Temple University
College of Engineering

MESA Mathematics Engineering Science Achievement Pennsylvania

MESA USA National Engineering Arduino Challenge Instructor Manual 2.1

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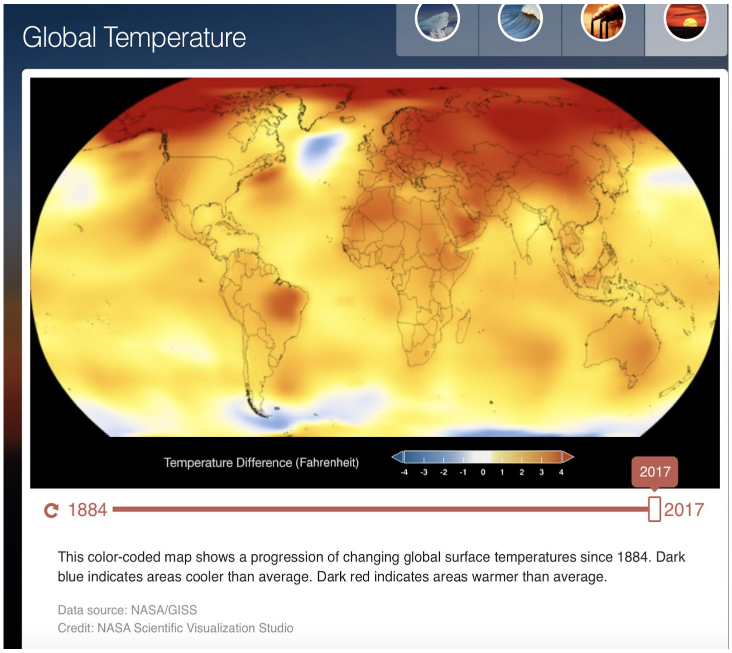
Introduction

Climate change is increasing the earth's temperature, and as the temperature rises planetary evaporation is threatening access to freshwater to sustain life.



In addition to droughts, glaciers are melting at an alarming rate. Glaciers are one of the most important sources of freshwater around the world and once they they melt they can't be restored.

Ecosystem relying primarily on glaciers for water will have to seek new sources as some are predicted to disappear in the next few decades, if not sooner.

Climate change predictions also suggest the rising temperatures will evaporate more moisture into the clouds, causing increased rainfall.

Since more than 50% of the world's freshwater is from mountain runoff and melting mountain snow, the problem with that prediction is that extra rainfall on mountains will fill water reservoirs faster than the slower method from snow and ice melting slowly down mountaintops.

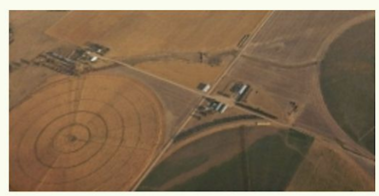
Filling water reservoirs faster results in excess water runoff that can't be stored, and since rainwater flows over the cold soil without being absorbed into groundwater basins, there will be water shortages because little to none is saved in the soil or underground.

Thus when it's time to actually use more water for growing during warmer seasons, the extra rain won't lead to more available water unless it is somehow collected and stored in large amounts.

For people who rely on public (municipal) water, shortages will not only be felt in less water available through municipal systems, but also increased energy usage to produce recycled water for all types of societal needs, from daily human use to impacting biodiversity around the planet .

Residents of Cape Town, South Africa, wait in line to fill containers with water at a source for natural spring water on February 2, 2018. The drought-stricken megacity introduced new water restrictions in an attempt to avoid what it calls "Day Zero," a day in May when it might have to turn off most taps. | AP Photo/Bram Janssen

The interconnected nature of food, water and energy requires interdisciplinary awareness, creativity and problem solving to help save our planet. Consider the following table:

		
Energy and Agriculture	**Energy and Water**	**Water and Agriculture**
As a result of the industrialization and consolidation of agriculture, food production has become increasingly dependent on energy.	It takes a significant amount of water to create energy, and it takes a significant amount of energy to treat and move water.	Freshwater is the lifeblood of agriculture. Learn why water is important to agriculture and how agriculture can impact water.

Downloaded 2.10.2018 http://www.gracelinks.org/468/nexus-food-water-and-energy

The urgency to address issues related to food, water and energy cannot be emphasized enough. Students in middle and high school are being asked to research, design and build a water detection device that can find and test for water suitability for human consumption and use.

Module 1: The Human Centered Design Process

Learning Goals & Objectives

Teachers will show increased confidence introducing and applying the human centered design process in response to a water access problem. Students will be able to identify and

interpret

data on why water access (or lack of) impacts life. From the data, students will suggest solutions with consideration of public health, safety, environmental and economic factors.

Materials

Process overview, research materials and resources related to climate change.

Human Centered Design in Engineering

Section 1.1: What is Human Centered Design Engineering ?

Human Centered Design Engineering (HCDE) is a creative approach to problem solving through a focus on the needs, contexts, behaviors, and emotions of the people that the solutions will serve.

MESA student teams are to develop and engineer a solution for monitoring water usage and soil moisture levels in a variety of contexts.

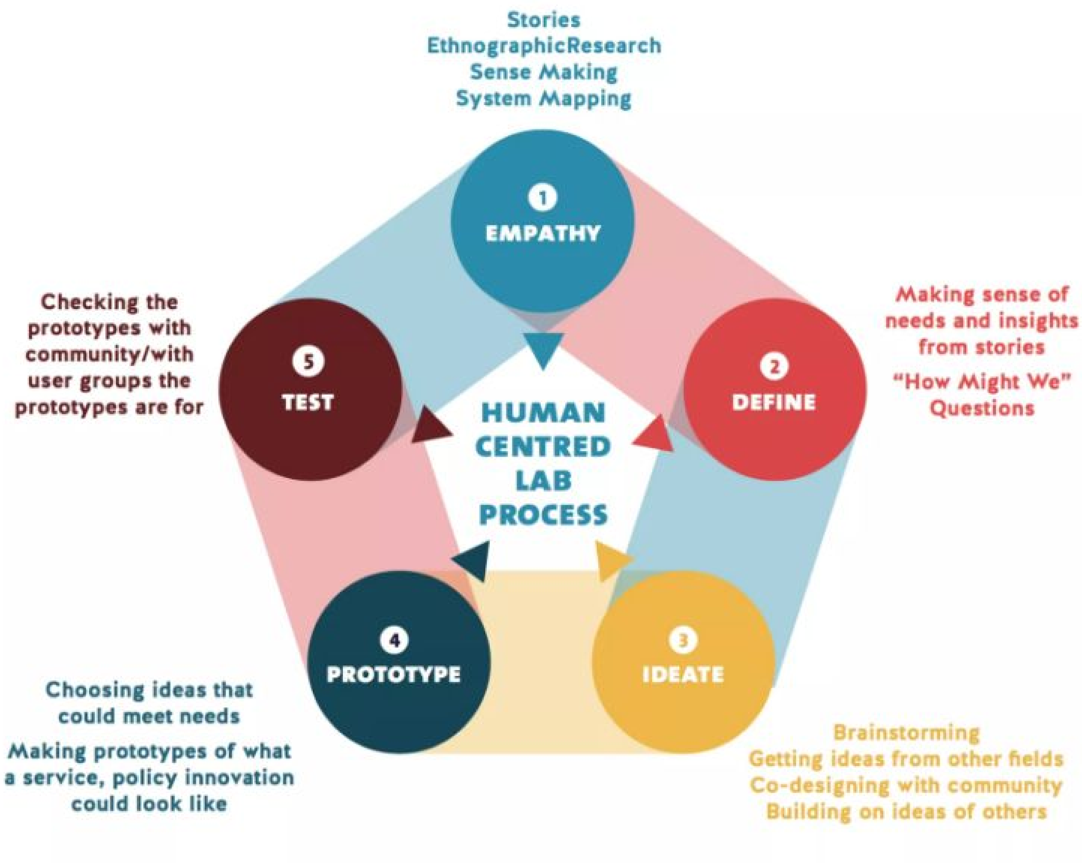
Examples:

- Monitoring water use for an in-door growing environment like an indoor farm
- Checking water levels after a flood using sensors to detect moisture levels
- A farmer is monitoring irrigation frequencies based on projected rainfalls

Teams have the flexibility to create their own scenarios.

Section 1.2 : Human Centered Design Process

The ability to help someone begins with empathizing with their situation, and understanding some of the basics about how they got to that point.

