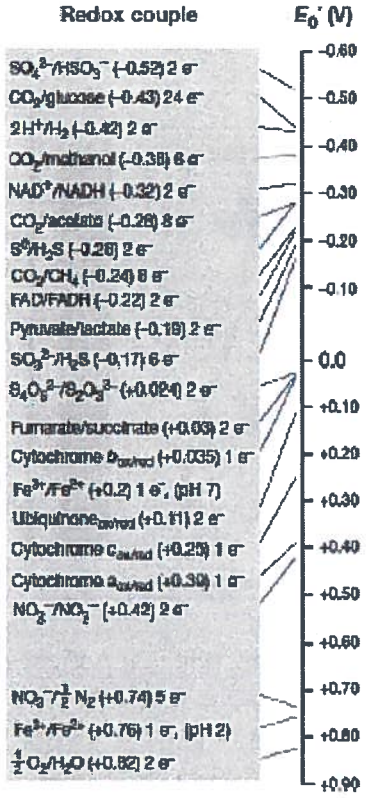


FIGURE 2: A REDOX TOWER LISTS REDOX COUPLES

Canonically, the example fuel molecule most often discussed is glucose; glucose is a highly prevalent and important molecule, and many larger molecules, such as starches, are first broken down to glucose before they are degraded further. While catabolism of other types of food molecules may follow slightly different pathways, most catabolic pathways have highly conserved motifs. Conveniently, glucose also serves as the fuel molecule used in the relevant project work, which will be discussed later.

In *S. cerevisiae*, our example microbe, anaerobic catabolism of glucose proceeds according to the pathway shown in Fig. 4.

Before catabolism begins, glucose diffuses into the cell. This transport is enabled by passive transport proteins, which specifically pass glucose through the cell membrane with a set permeability. In the first step of glucose catabolism, each glucose molecule undergoes *glycolysis,* or breakdown to two molecules of pyruvate while two molecules of adenosine diphosphate (ADP) are converted to two molecules of adenosine triphosphate (ATP), an energy storage molecule, and two molecules of nicotinamide adenine dinucleotide (NAD_+) are reduced to two molecules of NADH (simply referred to as reduced nicotinamide adenine dinucleotide), a different energy storage molecule. One molecule of carbon dioxide then separates from each molecule of pyruvate, forming acetaldehyde. While ATP is recycled to ADP when it is used to power the organism's other functions, NAD_+ is also required for glycolysis and must be recycled by a redox reaction. Therefore, NADH is oxidized by acetaldehyde to NAD_+, and acetaldehyde is reduced to ethanol.

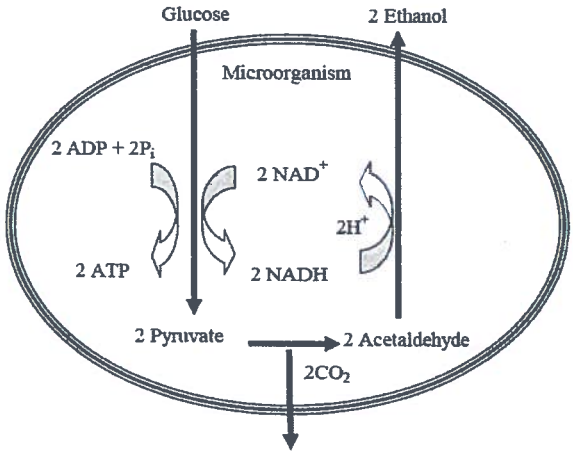


FIGURE 3: A SIMPLIFIED FLOW CHART OF ANAEROBIC GLUCOSE CATABOLISM IN S. CEREVISIAE VIA FERMENTATION [12].

When methylene blue is introduced to the *S. Cerevisiae* culture, it plays the role of NADH oxidizer, obtaining two electrons as NADH is converted to NAD^+. Although it seems that this leaves acetaldehyde to accumulate, these reactions are very tightly regulated by other metabolic players, particularly with respect to NAD^+/NADH [13]. Since methylene blue presence inhibits the reduction of acetaldehyde to ethanol, pyruvate is processed along an alternate metabolic pathway. For example, pyruvate can react to form any of a large number of other molecules, such as alanine, aspartate, isoleucine, phenylpyruvate, or valine. The degree and timescale of waste molecule buildup, as well as the identity of any waste molecules, is an ongoing topic of research.

Electron transfer

Much current research on MFCs focuses on determining more effective means of transferring electrons from within microbes to the anode [1–4, 8, 14]. While *S. Cerevisiae* requires the addition of an electron-mediator molecule, certain strains of bacteria called *exoelectrogens* are capable of attaching directly to the anode and depositing electrons on the anode directly. While exoelectrogens have been shown to produce much higher power densities in MFCs than non-exoelectrogenic microbes, we limit our discussion to the simple case of *S. Cerevisiae* due to safety and cost restrictions for the applications to be discussed.

While the exact mechanisms of electron delivery by the reduced form of methylene blue onto different anode materials are unknown, the reactions incur measurable activation loss. While this loss is important, it is heavily outweighed by ohmic loss [13].

Proton exchange and cathode reactions

Protons, another catabolic product, are secreted by the microbes during MFC operation. The protons diffuse across a cation-specific membrane to the cathode chamber, where they react with oxygen and electrons to form water, completing the circuit.

Different types of materials may be used for the cation exchange membrane, though the most successful ones tend to be porous polymers with complex structure and charged functional groups, such as sulfate. Positive ions diffuse through the pores, finding local potential energy minima at the charged functional groups. In order to achieve efficient transport through the membrane, it must be well hydrated beforehand. Often, potassium ferricyanide is added to the cathode as a catalyst to prevent the partial reduction of oxygen to peroxide, which results in dramatic voltage loss [13].

STEM 1.0 Activity - Prep & Setup

Andrew and Stefania will come and setup the experiments an hour before class begins.
Time: 1 hr

Introduction of electrical concepts – lecture & experimentation

Students will be introduced to concepts such as voltage, current, and resistance. Students will also experiment with batteries, resistors and LEDs and observe the effect of changing resistance on the brightness of an LED.
Time: 40 mins

Discussion of MFCs and their applications – lecture

Students will learn about how MFCs work and how this technology can be applied to "green" waste water treatment. The goals and procedure for MFC experiment will also be explained.
Time: 20 mins

MFC experimentation

Students will assemble and set up an MFC. They will measure voltage across various resistors. Students will be supplied with handouts to fill out with their results.
Time: 1 hr 30 mins

Discussion of results

Students will discuss what they observed during the experiments and compare their results.
Time: 20 mins

Clean Up

Andrew and Stefania will clean up and disassemble the MFCs.
Time: 30 mins

Materials (For 1 MFC)

MFC Construction:

- 2x Acrylic End Plates
- 2x Polypropylene Chambers
- 4x Rubber Gaskets
- 2x Graphite Electrodes
- 1x Cation Exchange Membrane

7.0 pH 0.1M Phosphate Buffer

- 10.71 g Potassium Phosphate Monobasic
- 5.24 g Potassium Phosphate Dibasic
- 1100 mL Distilled Water