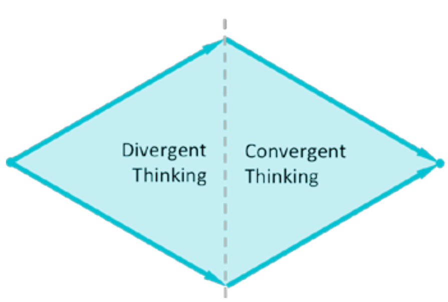


Section 1.3 How to Think About Design - The Diamond Model

THE DIAMOND MODEL

The Diamond Model is an approach to decision making that pairs two types of thinking, divergent and convergent

thinking. In order to allow individuals and teams to make effective choices from the possible solutions the recommend.



Divergent Thinking

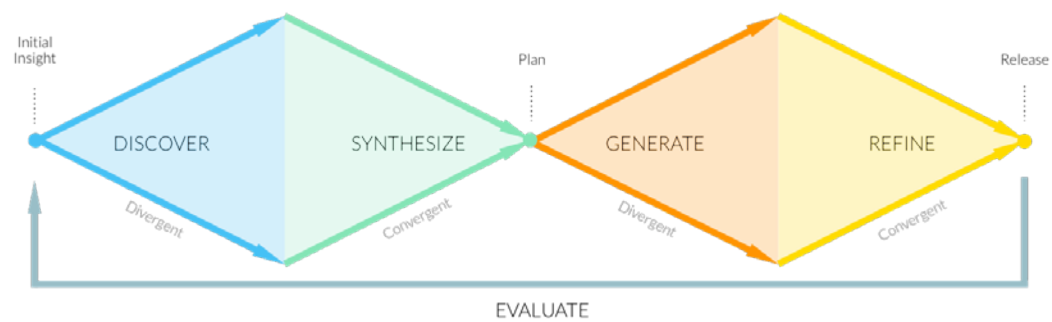
During the divergent phase, individuals/teams work to collect as much information as possible about the given prompt. This is similar to brainstorming.

Convergent Thinking

In the convergent phase, individuals and teams work towards decisions by examining the information gathered in the divergent phase and prioritizing, organizing and eliminating information/options based on their objectives.

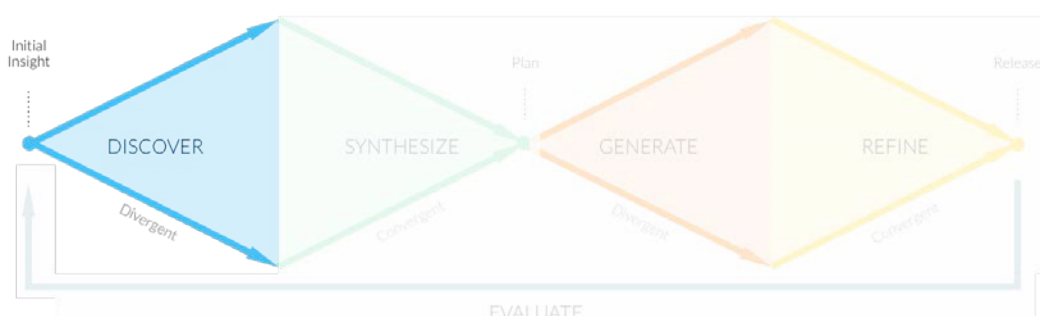
Connection to Human-centered Design

When paired with the principles of human centered design, the diamond model provides an effective structure for the human-centered design process.



Overlaying the human-centered design principles onto the diamond model provides us with a design process that can be broken down into 5 phases.

Discover



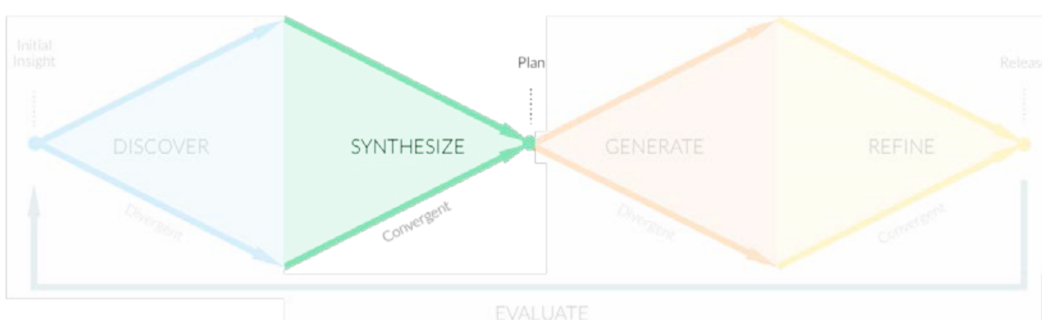
The Discover phase seeks to gather as much information about the initial insight. This discovery focuses on learning as much as possible about the people related to the problem or opportunity.

TEAM EXERCISE:

MESA teams should interview STEM college students, experts or community residents to hear people tell stories of their experiences or concerns related to water access. From these stories, teams can explore: **WHO**, **WHAT**, **WHEN**, **WHERE**, **WHY**, and **HOW**

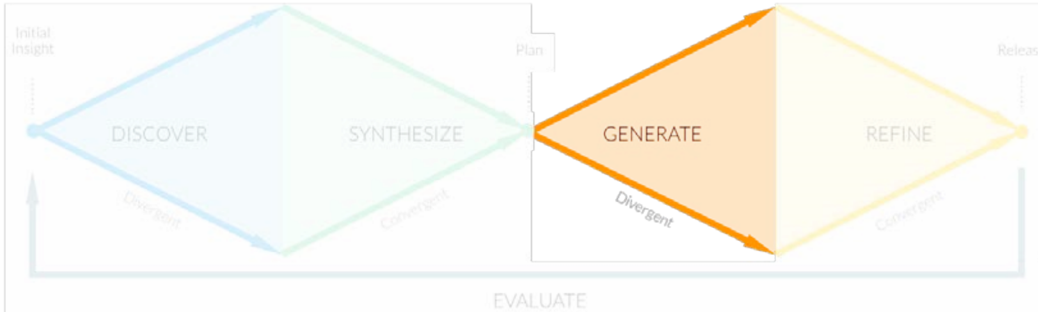
- **Who**: identify the people and systems involved that need a solution?
- **What**: identify the decisions and actions that need to be made to solve it
- **When**: when do these actions/decisions happen? What triggers them?
- **Where**: where do these things take place?
- **Why**: what leads people to make the decisions or take the actions they do? How are they processing information? How are emotions affecting things? What goals or objectives do they have?
- **How**: how do they go about taking their actions? What tools do they use?

Synthesize



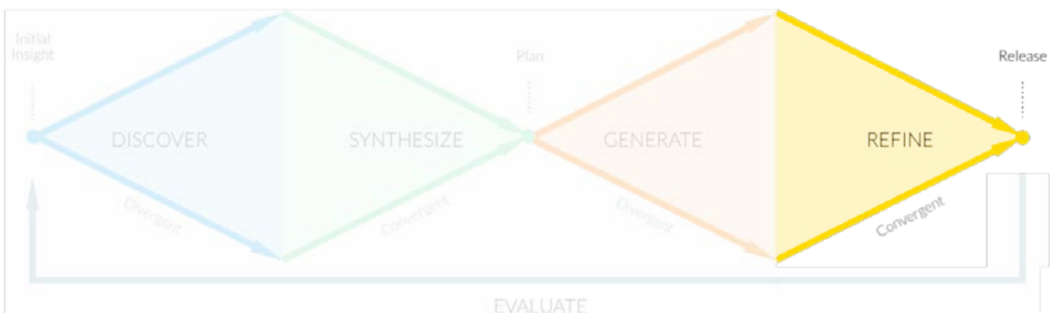
After discussing the information, the team has to decipher the information and determine what's most important. What have they learned, what should they focus on - the symptoms or the solution. If they were in that position, how would they feel?

Generate



After synthesizing, MESA teams should brainstorm potential solutions. The goal is to generate as many ideas as possible.

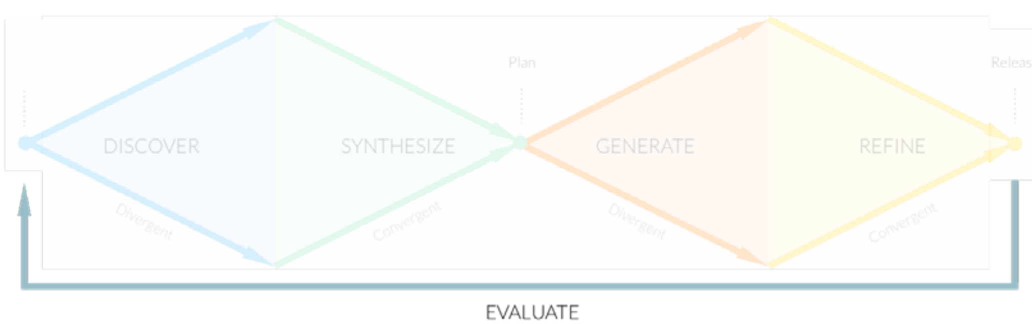
Refine



Teams can now begin to make decisions and further explore, develop and refine selected solutions. Considering the needs of the people discovered through discovery and synthesis, the team can critique ideas and create prototypes they feel present the most value or will be the most effective in meeting the human needs they've identified.

Prototypes help provide initial feedback for the proposed solutions. This feedback can then be further used to refine and recombine ideas until the final solutions begin to emerge.

Evaluate & Iterate



A final prototype has to be tested with the original clients to see if it answers the discovered need. This stage doesn't end since the solution presents an opportunity to learn more about those who are most likely to use it.

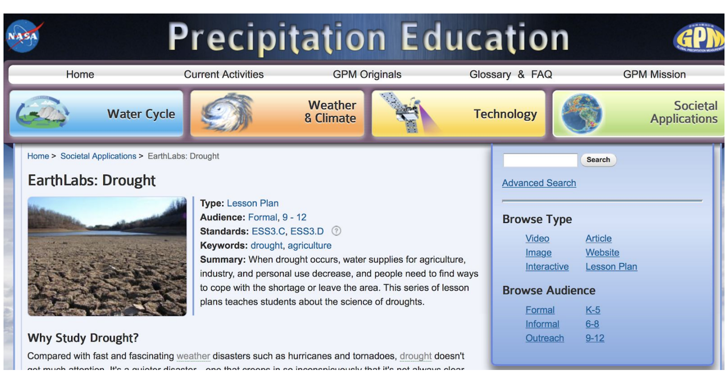
As people use and interact with whatever solutions have been designed, clients should provide feedback and more data from monitoring for quality assurance.

ACTIVITY:

Visit https://pmm.nasa.gov/education/lesson-plans/earthlabs-drought

- Use grade appropriate lesson plans from NASA's Precipitation Education website to guide student discussion of the impact of drought on access to water.
- Also have them use their smart-phones to look at time elapsed videos of how drought happens.
- Assess their understanding of causes and impact of decreased fresh water on biological systems.
- Next, break students into pairs or groups of four to select a specific region of the US experiencing decreased water, and serve as the "consultant" to that region.
- Have students practice using the human centered design process, basic research and diamond thinking to brainstorm whether water can be returned to that area, and if so, from where.
- If not, how would they recommend people living near drought areas change - stay and find new resources or leave?
- Each team should draw a schematic outlining the design and solution options (even if they aren't correct) to present to the class.

Best team process and solution thinking (voted on by the class) wins a prize of the teacher's choosing.



Module 2: The Engineering Design Process

Learning Goals & Objectives

MESA teachers and coaches will develop the ability to understand the process for

- Developing and documenting technical iterations (including conducting appropriate contextual research)
- Experimenting with new designs, analyzing data on effectiveness
- Ability to communicate design process and conclusions effectively in written form.

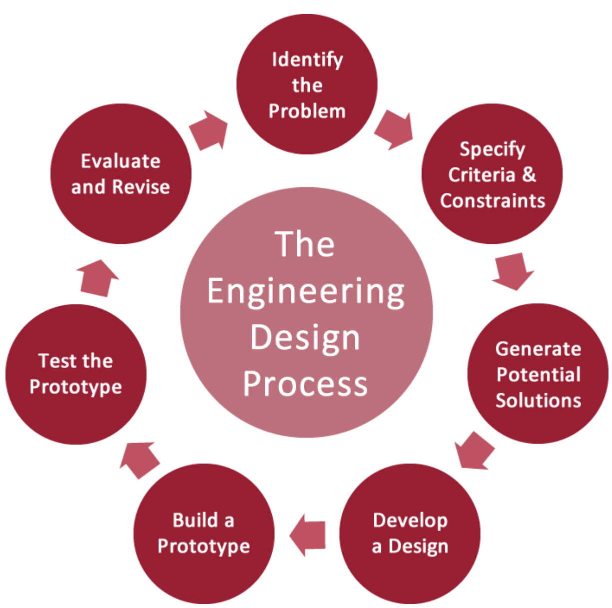
Materials Needed: Notebook, pens/pencils

Lesson Overview

This module continues to build design thinking by introducing the steps anyone can use to come up with an engineering or technology based solution to a problem.

Section 2.1: MESA Engineering Design Process

The MESA engineering design process is a series of steps that help students to create functional products and/or processes that solve problems. While the engineering design process can be defined in multiple ways, all versions of it have the same general structure.



Step 1: Identify the Problem through a Client's Viewpoint

The Engineering Design Process begins with the identification of a problem that must be resolved. For example, **"drought season is approaching so less water must be used to grow food"** or **"storm-water runoff needs to be managed since it is causing flooding within the city"** By defining the specifics of the problem, that ensures the functionality, 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 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 household materials. 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.

Section 2.2:

Developing An Engineering Design Notebook

Purpose

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

Content

EDN's are used to record 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 the steps taken so that others can easily follow along.

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

ACTIVITY:

https://www.scientificamerican.com/article/build-an-artificial-hand/

Have students use an engineering design notebook to document and record pictures, notes, drawings and labeling of possible prototypes.

Module 3: Water, Microbes & Biology

Learning Goals & Objectives

Teachers will show increased confidence introducing and applying the human centered design process in response to finding and testing soil for the presence of water to allow the growth of the soil food web, which relies on the existence of microbes. Students will then be led by their teacher, and demonstrate an ability to identify, suggest and invent initial solutions that meet environmental, social and cultural needs to grow food with minimal water and energy. Detecting water is one phase of the process, followed by collecting data to confirm microbes are available. public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Materials

Process overview, research materials and resources related to climate change.

Lesson 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.

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.

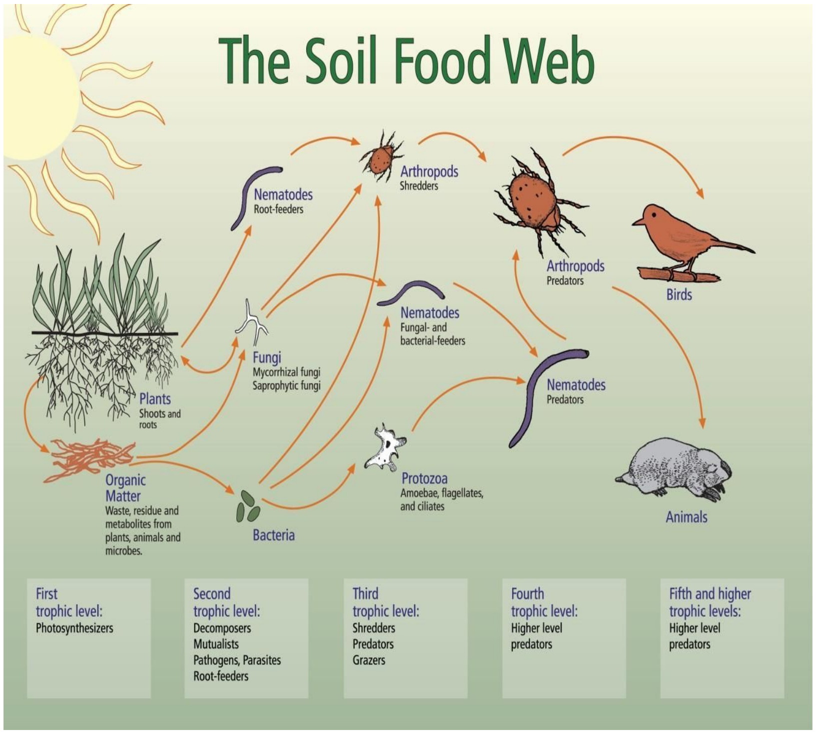


Image Courtesy of the National Resource Conservation Service

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 r**hizosphere**. 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.