Anode Solution:

- 40 mL 7.0 pH 0.1mM Phosphate Buffer
- 0.13 g Methylene Blue
- 3.4 g Yeast
- 7.20 g Glucose

Cathode Solution:

- 40 mL 7.0 pH 0.1mM Phosphate Buffer
- 0.13 g Potassium Ferricyanide

8% Salt Solution

- 4 g Sodium Chloride
- 50 mL Distilled Water

Equipment for Setup and Experimentation

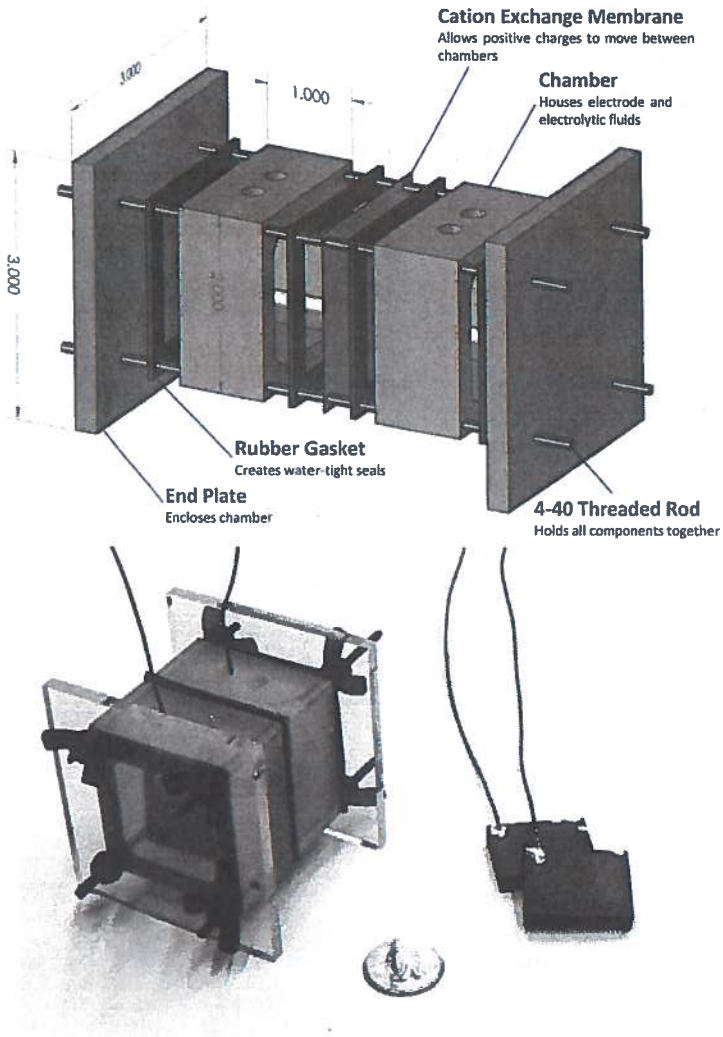
- 1x Multimeter
- 5x Resistors
- 1x LED
- 1x Breadboard
- 1x Funnel
- Glassware

Teacher Preparation

1. Prepare 8% NaCl solution, and soak cation exchange membrane in salt solution for at least 24 hours.
2. Prepare phosphate buffer, anode solution and cathode solution.

Student Procedure

1. Put on latex gloves and safety goggles.
2. Assemble MFC with pre-soaked cation exchange membrane and graphite electrodes as shown below



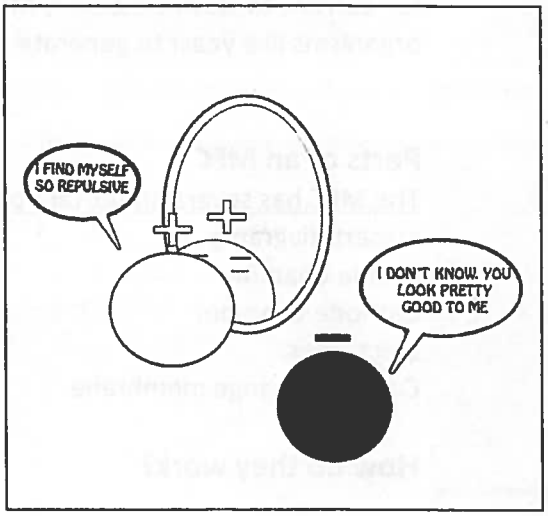
3. Pour cathode solution into one chamber, then anode solution into the other chamber using a funnel.
4. Hook up graphite leads to multimeter and observe the voltage.
5. Hook up graphite leads in series with various resistors and measure the change in voltage.
6. Record voltage measurements on handout.

Student Handouts

Introduction to Electrical Concepts

What is electricity?

Electricity exists everywhere around us from lighting in the sky to the batteries in your calculator to the electrical impulses in our nerves. This phenomenon can be attributed to small *charged* particles interacting with each other and their surroundings.



"Opposites Attract"

These charged particles can be negatively (-) and positively (+) charged. One special characteristic of such particles is that they can be attracted or repelled by each other. The saying "opposites attract" is useful when remembering how these particles interact with each other. Negative and positive charges are attracted to each other, 2 positive charges repel each other, and 2 negative charges will repel each other.

Voltage, Current, and Resistance

By the laws of physics, when two oppositely charged particles are close together, they will move toward each other. The flow or movement of these charged particles is called **current**. Another electrical quantity, **voltage**, is used to measure the "electric potential energy" between two points. The concept of voltage can be quite confusing, but it is similar to a person on a slide. The person on the top of the slide is like a charged particle. The voltage can be compared to the height difference between the top and bottom of the slide. Once the person starts moving, he represents the current. If the slide is higher, the person will reach a faster speed at the bottom of the slide. The same is true of a charged particle. If the voltage is larger, the charged particle will move faster. In other words, if the voltage is higher, the current is higher. This relationship between voltage and current is very important in studying electricity, and it is called **Ohm's Law**. There is one more property that plays a part in Ohm's Law, called **resistance.** Resistance is the opposition to the flow of charged particles. You can imagine that how fast you go down a slide depends on the type of clothes you wear. For example, to slow down on a slide, you can use your shoes as "brakes". In this situation, your shoes are like the resistance that decreases the current. So if there is a large resistance, the current will be much smaller.