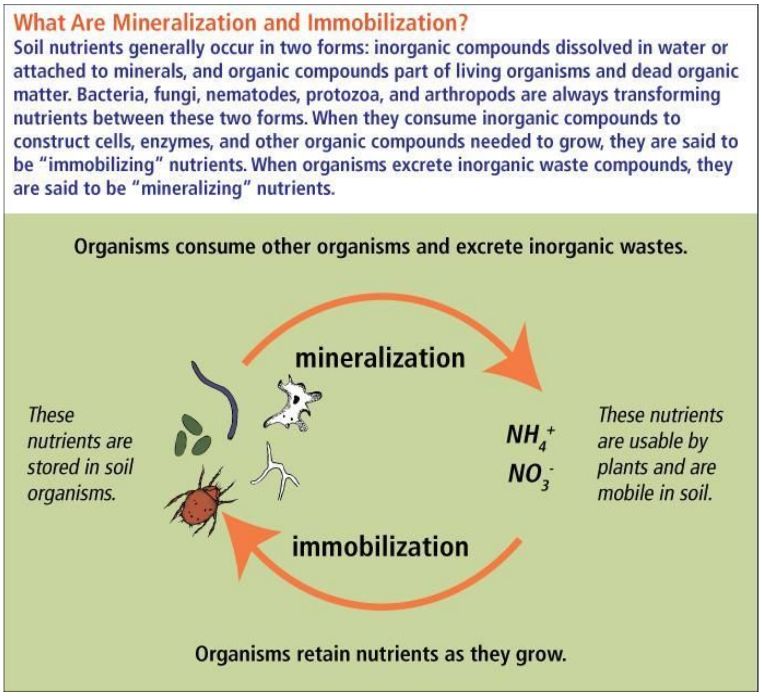
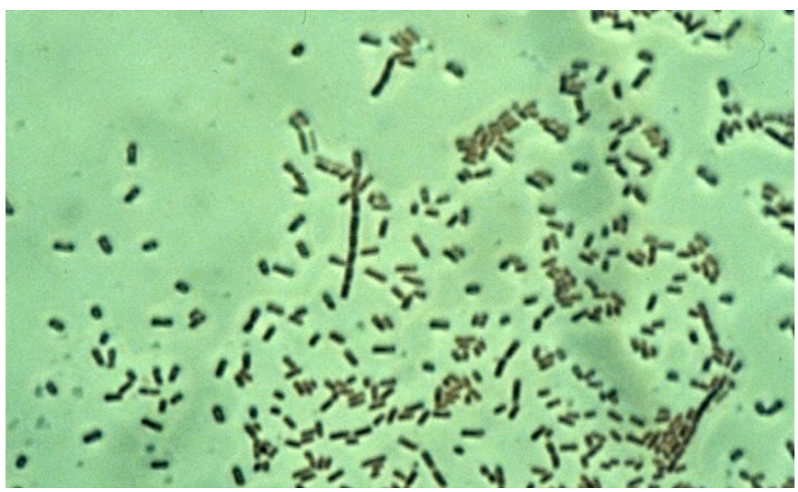


Image courtesy of National Resource Conservation Service

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 bacteria 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.

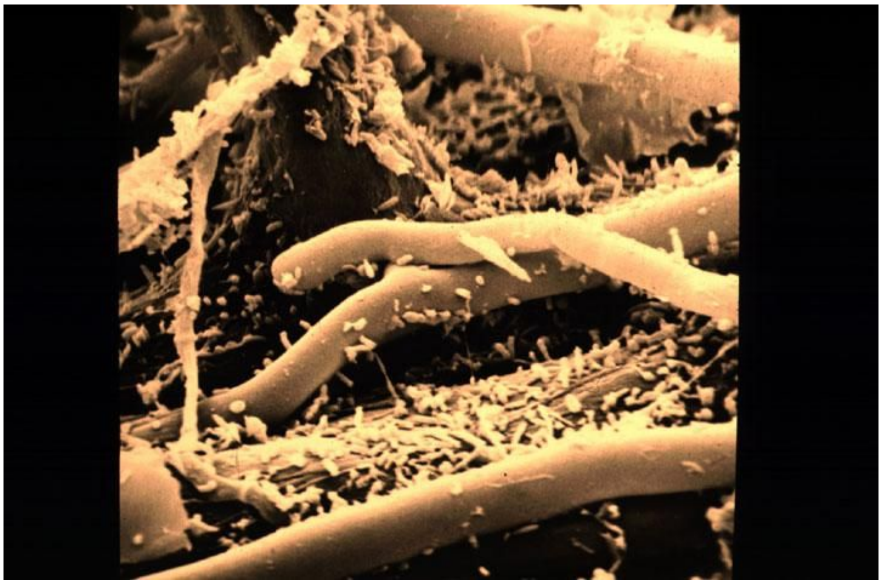
Function

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 seafloor 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 there are 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.

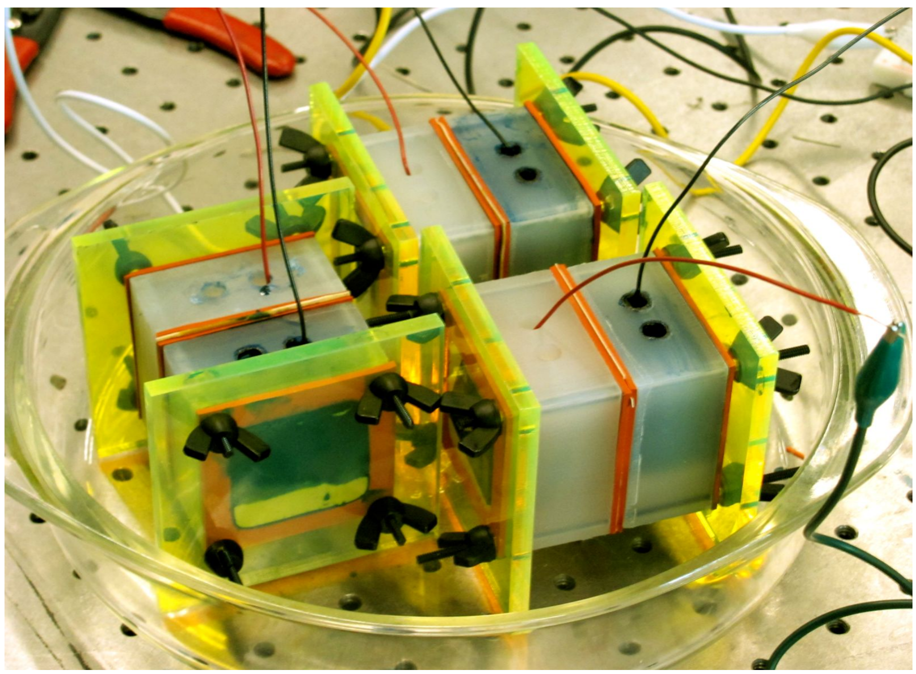
Agricultural Effects

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.

Microbial Fuel Cells (MFCs)

Using Biology to Create Energy-Microbial Fuel Cells
Building on the power of microbes discussed earlier, energy can be generated by bacteria. Given the fact that energy is needed to not only produce water but to grow food, powering systems using an innovative way to leverage nature to solve the need for microbial fuel cell is renewable power sources.

A microbial fuel cell (MFC), or biological fuel cell, is a bio-electrochemical system that drives an electric current by using bacteria and mimicking bacterial interactions found in nature. MFCs can be grouped into two general categories: mediated and unmediated. The first MFCs, demonstrated in the early 20th century, used a mediator: a chemical that transfers electrons from the bacteria in the cell to the anode. Unmediated MFCs emerged in the 1970s; in this type of MFC the bacteria typically have electrochemically active redox proteins such as cytochromes on their outer membrane that can transfer electrons directly to the anode.[1][2] In the 21st century MFCs started to find a commercial use in wastewater treatment.



Lesson 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

andoxygen 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.

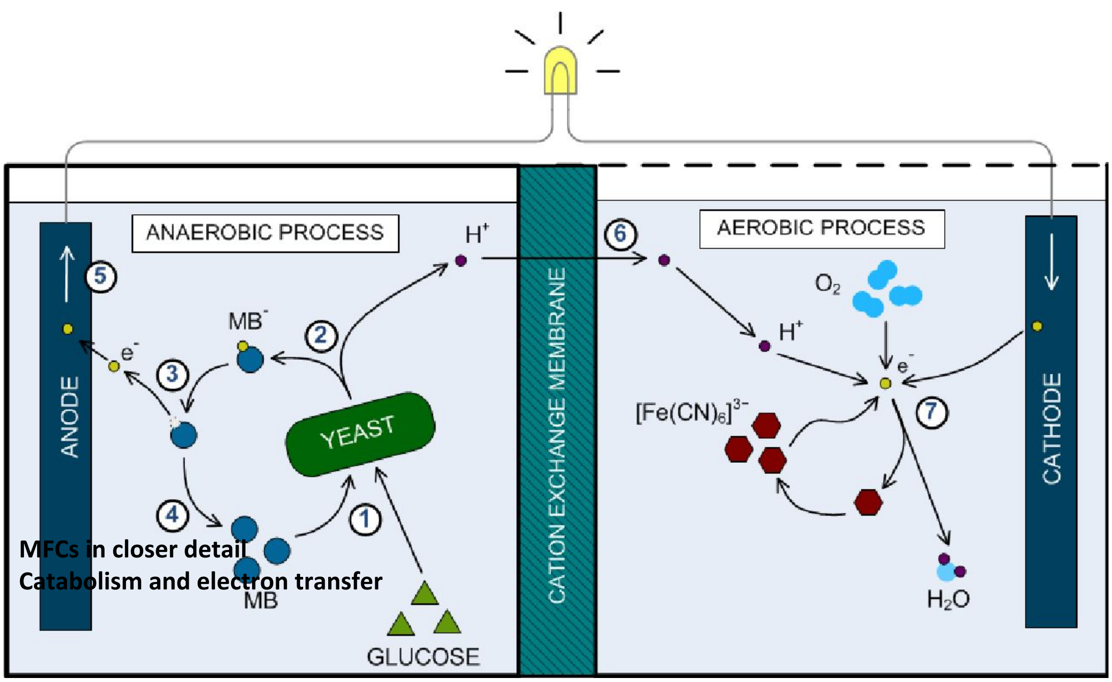
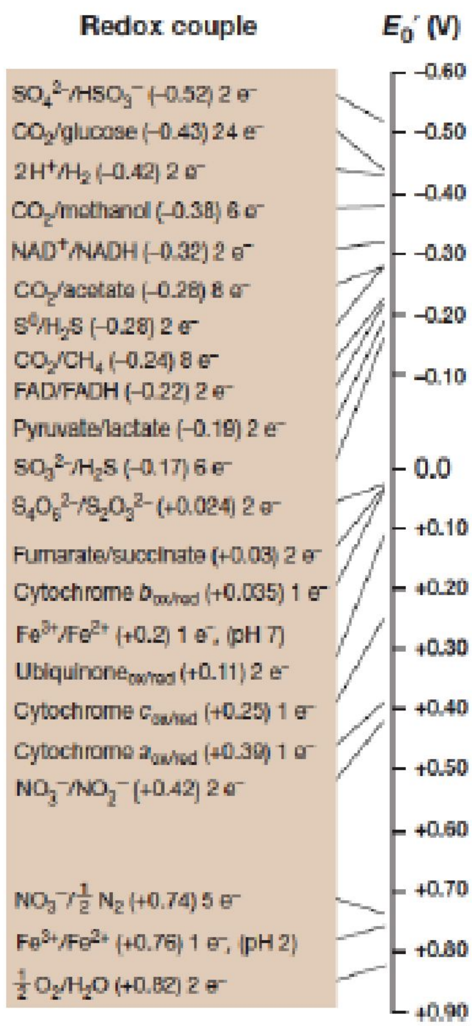


Figure 1: Diagram of MFC Processes

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.

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].



LISTS REDOX

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. 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.

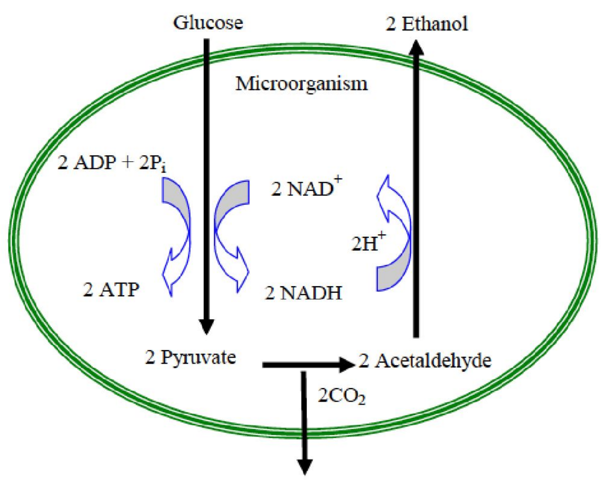


FIGURE 3: A SIMPLIFIED FLOW CHART OF ANAEROBIC GLUCOSE CATABOLISM IN S. CEREVISIAE VIA FERMENTATION [12].

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

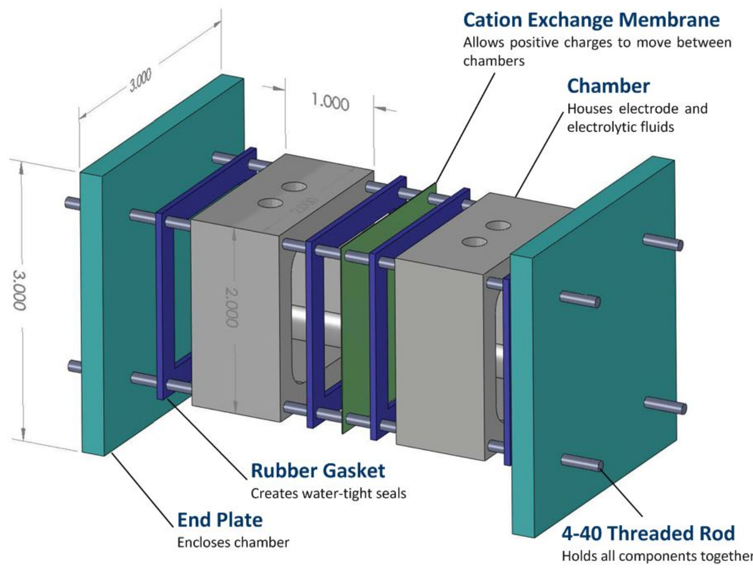
- 1x Multimeter
- 5x Resistors
- 1x LED
- 1x Breadboard
- 1x Funnel
- Glassware

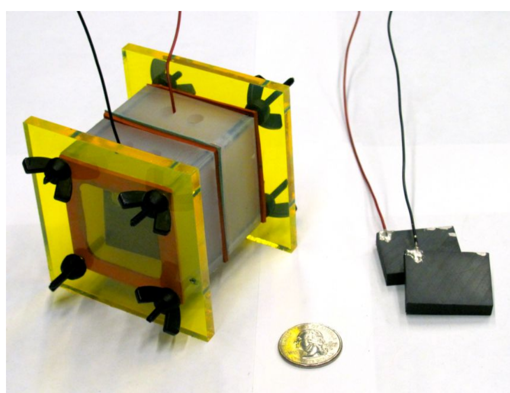
Teacher Preparation

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.

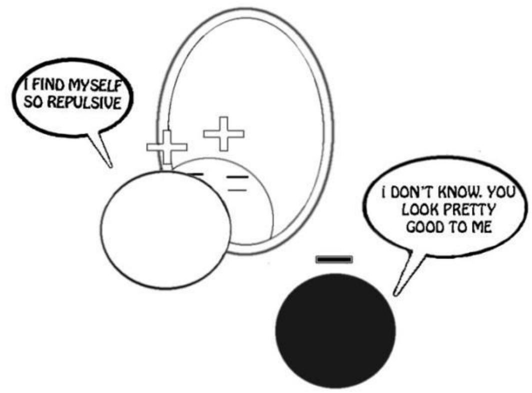
Section 3.3

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 a 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 Ohm's Law where 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.

Module 4: Using Arduino Microcontrollers

Learning Goals & Objectives

Teachers and students will begin to introduce the internet of things into their design using arduino microcontrollers to control the rover device. Combining computer science with engineering will increase the use of "constructivist" learning strategy, eg project based learning to ensure the device can move autonomously with sensors. By applying new knowledge, the solution to water detection will be broadened.

Lesson Overview

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 4.1: 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

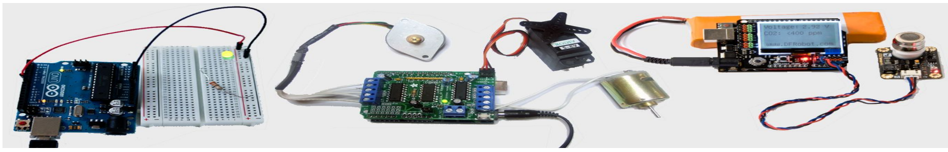
Output: power leaving the system

Circuit: a path where a current source flows through

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

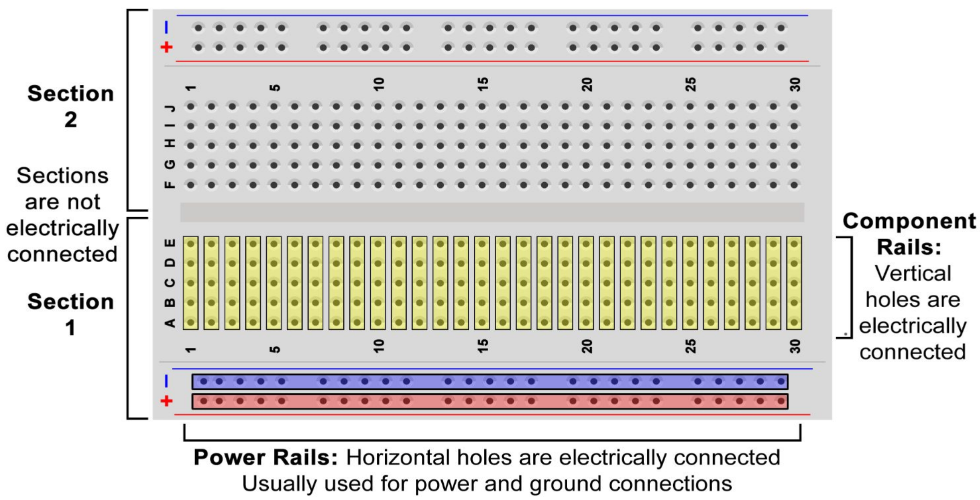
What does Arduino do?