Procedure

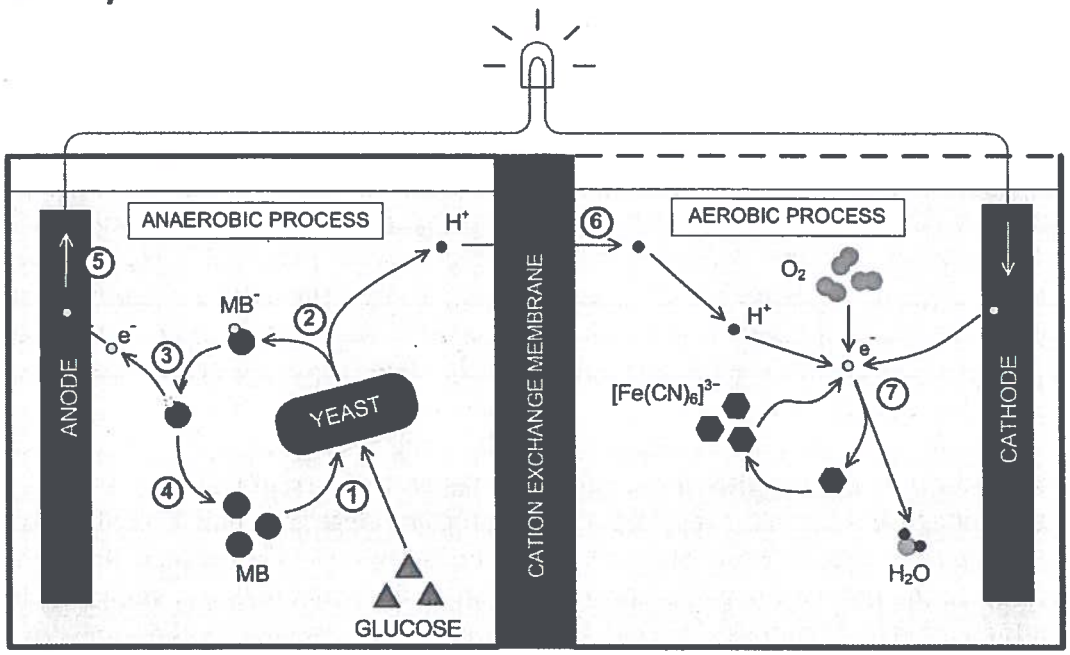
Introduction to Microbial Fuel Cells

A microbial fuel cell (or **MFC**) is very similar to a battery which provides a voltage between the two points. If these two points are connected together through a wire, they can provide a path for current to flow. However, MFCs are much different than batteries because they use small organisms like yeast to generate a voltage.

Parts of an MFC

The MFC has several important parts.
<insert diagram>
Anode Chamber
Cathode Chamber
Electrodes
Cation exchange membrane

How do they work?



How are they used?

Green energy!
Waste water treatment!

MESA USA

NATIONAL ENGINEERING DESIGN COMPETITION (NEDC/PA MESA)

2017-2018

MESA Arduino STEM Solutions

Overview

In order to maximize each team's experience during this event, it is important to properly execute all aspects of the judging process and event administration. Although each MESA state may elect to present this event in different format(s), the MESA USA host site and the corresponding National Event Planning Committee will be required to adhere to the processes outlined below. Please note that the following processes not only outline the event but also the roles and responsibilities of student team members and advisors.

MESA USA Code of Sportsmanship

During the course of this event, MESA students, staff, advisors and supporting family members will be expected to act in a professional and courteous manner at all times. All judges' decisions are final. Staff, advisors and parents shall not engage judges during the event.

Contents

Introduction:

There's an old saying that states "Necessity is the mother of invention." Humans have always been most creative, most inventive when they've had a need and lacked a way of resolving it. This idea is the basis for what we know as the field of Engineering.

As a way to find a solution to a need, Engineers implement the Engineering Design Process. This process allows Engineers to systematically identify the need and any obstacles or challenges; draft ideas for a solution using their knowledge of math and science; refine their ideas through testing; and ultimately develop a way to meet the initial need.

Human-Centered Design is an approach in engineering that focuses on people and their specific needs. According to IDEO.org (http://www.designkit.org/human-centered-design), "Human-centered design is all about building deep empathy with the people you're designing for…" IDEO further suggests that Human-Centered Design consists of three phases.

1. Inspiration - Engineers learn directly from their client in order to deeply understand their needs.
2. Ideation - Analysis of what's learned from the client leads to design ideas and possible prototypes.
3. Implementation - building of the final proposed solution knowing that it meets the needs of your client.

Competition Overview:

MESA USA presents the National Engineering Design Competition specifications for the 2017-2018 year. MESA Arduino STEM Solutions asks students to implement the Human-Centered Design approach to find a client in your community who has a need, design a solution for this need using Arduino, and present your solution and recommendation(s) for next steps at the MESA USA National Engineering Design Competition.

MESA states may choose to require teams to focus on a particular area of need (i.e. agriculture, physical disabilities) or provide a specific client for teams to focus on at their state competitions.

The components listed below will be used to assess the effective implementation of a Human-Centered Design approach, effective implementation of the Engineering Design Process, and the functionality of the prototype and successful integration of Arduino into the prototype.

High school and middle school teams selected to participate at the national event will compete in the four components below:

1. Technical Interview & Poster- Students will prepare a short presentation and give a full demonstration of the functionality of the prototype. Poster will provide an overview of their project, highlighting key points of the design process including relevant data, and conclusions and recommendations for further development. The purpose is to review and assess the following:
   a. How the prototype meets the client's needs
   b. The use of materials and technologies (Arduino hardware, sensors, etc.)
   c. Originality of the prototype
   d. Usability of the prototype
   e. Design of the prototype
2. Project Report -
   a. Students will write a 5-10 page report that contains their problem statement, summary of the design process, results, conclusion and next steps supported by pictures, charts, tables, and/or graphs
   b. The report should be a journey through the design process and demonstrate key points of the design process and why design choices were made.
   c. The report will have an appendix containing the commented Arduino code and detailed budget.
3. Prototype Pitch
   a. Students will prepare a presentation and creatively pitch their prototype, including a demonstration of the prototype, to a group of judges.
   b. The presentation should define the problem; provide a detailed description of their client and their needs; discuss current solutions to the problem and their weaknesses; and provide a demonstration of their prototype highlighting its advantages.

Each competing team must consist of 2-4 students who are active members of a MESA program in a MESA USA state. Individual states should encourage their respective teams to participate in all performance components at the statewide level. Although states may opt not to do all components or alter some requirements for their local and state events as needed. Individual states will determine the dates and location of their respective events.

The first place middle and high school teams from State events will travel to the national competition. These teams must compete in all tasks listed above. This event is scheduled to occur in **June 2018** hosted by Pennsylvania MESA.

Plagiarism Policy

Academic honesty and personal integrity are essential to ensure future success as college students and STEM Professionals. As such, MESA USA expects that the work presented as a part of the National Engineering Design Competition will be solely the work of the students. If the work or ideas of another are used to further students' work then proper credit must be given to the owner (see resource document for information on citing sources). Failure to do so will result in an act of Plagiarism. If it is determined that a student committed plagiarism, they will be disqualified from the competition and they will be ineligible to receive any awards. They may also risk further sanctions from MESA USA and/or their MESA State.

Scoring Summary

Final team rankings will be based on the total score, which is derived by adding all of the component scores

Technical Interview & Poster Symposium	150 points
Project Report	100 points
Prototype Pitch	100 points
Device Performance performance)	150 points (Only PA MESA will include this in the regional
Device Efficiency	
If based model is used to produce a rover	25 pts
If additional add ons are done to base model (50% changes must be made)	50 pts

PA MESA Competition Overview

PA MESA USA presents the regional engineering design competition specifications for the 2017-2018 year. The Rover Challenge involves developing a robotic car that is integrated with Arduino programming to complete a set of predefined tasks.