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.

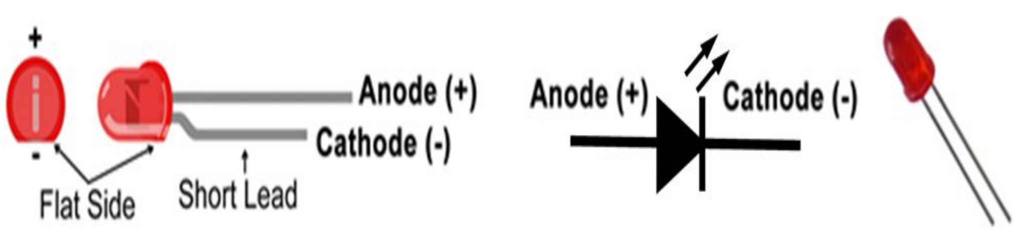


Section 4.2: Electrical Components

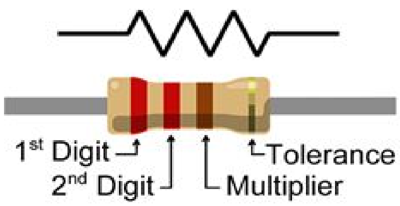
Breadboards are perforated plastic blocks that allow of solderless prototyping of electrical circuits. The holes in the breadboard contain metal contact points that can hold electronic components and connect them with an underlying strip of metal.



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

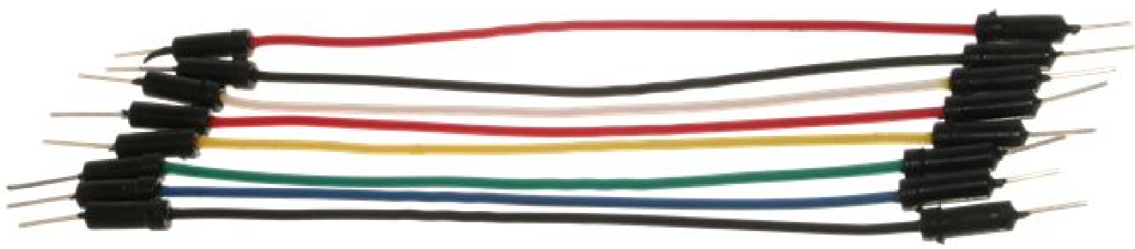


Resistor is an electrical component that limits or regulates the flow of electricity, which can be for the purpose of reducing current in a circuit or lowering voltage levels.



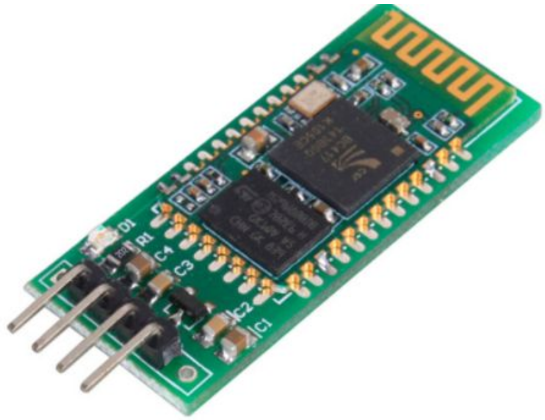
1st digit	2nd digit	Multiplier	Tolerance
0	0	x 1	
1	1	x 10	±1%
2	2	x 100	±2%
3	3	x 1K	
4	4	X 10K	
5	5	x 100K	
6	6	x 1M	
7	7		
8	8	x 0.1	±5%
9	9	x 0.01	±10%

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.

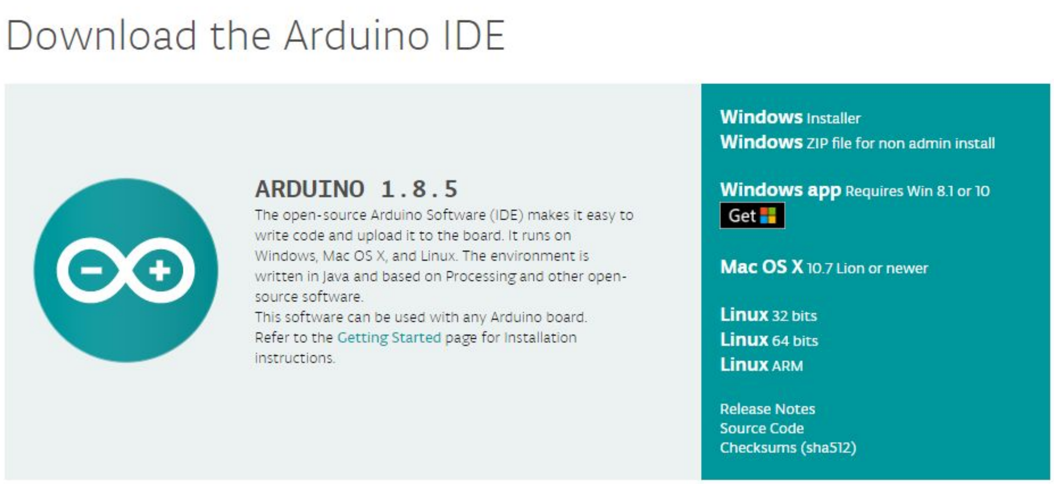
Ultrasonic Sensor is used for obstacle avoidance tasks by emitting ultrasound to detect objects. The ultrasound moves through the air and hits the object and bounces back to the sensor.

Programming Arduino Microcontrollers

There are a series of steps to programming your micro-controller to control your rover.

STEP 1: Download Arduino IDE:

Go to the website: https://www.arduino.cc/en/Main/Software
Scroll down to where it says: Download the Arduino Software
Pick the operating system for your device



What is included in the folders downloaded:

In the folders that you will find a link to the Arduino IDE, how to connect the car to the computer, already written programs you will use for the car.

What is the Code used for?:

The code that you will download is available online in "open source" format which means they're free for anyone to use and improve. The code you've downloaded controls the motors, how the rover moves, and how the sensors you'll install will function.

Module 5: Designing a Water Detection Rover with Arduino

Learning Goals & Objectives

Teachers and students will increase their ability to solve the problem of detecting water under various conditions. By applying engineering design, students should be able to produce a battery powered remote control or autonomous device that uses micro-controllers, sensors, bluetooth or infrared communications. Students should be able to make informed decisions about the data their device collects, interpret and draw conclusions about the status of the environment to share with a "client".

Materials: Rover Kit, EDN, Arduino board

Lesson Overview

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. There are three potential industries that your team can focus on: Aerospace industry, Natural Disaster Search and Recovery, or Agriculture Automation. Your team's "Natural Detection 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 5.1: Activity - Identify the problem

Use the human centered design process to review the elements of the problem your 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 5.2: Prototyping

Begin with online research to identify mobile devices that have been used to search and find in harsh conditions. 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.

Section 5.3: 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 isimportant to understand the PA MESA performance rules. For example, your rover needs to be programmed by Arduino and have at least three wheels.

Section 5.4: 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 and rebuild it using cardboard to vary the design. It's a good starting point but is not the only way to meet the needs of the client.

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 3D printed or laser cut? These are all questions that need to be considered be developing your final design.

Section 5.5: 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 are step-by-step instructions in that kit.