Performance – Teams will research, design, build, test and compete using a rover designed to complete the following tasks:

a) **Autonomous Maze Task**: *greatest distance and accuracy* traveled by the rover through the 3 Target Zones in the fastest time. *(2 trials)*
b) **Object Relocation 2.0 Task**: *fastest time* achieved by placing designated objects across designed safe zone line.*(2 trials)*
c) **Soil Sensor Maze Task**: *the most accurate reading* from the soil sensor using IR, bluetooth, etc. while navigating the rover through the 3 Target Zones collecting soil data from each zone. *(2 trials)*

Both middle school teams and high school teams will compete in all tasks.

Objective

Teams will build a low-cost rover that will provide a solution for a problem determined by the specific team. This will be evident by the device meeting the criteria outlined in the rules and performing the following tasks: Autonomous Maze Task, Object Relocation 2.0 Task, and Soil Sensor Maze Task.

Grand Total:

MESA Mathematics Engineering Science Achievement

2017-2018 MESA USA/PA MESA
National Engineering Design Competition
MESA Arduino STEM Solutions

Technical Interview: Poster Rubric	Exceptional (5 points)	Excellent (4 points)	Good (3 points)	Fair (2 points)	Poor (1 point)	Not present (0 points)	Observation Notes
Organization	All content areas are included, clearly presented, labeled, and easy to follow even in the absence of the team	Content areas are found, but the presentation is a bit crowded, not all is labeled, or disorganized. Requires the team for full comprehension	Most of the expected content areas are there, but the presentation is confusing, not all is labeled, and difficult to follow in the absence of the team.	Some of the expected content areas are present, but poorly laid out and confusing to follow without the team	Have at least one content area present, but poorly laid out and entirely confusing to follow without the team	There is not a clear content area present and unable to follow without the team.	
Coherence	All content is carefully chosen to overview the team's project and present the prototype. There is no extraneous information. Information is succinct and important.	Content is carefully chosen to overview the team's project and present the prototype. There may be a few extraneous points. Information could be more succinct.	Some content is not consistent with the overview of the team's project and presentation of the prototype. There is a moderate amount of extraneous information.	Content appears inconsistent with much of the overview of the team's project and presentation of the prototype and is difficult to follow. There is a moderate amount of extraneous information.	Content appears inconsistent and does present a clean overview of the team's project or presentation of the prototype. It is difficult to follow because of too much extraneous information or too little relevant information.	There is no clear coherence. Content does not relate to project. There is an abundance of extraneous information or not enough information.	
Content Area: Objective	The objective of the project and requirements of the design are all: conveyed succinctly, they are articulate, they convey a clear scope of the project, and the quality of background information is exceptional.	The objective of the project and requirements of the design are mostly conveyed succinctly, they are articulate, they convey a good scope of the project, and the quality of background information is above average.	The objective of the project and requirements of the design are mostly conveyed succinctly, they are mostly articulate, they convey a satisfactory scope of the project, and the quality of background information is enough to define basic objective.	The objective of the project and requirements of the design are not conveyed succinctly, they are not articulate, they convey a fair scope of the project, and the quality of background information does not define objective entirely.	The objective of the project and requirements of the design are not conveyed succinctly, they are not articulate, they do not convey a scope of the project, and the quality of background information is poor.	The objective of the project and requirements of the design are not conveyed succinctly or at all, they are not articulate, they are missing or do not convey a clear scope of the project, and the quality of background information is extremely poor or absent.	
Content Area: Engineering/Design Process Methodology	There is a clear description and exceptional visual representation of the	There is an above average description and visual representation of the teams Methodology and Design Process.	There is an adequate description and visual representation of the teams Methodology and Design Process.	There is a fair description and minimal visual representation of the teams Methodology and Design Process. Needs	There is a poor description and no visual representation of the teams Methodology and Design Process. Needs a	There is no clear description and visual representation of the teams Methodology and Design Process is unclear	

	teams Methodology and Design Process.			some additional information to understand entire process.	fair amount of additional information to understand entire process.	or absent. Needs a large amount of additional information to understand entire process.	
Content Area: Engineering Design Process Evaluation	There is a complete analysis of project challenges and the correlating solutions; there is a superior evaluation of any competing design solutions; section includes succinct and relevant research and/or background.	There is a good analysis of project challenges and the correlating solutions; there is a good evaluation of any competing design solutions; section includes succinct and relevant research and/or background.	There is an adequate analysis of project challenges and the correlating solutions; there is a fair evaluation of any competing design solutions; section includes succinct and a fair amount of relevant research and/or background.	There is a limited analysis of project challenges and the correlating solutions are not adequate or missing; there is somewhat relevant evaluation of any competing design solutions; section includes a minimal amount of research and/or background.	There is not an adequate analysis of project challenges and the correlating solutions are poor or missing; there is minimal evaluation of any competing design solutions; section does not include succinct or relevant research and/or background.	Project challenges and the correlating solutions are extremely minimal or missing; there is no evaluation of any competing design solutions; section does not include succinct or relevant research and/or background.	
Content Area: Data	Excellent charts and/or graphs are present that support exemplary research and testing. They are appropriate, clear, and provide a superior perspective to their project. There is logical and clear Arduino Diagram(s) to support programming choice.	Above average charts and/or graphs are present that support complete research and testing. They are appropriate, clear, and provide a complete perspective to their project. There is logical and clear Arduino Diagram(s) to support programming choice.	Charts and/or graphs are present that support adequate research and testing. They are appropriate, clear, and provide a satisfactory perspective to their project. There is an Arduino Diagram(s) to support programming choice that is understandable and satisfactory.	Charts and/or graphs support some amount of research and testing. They are somewhat appropriate, and provide a minimal perspective to their project. There is an Arduino Diagram(s) to support some programming choice(s).	Charts and/or graphs support minimal amount of research and testing. They are somewhat appropriate, and provide a minimal perspective to their project. Arduino Diagram(s) minimally supports any programming choice(s).	Charts and/or graphs are absent or do not support research and testing. They are not appropriate, and provide no perspective to their project. Arduino Diagram(s) do not supports any programming choice(s) or are absent.	
Content Area: Conclusions and Recommendations	Includes a superior design flaw analysis and justification for their design choice. Includes clear and relevant next steps for their project.	Includes an above average design flaw analysis and justification for their design choice. Includes clear and relevant next steps for their project.	Includes a satisfactory design flaw analysis and justification for their design choice. Next steps for their project are satisfactory.	Includes a vague or limited design flaw analysis and justification for their design choice. Includes some next steps for their project, but could use work.	Includes minimal design flaw analysis and poor justification for their design choice. Includes minimal next steps for their project, but could use work.	Includes no design flaw analysis or justification for their design choice. Next steps for their project are missing or entirely inadequate.	

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Content Area: Support Concepts	Poster includes quality Math and Science concepts that are relevant and clearly show a superior use of those concepts.	Poster includes quality Math and Science concepts that are relevant and clearly show an above average use of those concepts.	Poster includes quality Math and Science concepts that are relevant and clearly show a satisfactory use of those concepts.	Poster includes Math and/or Science concept(s) that are somewhat relevant and show some use of those concepts.	Poster includes Math and/or Science concept(s) that are minimally relevant and show poor use of those concepts.	Poster does not include any Math and/or Science concept(s) and/or does not show any use of those concepts.	
Content Area: Support Visualization	Excellent use of support materials to include: illustrations, diagrams, sample code, and/or photos. Support materials significantly improve understanding and enhance visual appeal. All items are properly labeled and are completely significant to project.	Above average use of support materials to include: illustrations, diagrams, sample code, and/or photos. Support materials greatly improve understanding and enhance visual appeal. Most of items are properly labeled and are completely significant to project.	Adequate use of support materials to include: illustrations, diagrams, sample code, and/or photos. Support materials improve understanding and enhance visual appeal. Some of items are properly labeled and most are significant to project.	Fair use of support materials to include: illustrations, diagrams, sample code, and/or photos. Support materials somewhat improve understanding and enhance visual appeal. Most or all of items are not properly labeled. Most items are not significant to project.	Poor use of support materials to include: illustrations, diagrams, sample code, and/or photos. Support materials minimally improve understanding and enhance visual appeal. Most or all of items are not properly labeled. Most or all of items are not significant to project.	Support items are completely inadequate or missing sample code. If present, support materials offer no understanding or inadequate significance to project.	
Text Font, Spelling and Grammar	All text is clear and readable at a distance of 3 feet. Contains no errors in spelling or grammar including definition of acronyms at their first use.	All text is clear and readable at a distance of 3 feet. Contains minimal errors in spelling or grammar including definition of acronyms at their first use.	Most of text is clear and readable at a distance of 3 feet. Contains minimal errors in spelling or grammar including definition of acronyms at their first use.	Font is a bit distracting or too small to read at 3 feet. Contains a fair amount of errors in spelling or grammar including definition of acronyms at their first use.	Font is entirely distracting or too small to read at 3 feet. Contains a large amount of errors in spelling or grammar including definition of acronyms at their first use.	Font is entirely distracting or too small to read at 3 feet. Contains an extraordinary amount of errors in spelling or grammar including definition of acronyms at their first use.	
Column Totals							
Total							

2017-2018 MESA USA/PA MESA
National Engineering Design Competition
MESA Arduino STEM Solutions

Technical Interview: Presentation Rubric	Exceptional (5 points)	Excellent (4 points)	Good (3 points)	Fair (2 points)	Poor (1 point)	Not present (0 points)	Observation Notes
Nonverbal Skills	Team holds attention of audiences with the use of direct eye contact; uses poster to guide interview exceedingly well; helps the audience visualize. Team displays relaxed, self-confident nature, and is free of fidgeting and/or nervous movement. Exceptional use of body language.	Team holds attention of audiences with the use of direct eye contact; effectively uses poster to guide interview. Team displays relaxed, self-confident nature, and has minimal use of fidgeting and/or nervous movement. Good use of body language.	Team uses good direct eye contact with audience, but reads some parts from the poster. Movements/gestures enhance articulation. Team somewhat displays relaxed, self-confident nature, and has minimal use of fidgeting and/or nervous movement. Adequate use of body language.	Team uses some direct eye contact with audience, but mostly reads from the poster. Team uses minimal Movements/gestures that enhance articulation. Team mostly displays nervous nature and has a substantial amount of fidgeting and/or nervous movement. Some use of body language.	Team uses minimal eye contact with audience. Mostly reads from and/or has little interaction with poster. Very little movement or descriptive gestures. Team mostly displays nervous nature and shows mostly fidgeting and/or nervous movement. Minimal use of body language.	Team makes no eye contact with audience. Does not interact with poster at all. No movement or descriptive gestures. Obvious tension or nervousness.	
Verbal Skills	Team shows extreme enthusiasm and can verbally convey knowledge about the topic during entire presentation. Uses clear voices and correct usage of technical terms. Can be heard clearly for entire presentation. Entire team shares equally in presentation and all are equally superior in skill.	Team shows mostly enthusiasm and can verbally convey knowledge about the topic during entire presentation. Uses clear voices and correct usage of technical terms. Can be heard clearly for entire presentation. Entire team shares equally in presentation and most team members are above average in skill.	Team occasionally shows positive feelings about the topic, but is adequately knowledgeable. Uses clear voice and most technical terms are used correctly. Can be heard clearly for most of presentation. Entire team shares equally in presentation and all team members show proficiency.	Team occasionally shows positive feelings about the topic and is somewhat knowledgeable. Uses mostly clear voice and some technical terms are used correctly. Can be heard clearly for some of presentation. Entire team shares equally in presentation but some team members are less than proficient.	Team shows only mild interest in the topic during presentation. Uses low voice and/or technical terms incorrectly. Is difficult to hear during presentation. Most of team shares equally in presentation but some team members are less than proficient.	Team shows no interest in the topic presented. Mumbles, uses technical terms incorrectly, or speaks too quietly to hear during presentation. Team does not share equally in presentation and most of team members are less than proficient.	
Project Knowledge	Team demonstrates full knowledge of project. Team presents information in a logical and interesting sequence.	Team answers expected questions and can mostly elaborate. Team presents information in a logical sequence that can be easily followed.	Team answers expected questions and can adequately elaborate. Team presents information in a logical sequence that can be easily followed.	Team answers expected questions but cannot elaborate. Team presents information in a mostly logical sequence.	Team can only answer simple questions. Audience has difficulty following incoherent organization, as team jumps around and does not follow a sequence of information well.	Team does not grasp information and cannot answer questions. Audience cannot understand presentation as there is no clear sequence of information.	