STEP 2: TEST ABILITY TO CONTROL YOUR DEVICE

If your school has decided to use a kit, like the sample Elegoo Car Kit found on amazon, here's how to download the code for the device:

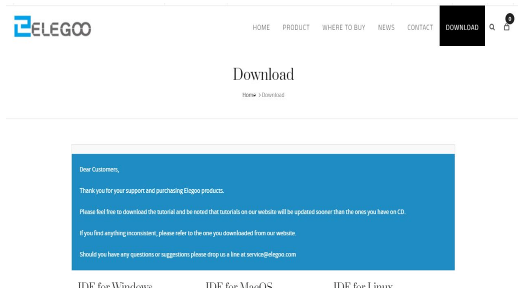
Go to the website: https://www.elegoo.com/download/

Scroll down to where it says: Elegoo Smart Robot Car Kit V3.0 2017 New Version or Elegoo Smart Robot Car V2.0

Elegoo Smart Robot Car Kit V3.0 2017 New Version

Elegoo Smart Robot Car V2.0

elegoo-smart-robot-car-2.0



How to upload the code to the car:

Step 1: Open the Arduino IDE

Select “Tool” → “Board:” → “Arduino/Genuino Uno”
Select “Tool” → “Port” → “COM(Arduino/Genuino Uno)”

[INSERT SCREENSHOTS]

How to make the car move:

Step 1: Open the code file from the downloaded folders and upload to the UNO controller board. *The bluetooth module should be pulled out when uploading the programs every time, or it will fail to upload the program*

“Lesson 1 Make the Car Move\AUTO_GO\AUTO_GO.ino”

[INSERT SCREENSHOTS]

STEP 3: DEBUG COMMON PROBLEMS

Notes:

Module 6: Understanding Arduino Sensors to Test for Water & Soil

Learning Goals & Objectives

Teachers and students will show an ability to augment their engineering designs by applying sensors to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

Lesson Overview

In this module you will gain a better understanding what sensors could possibly be used for the performance aspect of the competition. This will allow you to create a optimal rover based on cost, performance, and efficiency of the sensors as it relates to your problem statement.

Each MESA should break down what sensor can be used for which performance task. You are not limited to what is suggested in this module. This module is here as a guide.

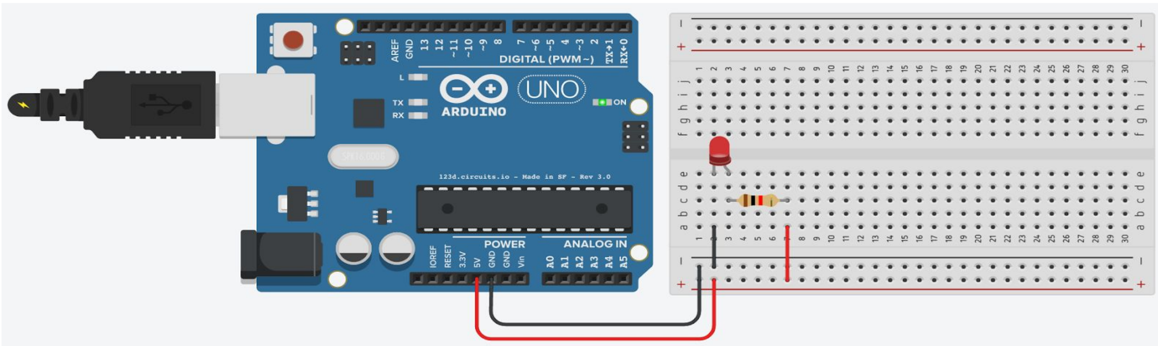
Activity: Practice Using Arduino to Turn on a LED

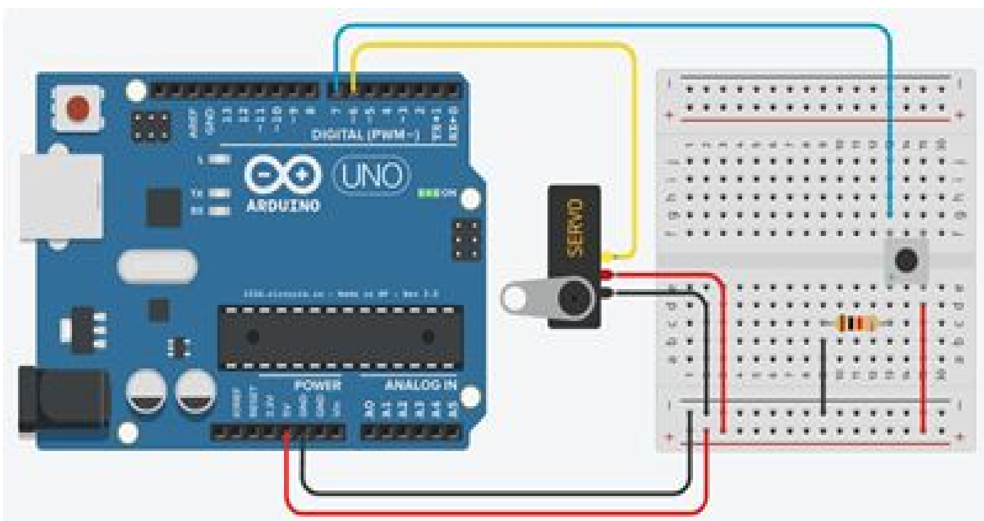
The objective of this first activity is to understand how to source power from the Arduino board. Follow the procedure on the next page to properly setup the circuit.

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*





Section 6.1 : Objective Avoidance Sensors (Autonomous Maze)

Section 6.1 a:

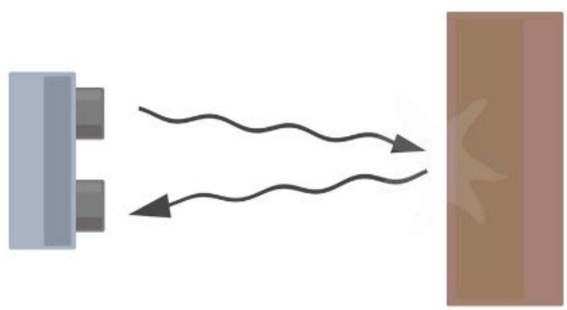
What is the autonomous maze task ?

It is the *greatest distance and accuracy* traveled by the rover through the 3 Target Zones in the fastest time. The objective of this task is for the team's rover to successfully travel an unknown maze autonomously as fast as possible with minimal collisions.

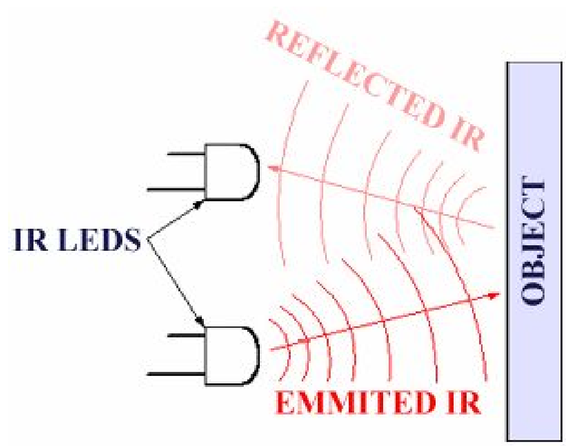
Section 6.1 b: Object Avoidance Sensors

Guide your team to research what type of sensors can be used to avoid obstacles. Teams should be able to identify the following sensors on their own. Listed are two sensors that can be used but not limited to these sensors.

Ultrasonic Distance Sensor - It detects the **distance** of the closest object in front of the **sensor** (from 3 cm up to 400 cm). It works by sending out a burst of **ultrasounds** and listening for the echo when it bounces off of an object. It pings the obstacles with **ultrasounds.**



IR Proximity Sensor - Is a multipurpose **infrared** sensor which can be used for obstacle sensing, color detection (between basic contrasting colors), fire detection, line sensing, etc. and as an encoder sensor. The sensor provides a digital output.



Section 6.2 : Object Avoidance and Relocation

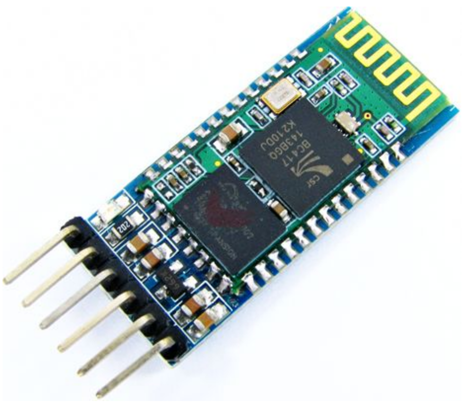
Section 6.2 a:
What is the object relocation task ?

It is the *fastest time* achieved by placing designated objects across designed safe zone line. The objective of this task is for the rover to successfully move objects in and out of the designated arena as fast as possible with minimal collisions.

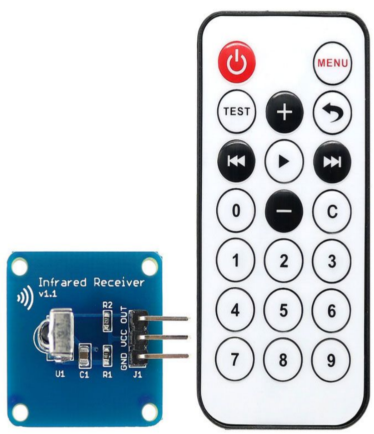
Section 6.2 b:
Non-autonomous Movement

There is no limitation to these controllers. Teams can decide to choose something different but guide them in making this decision.