Audience Awareness	Interview significantly increases audience's understanding of importance of project and future impact.	Interview increases audience's understanding of importance of project and future impact.	Interview minimally raises audience's understanding of importance of project and future impact.	Interview minimally raises audience's understanding of importance of topic, shows some development with little future impact.	Interview contributes something, but fails to increase audience's understanding of importance of topic. Lacks development and little future impact.	Presentation fails to increase audience's knowledge of topic and has no future impact.	
Response to Questions	Answers to technical questions demonstrate superior knowledge of the concepts and processes used in project. All members contribute equally to answers and all are equally superior in responses.	Answers to technical questions demonstrate above average knowledge of the concepts & processes used in project. All members contribute equally to answers & most team members are above average in responses.	Answers to technical questions demonstrate a textbook knowledge of concepts and processes used in project. All team members answer questions, but half or less than team can elaborate well.	Answers to technical questions demonstrate some knowledge of concepts and processes used in project. All team members answer questions, but most responses are vague.	Answers to technical questions demonstrate minimal knowledge of concepts and processes used. All team members do not answer questions.	Team is unable to answer technical questions and/or one member of team answers all the questions.	
Content Area: Objective	Team states their project objective exceedingly well. Interview stays on topic to address objective to the highest level.	Team clearly states their project objective. Interview stays on topic to properly address objective.	Team clearly states their project objective. Interview stays mostly on topic to properly address objective with some excess information.	Team states their project objective. Interview stays somewhat on topic to properly address objective with a fair amount of excess information.	Team does not state their project objective well. Interview does not stay on topic well to properly address objective with a large amount of excess information.	Team does not state their project objective. Interview does not stay on topic to properly address objective.	
Content Area: Engineering Design Process	Team exceptionally conveys their Methodology and Process; and their project challenges and correlating solutions through presentation or interview. Team is able to incorporate how their research informed their decisions exceedingly well.	Team effectively conveys their Methodology and Process; and their project challenges and correlating solutions through presentation or interview. Team is able to incorporate how their research informed their decisions.	Team effectively conveys their Methodology and Process; and their project challenges and correlating solutions through presentation or interview. Team is able to incorporate how their research informed most of their decisions.	Team mostly conveys their Methodology and Process; and their project challenges and correlating solutions through presentation or interview. Team is able to incorporate how their research informed some of their decisions.	Team inadequately conveys their Methodology and Process; and their project challenges and correlating solutions through presentation or interview. Team is minimally able to incorporate how their research informed any of their decisions.	Team fails to convey their Methodology and Process; and their project challenges and correlating solutions through presentation or interview. Team is unable to incorporate how their research informed any of their decisions.	

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Content Area: Data	Team uses and references data to inform and convey their project choice(s) and reasoning through presentation or interview exceedingly well.	Team effectively uses and references data to inform and convey their project choice(s) and reasoning through presentation or interview.	Team mostly uses and references data to inform and convey their project choice(s) and reasoning through presentation or interview.	Team rarely uses and references data to inform and convey their project choice(s) and reasoning through presentation or interview.	Team uses and references data to inform and convey their project choice(s) and reasoning through presentation or interview at minimum of 1 time.	Team does not use and/or reference data to inform and convey their project choice(s) and reasoning through presentation or interview.	
Content Area: Conclusions and Recommendations	Team is able to effectively present to the highest level their final project and discuss conclusive findings, limitations, next steps, and recommendations for further development through presentation or interview. Team is able to incorporate how their tests resulted in their conclusions exceptionally well.	Team is able to effectively present at an above average level their final project and discuss conclusive findings, limitations, next steps, and recommendations for further development through presentation or interview. Team is able to incorporate how their tests resulted in their conclusions well.	Team is able to effectively present their final project and discuss conclusive findings, limitations, next steps, and recommendations for further development through presentation or interview. Team is able to incorporate how their tests resulted in their conclusions adequately.	Team is able to somewhat effectively present their final project and discuss conclusive findings, limitations, next steps, and recommendations for further development through presentation or interview. Team is minimally able to incorporate how their tests resulted in their conclusions.	Team is somewhat unable to present their final project and discuss conclusive findings, limitations, next steps, and recommendations for further development through presentation or interview. Team is unable to incorporate how their tests resulted in their conclusions.	Team is unable to present their final project and discuss conclusive findings, limitations, next steps, and recommendations for further development through presentation or interview. Team is unable to incorporate how their tests resulted in their conclusions.	
Content Area: Support	Team is able to use and reference support materials on poster to enhance interview and convey understanding of project through presentation or interview exceedingly well. Team logically and clearly utilizes other support material to greatly enhance interview.	Team is able to effectively use and reference support materials on poster to enhance interview and convey understanding of project through presentation or interview. Team utilizes other support material to enhance interview.	Team is able to effectively use and reference support materials on poster to enhance interview & convey understanding of project through presentation or interview. Team utilizes other support material to enhance interview, but some material is unused or does not add to the enhancement of the interview.	Team is able to mostly use and reference support materials on poster to enhance interview and convey understanding of project through presentation or interview. Team could use additional material to enhance interview and/or what is available is mostly unused or does not add to the enhancement of the interview.	Team is not adequately able to use and reference support materials on poster to enhance interview and convey understanding of project through presentation or interview. Team could use additional material to enhance interview and/or what is available is mostly unused or does not add to the enhancement of the interview.	Team does not use and/or reference support materials on poster to enhance interview and convey understanding of project through presentation or interview.	
Column Totals							

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Total	

Project Report Rubric	Exceptional (5 points)	Excellent (4 points)	Good (3 points)	Fair (2 points)	Poor (1 point)	Not present (0 points)	Observation Notes
Problem Statement	[ ] The problem is clearly articulated with well-defined parameters. The needs of the client have been carefully weighed to design a solution. All limitations are clearly identified.	[ ] The problem is adequately articulated with some parameters. The needs of the client are evident but not fully demonstrated. Most limitations are identified.	[ ] The problem is articulated with some parameters. The needs of the client are evident but leave some questions. Some limitations are identified.	[ ] The problem is poorly articulated with little to no parameters. The needs of the client are barely evident. A few limitations are evident.	[ ] The problem is barely articulated. The needs of the client are not evident. No limitations are evident.	[ ] The problem statement is not present or not understandable.	
Design Process – Inspiration: Research	[ ] The prior knowledge, research, and interviews with client(s) is clearly articulated	[ ] The prior knowledge, research, and interviews with client(s) is adequately articulated.	[ ] The prior knowledge, research, and interviews with client(s) is articulated but leaves some questions.	[ ] The prior knowledge, research, and interviews with client(s) is poorly articulated.	[ ] The prior knowledge, research, and interview with client(s) is minimal.	[ ] The prior knowledge, research, and interview with client(s) is not present	
Design Process – Inspiration: Client's Needs (x2)	[ ] The client's needs are clearly accounted for during the Inspiration process	[ ] The client's needs are accounted for during the Inspiration process.	[ ] The client's needs are adequately accounted for during the Inspiration process.	[ ] The client's needs are poorly accounted for during the Inspiration process.	[ ] The client's needs are mentioned but not accounted for during the Inspiration process.	[ ] The client's needs are not accounted for during the Inspiration process.	
Design Process – Inspiration: Repeatability (x2)	[ ] The design process is clearly iterative and clearly shown to have been repeated with multiple iterations.	[ ] The design process is iterative and adequately shown to have been repeated at least one time.	[ ] The design process is iterative and is minimally shown to have been repeated at least one time.	[ ] The design process is not iterative **or** not adequately shown to have not have been repeated.	[ ] The design process is not iterative **and** is not adequately shown to have been repeated.	[ ] There is no evidence of repeatability in the Inspiration phase.	
Design Process – Ideation: Link to Inspiration (x2)	[ ] A clear path leads from Inspiration to Ideation.	[ ] A path leads from Inspiration to Ideation.	[ ] A path leads from Inspiration to Ideation but has some holes.	[ ] A path leads from Inspiration to Ideation that is minimal.	[ ] Little evidence of a path from Inspiration to Ideation.	[ ] No evidence of a path from Inspiration to Ideation.	
Design Process – Ideation: Design (x2)	[ ] Designs are clearly articulated with reference to knowledge gained.	[ ] Designs adequately reference the knowledge gained.	[ ] Designs minimally reference the knowledge gained.	[ ] Designs poorly reference the knowledge gained.	[ ] Designs barely reference the knowledge gained.	[ ] Designs do not reference knowledge gained.	

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Design Process – Ideation: Math and Science (x2)	[ ] Math and Science concepts are clearly articulated as part of the design.	[ ] Math and Science concepts are articulated as part of the design.	[ ] Math and Science concepts are adequately articulated as part of the design.	[ ] Math and Science concepts are poorly articulated as part of the design.	[ ] Math and Science concepts are barely articulated as part of the design.	[ ] No Math and Science concepts are present.	
Design Process – Implementation: Data (x2)	[ ] Data is recorded and shown as part of tests in graphical form. The data is relevant and useful.	[ ] Data is recorded and shown as part of tests. The data is mostly relevant and useful.	[ ] Some data is recorded and shown as part of tests The data is partly relevant and useful.	[ ] Minimal data is recorded. Data is mostly irrelevant.	[ ] Little data is recorded. Data is mostly irrelevant	[ ] No data is recorded.	
Design Process – Implementation: Analysis (x2)	[ ] Data is clearly used to determine strengths and/or weaknesses. Data is used to inspire new ideas.	[ ] Data is used to determine strengths and/or weaknesses. Data may or may not be used to inspire new ideas.	[ ] Data is adequately used to determine strengths and/or weaknesses. Data is adequately used to inspire new ideas.	[ ] Data is minimally used to determine strengths and/or weaknesses. Data is minimally used to inspire new ideas.	[ ] Data is barely used to determine strengths and/or weaknesses. Data is barely used to inspire new ideas.	[ ] Data analysis is not present.	
Design Process – Implementation: Process (x2)	[ ] Data is clearly used to return to the Inspiration phase to improve the design.	[ ] Data is used to return to the Inspiration phase to improve the design.	[ ] Data is adequately used to return to the Inspiration phase to improve the design.	[ ] Data is minimally used to return to the Inspiration phase to improve the design.	[ ] Data is barely used to return to the Inspiration phase to improve the design.	[ ] Data is not used to return to the Inspiration phase to improve the design.	
Spelling & Grammar				[ ] No errors in spelling and grammar.	[ ] Minor errors in spelling and grammar.	[ ] Numerous errors in spelling and grammar.	
Code				[ ] Code is easy to read with some comments	[ ] Code is difficult to read.	[ ] Code is minimal or non-existent.	
Budget				[ ] All items are clearly accounted for.	[ ] The majority of items are accounted for.	[ ] Less than half of the items are accounted for.	
Bibliography				[ ] All research is accounted for using a consistent format.	[ ] Most research is accounted for using a consistent format.	[ ] Less than half of the research is accounted for.	
Length				[ ] The report is 5-10 pages in length.	[ ] The report is 4-11 pages in length.	[ ] The report is less than 4 or more than 11 pages in length.	
Column Totals							
Total							

MESA Mathematics Engineering Science Achievement

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Pitch Presentation	Exceptional (5 points)	Excellent (4 points)	Good (3 points)	Fair (2 points)	Poor/Lacking (1 point)	Not present (0 points)	Observation Notes
Problem Definition (Total 20 Points)							
Client description • market size (# of people) • impact on client • market area (where are the clients located)	Client base is clearly identified and a complete profile, including information on population size and location, is provided so that observers have no questions about the client base	Client base is clearly identified and a profile is provided but may be missing a few minor details leaving observes with less than 100% clarity about the client base	Client base is identified and the profile includes the essential details, but observers need some crucial information for full clarity about the client base	Client base is mostly identified, but the profile is incomplete and observers need a significant amount of information to be clear about the client base	Client base is minimally identified and a profile, if included, provides little useful information about the client base	It is unclear who the client base is and a profile, if included, does not provide any useful information about the client base	
Client Impact How is client affected by Problem • Did they talk to actual clients?	Articulately explains how the client is affected by the problem and includes all necessary data gathered from research and anecdotal information from clients to provide a complete picture	Explains how the client is affected and includes significant data gathered from research and anecdotal information from clients to provide a clear picture	Explains how the client is affected and includes essential data gathered from research and anecdotal information from clients to provide a mostly clear picture	Explains how the client is affected and includes somewhat useful data gathered from research and anecdotal information from clients to provide a less than adequate picture	Somewhat explains how the client is affected and includes inconsequential data gathered from research and anecdotal information from clients to provide a unclear picture	Does not explain how the client is affected and data included, if any, is not useful. Anecdotal information from clients is random.	
Problem Description Must outline what the problem is that they are trying to solve.	A clear and complete description is provided, and includes all significant variables or aspects of the problem that need to be addressed	A clear and almost complete description is provided, and includes most variables of the problem that need to be addressed	An adequate description is provided, and includes enough variables of the problem that need to be addressed	A inadequate description is provided, and is missing crucial variables of the problem that need to be addressed	A description is provided, but lacks enough variables of the problem that need to be addressed to understand the problem	Little to no description is provided. Variables, if included are illogical.	

Current Solutions How is problem currently being solved, Weakness of these solutions	All current solutions are listed and a complete breakdown of their weaknesses is provided	Most of the current solutions are listed and a breakdown of most of their weaknesses is provided	The essential current solutions are listed and an adequate breakdown of their weaknesses is provided	A few of the current solutions are listed and an incomplete breakdown of their weaknesses is provided	Little to none of the current solutions are listed and very little breakdown of their weaknesses is provided	Current solution are glossed over or left out completely. There is no breakdown of weaknesses or breakdown is illogical.	
Product (Total: 10 points)							
Why did they choose this solution - How their research and design process led to this prototype	Team clearly articulates research, design, and testing that led to the prototype.	Team adequately articulates research, design, and testing that led to the prototype.	Team articulates research, design, and testing that led to the prototype but leaves out a key component.	Team somewhat adequately articulates research, design, and testing that led to prototype but leaves out key components.	Team barely articulates research, design, and testing that led to prototype. Information is sparse.	Team does not discuss research, design, and testing.	
Advantages - What makes their solution better than others and best for client	Team clearly describes advantages of prototype over other solutions for client citing multiple reasons	Team clearly describes advantages of prototype over other solutions for client citing one reason	Team describes advantages of prototype over other solutions with some degree of clarity.	Team describes advantages of prototype over other solutions with no clear reason as to why.	Team description of advantages of prototype over other solutions is unclear.	No mention of advantages over other solutions	
Prototype Demo (Total: 25 points)							
Demonstration - Shows how client will use it	Demonstrates that easily used by client and is intuitive. Explains all of the features and functions of the prototype	Demonstrates that easily used by client and is mostly intuitive. Explains most of the features and functions	Demonstration shows that minimal training is needed for client to use. Explains the essential features and functions	Demonstration shows that some training is needed for client to use. Explains some of the features and functions.	Demonstration was not clear and concise on how to use. Vague explanation of features and functions	Not easy to use. Client would need significant training. No explanation of features and functions provided.	
Functionality (as proclaimed by students)	Fully functional, smooth no pauses or bugs	Fully functional with one pause or bug.	Mostly functional with several pauses or bugs.	Somewhat functional with many pauses or bugs	Barely functional. Numerous pauses or bugs	Does not function	
Ease of use (Someone else tries to use the device)	Client was able to use it with no assistance from team.	Client was able to use it with minimal assistance from team.	Client was able to use it with some assistance from team.	Client was able to use it with a lot of assistance from team.	Client could use it with total assistance from team.	Client could not use it at all	

Next Steps - What happens next in order to bring to the client -Scalability	Team clearly describes the next steps they need to undertake to bring prototype to the client	Team adequately describes the next steps they need to undertake to bring prototype to the client	Team somewhat adequately describes the next steps they need to undertake to bring prototype to the client	Team, with some degree of clarity, describes the next steps they need to undertake to bring prototype to the client	Team minimally describes the next steps they need to undertake to bring prototype to the client	Team does not describe the next steps they need to undertake to bring prototype to the client	
Potential of design - What would the next iteration look like?	The team clearly identifies what steps they will take to create the next iteration of the prototype.	The team adequately identifies what steps they will take to create the next iteration of the prototype.	The team somewhat adequately identifies what steps they will take to create the next iteration of the prototype.	The team inadequately identifies what steps they will take to create the next iteration of the prototype.	The team minimally identifies what steps they will take to create the next iteration of the prototype.	The team does not identify identifies what steps they will take to create the next iteration of the prototype.	
Presentation (Total: 45 points)							
Communication	• Speech flows nicely with no pauses • Speaks clearly • speaks loudly enough for everyone to hear; changes tone and pace to maintain interest • Does not use filler words	• Speech includes 1-2 distracting pauses • speaks clearly; not too quickly or slowly • speaks loudly enough for everyone to hear; changes tone and pace to maintain interest • rarely uses filler words (<3)	• Speech includes some distracting pauses • speaks clearly most of the time • speaks loudly enough for the audience to hear most of the time, but may speak in a monotone • occasionally uses filler words (3-5)	• Speech includes several distracting pauses • mumbles or speaks too quickly or slowly • speaks too softly to be understood • frequently uses "filler" words ("uh, um, so, and, like, etc." more than 5 times)	N/A	Did not present speech	
Speech organization	Presents ideas and information with excellent effectiveness. Introduction is strong and inviting, body is focused and clearly manipulated, and closing is effective in unifying entire presentation	Presents ideas and information with competent effectiveness. Introduction is clear and effective, body is focused, and closing assists in unity.	Presents ideas and information with acceptable effectiveness. Presentation has generally effective introduction, organization for body and closing.	Presents ideas and information with passable effectiveness. Organization is only partly effective and transitions are rough.	Presents ideas and information with insufficient effectiveness. Organization is lacking	Did not present speech	

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Content	Shows an excellent degree of understanding of ideas, concepts, themes and information	Shows a competent degree of understanding of ideas, concepts, themes and information	Shows an acceptable degree of understanding of ideas, concepts, themes and information	Shows a passable degree of understanding of ideas, concepts, themes and information	Shows an unsatisfactory degree of understanding of ideas, concepts, themes and information	Did not present speech	
Visual Aids/Creativity	Overall presentation shows excellent evidence of creativity, leading to a masterful, compelling and provocative presentation.	Overall presentation shows a strong evidence of creativity, leading to an interesting presentation that affects the audience	Overall presentation shows an acceptable level of creativity, leading to a satisfactory and general presentation.	Overall presentation shows some evidence of creativity, leading to a passable presentation that falls somewhat short on detail	Overall presentation shows little or no evidence of creativity, leading to a dull and prosaic presentation that is lacking in detail	Did not present speech	
Eye Contact	keeps eye contact with audience most of the time; does not use notes or slides	sometimes makes eye contact; only glances at notes or slides	makes infrequent eye contact; reads notes or slides most of the time	does not look at the audience; reads notes or slides	N/A	Did not present speech	
Body Language	• uses natural movements and gestures • looks poised and confident	• use a few movements appearing natural • Shows some poise and confidence, (only a little fidgeting or nervous movement)	uses a few gestures or movements but they do not look natural Shows some poise and confidence, (only a little fidgeting or nervous movement)	• Does not use gestures or movements • lacks poise and confidence (fidgets, slouches, appears nervous)	N/A	Did not present speech	
Intro of team members	All team members are introduced	N/A	some team members are introduced	N/A	N/A	no team members were introduced	
Participation	All team members participate for about the same length of time	N/A	All team members participate, but not equally	N/A	Not all team members participate; only one or two speak	Did not present	
Time	Presentation finishes within time	Presentation finishes within + 1 minute of time limit	Presentation finishes within + 2 minute of time limit	Presentation finishes within +3 minute of time limit	Presentation finishes greater than 4 minute of time limit	Did not present or goes more than 5 minutes over time limit.	
Column Totals							

Total	

2017-2018 PA MESA USA
National Engineering Design Competition
Prosthetic Arm Challenge 2.1
Device Performance
150 points

Inspection and Performance Datasheet

MESA Center:_____ MESA School: _____ Level: MS HS

Advisor/Teacher:_____ Student Team:_____

INSPECTION LIST:	**YES**	**NO**
Device is a generalized tool and includes all parts necessary to accomplish all tasks	☐	☐
Includes at least three wheels	☐	☐
Ability to move right, left, front, and back	☐	☐
Rover controlled by an Arduino microprocessor which is programmed with the Arduino language	☐	☐

Device Total Cost: $_____
% of changes made ____ 25 pts _____ 50 pts

PERFORMANCE:

Autonomous Maze Task

Trial 1	Zone 1	Zone 2	Zone 3
# of collisions			
Trial Time (00.00 seconds)			

Penalty Seconds _____ (s)
Total Trial Time _____ (s)

Trial 2	Zone 1	Zone 2	Zone 3
# of collisions			
Trial Time (00.00 seconds)			

Penalty Seconds _____ (s)
Total Trial Time _____ (s)

Object Relocation 2.0 Task

Trial 1
Trial Time _____ (s)

Check items that were avoided and circle items moved in safe area

☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Blue item (15 pts)
☐ Blue item (15 pts)

Total pts_____ Penalty Secs _____

Trial 2
Trial Time _____ (s)

Check items that were avoided and circle items moved in safe area

☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Red item (30 sec penalty) ☐ Blue item (15 pts)
☐ Blue item (15 pts)
☐ Blue item (15 pts)

Total pts _____ Penalty Secs _____

Soil Sensor Maze Task

Trial 1	Zone 1	Zone 2	Zone 3
Soil Sensor Team Reading			
Soil Sensor Theoretical Reading			
Trial Time (*00.00* seconds)			

Trial 2	Zone 1	Zone 2	Zone 3
Soil Sensor Team Reading			
Soil Sensor Theoretical Reading			
Trial Time (*00.00* seconds)			