Bluetooth– There is an app that is designed to send serial data to the ***Arduino Bluetooth*** module when a button is pressed on the app. The **Arduino Bluetooth** module at other end receives the data and sends it to the Arduino through the TX pin of the Bluetooth module.



IR Controller - Infrared light is in the invisible portion of the electromagnetic spectrum. An IR remote control (the transmitter) sends out pulses of infrared light that represent specific binary codes. These binary codes correspond to commands, such as Power On/Off and Volume Up.



Section 6.3: Soil Sensors

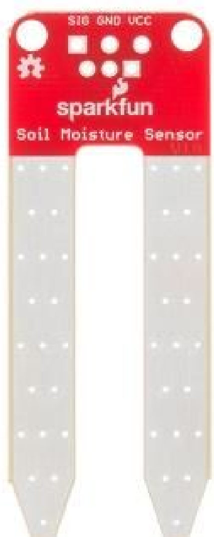
Section 6.3 a:

What is the soil sensor maze task ?

It is 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. The objective of this task is for the rover to successfully navigate through the maze and hit each of the Target Zone and accurately collect data.

Section 6.3 b:

Soil Sensor - This sensor measures the volumetric content of water in soil and gives us the moisture level. The sensor gives us both analog and digital output, so it can be used in both analog and digital mode.



Module 7: Test, Modify, & Finalize the Prototype

Learning Goals & Objectives

Teachers and students will demonstrate the ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics on the rover prototype. The final model will reflect an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors and constraints.

Materials

Lesson Overview

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 7.1: 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 7.2: 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 7.3: 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 8: Communicating Engineering Technical Aspects

Learning Goals & Objectives

Teachers and students will show an ability to communicate effectively with a range of audiences regarding the appropriateness of the proposed rover solution on the "client's" contexts. Presentations of design decisions and effectiveness will include an ability of students to demonstrate individual and team leadership reflected in discussing their collaborative and inclusive environment, goals, project plan and tasks required to meet the project objectives.

Materials

Lesson Overview

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).

Materials:

- 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

Posters should include the following elements:

a. Objective: This defines the requirement (s) of the design. Could include:
    - Desired attributes of the design, what it will be, and what qualities it will have.
    - Any user requirements which are a mix of project goals and constraints.

- Design choices to fulfill client's needs.
- Scope of the project and any priorities in design.

b. Engineering Design Process: Engineering design is a process for generating the team prototype that meets the specified objective while adhering to specified constraints. The poster could include:
   - Specification of team methodology and process.
   - An analysis of challenges and correlating solutions.
   - Any evaluation of competing design solutions.
   - Any relevant research or discovery which led to chosen design solution.

c. Data: Any visual representation of research, analysis, inspection, and/or testing which led to the prototype design. Can include:
   - Charts and/or graphs.
   - Arduino Diagram(s) such as schematics, block-logic diagram, function block diagram.

d. Conclusions and Recommendations: Identification of the chosen solution and any recommendations for further progress. Could include:
   - Design Flaw Analysis
   - Justification for design choice
   - Plans for next steps

e. Support Materials: Anything to improve the understanding of the team project and to enhance the visual appeal of the project. Could include:
   - Any relevant diagram or layout of the prototype.
   - Commented Arduino code or Logic Diagrams
   - Any relevant prototype drawing(s). Should include scale and labels.
   - Relevant photo(s) of prototype, testing conditions/environment, and/or prototype parts. Should include scale (if needed) and labels.

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

Introduction: ATTENTION GETTER/ You need to hook your audience.

- Introduce yourself to the judges and introduce your topic at hand
- The introduction should make the judges interested in your speech and clearly state the main idea.
- Here are some possible creative ways to begin the introduction:
  - Use an interesting quotation (Not one everyone has heard before)
  - Act something out- like a very short play
  - Tell a joke which fits the subject
  - Get the judges involved by having them do something
  - Use a game which fits the subject
  - Use an audio / visual aid
  - Demonstrate something
  - Ask questions about your subject which you will then answer in the rest of the speech.

The presentation is a summary of their project and the interview is a discussion with the judge panel. Together, they should include:

1. Project Objective
   a. Who is the client and what are the client's needs?
   b. How does this project fulfill the client's needs?
   c. What are the current constraints of your project?
2. Engineering Design Process
   a. What was your team methodology and process?
   b. What research did your team do during the process of your project?
   c. What were other solutions that your team thought of to fill the needs of your client?
   d. What were any major challenges and any correlating solutions?
3. Conclusion and Recommendations for their project
   a. What tests were completed on your prototype?
   b. What is your final assessment/evaluation of your prototype?
   c. What are the next steps for the implementation of your project?

d. Are there any suggestions for improvement and/or redesign?

e. Are there any conclusive findings?

Project Based Learning : Mock Interview

Teams should individually present to each other. For example, A team of three , each person would present to the two other team members. This will allow for team to present in the most efficient way and see where they are deficient and where they are proficient. Here are some example mock interview questions.

- Why did you chose this project ?
- What you already knew about this subject that made you want to do this particular project ?
- The details about what you did for your project, when and where you did it ?
- What was unique or creative about the project?
- Who your mentor was and how your mentor helped you ?
- Anyone else who helped or worked with you besides your mentor ?
- What problems you had in doing the project, and how you solved the problems ?
- What you would do differently if you could do the project over ?
- What you still plan to do ?
- What special things you want the judges to consider as they look at or hear about the project ?
- Would you recommend other students in the future do this type of project? Why?

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.

Project-based Learning

Think of an elevator pitch or the show Shark-tank. The prototype pitch should embody these examples. Students should brainstorm different ideas to captivate their audience. Here are some important elements of the pitch :

1. The Hook: pitch opening that grabs the listeners attention
2. Brief description of product/service
3. Brief target market description
4. Brief description of how the product is different from the competition
5. Brief description of how you will make money
6. Brief description of resources needed

Microbes: The Rodney Dangerfield's of the Dirt

Written by

Bertram Johnson, AG, IT and Math Teacher

W.B. Saul High School of Agricultural Sciences

Philadelphia, PA

Mr. Johnson's 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 microbes for years!

I was floored and 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".

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

ACTIVITY: Do Microbes Need Water to Live?

Absolutely! Water is what makes it possible for enzymatic activity to take place. Microbes (the bacteria, fungi, archaea and earthworms) can actually remove water from themselves to hibernate when water is not sufficient, surviving on minute amounts until water returns. Although drying out does not necessarily kill microbes, their ability to degrade biomaterials are based on access to water, so the quality of soil is ultimately dependent on access to water. Without it the microbes not only stop working, but can't multiply as needed to condition the soil.

Experiment on microbes in water using any of the following exercises

https://www.researchgate.net/publication/241028913_Microorganisms_in_Soil_Water_and_Air

http://www.nuffieldfoundation.org/practical-biology/microbes-all-around-us

ACTIVITY: What's all this fuss about Inoculants?

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.

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

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

Article - American Journal of Botany. "The secret life of underground microbes: Plant root microbiomes rule the world." Science Daily. Science Daily, 18 September 2013. <www.sciencedaily.com/releases/2013/09/130918181104.htm>.

Annotated Bibliography / Resources

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

Vocabulary

Adenosine Diphosphate - A nucleotide made up of adenine, ribose, and two phosphate units

Alanini - an amino acid that is a constituent of most proteins.

Amino Acids - a simple organic compound containing both a carboxyl (—COOH) and an amino (—NH2) group.

Aspartate - a salt or ester of aspartic acid

Autonomous - navigated and maneuvered by a computer without a need for human control or intervention under a range of driving situations and conditions

Carbohydrates - any of a large group of organic compounds occurring in foods and living tissues and including sugars, starch, and cellulose. They contain hydrogen and oxygen in the same ratio as water (2:1)

Catabolism - the breakdown of complex molecules in living organisms to form simpler ones, together with the release of energy; destructive metabolism.

Celluse - an insoluble substance that is the main constituent of plant cell walls and of vegetable fibers such as cotton. It is a polysaccharide consisting of chains of glucose monomers.

Ethanol - a colorless volatile flammable liquid which is produced by the natural fermentation of sugars; alcohol

Exoelectrogens - a microorganism that has the ability to transfer electrons extracellularly

Ferricyanide - a salt containing the anion Fe(CN)63−.

Immobilization - the act of immobilizing or state of being immobilized

Isoleucine - a hydrophobic amino acid that is a constituent of most proteins. It is an essential nutrient in the diet of vertebrates.

Lipids - any of a class of organic compounds that are fatty acids or their derivatives and are insoluble in water but soluble in organic solvents. They include many natural oils, waxes, and steroids

Mediator Molecules - is a multiprotein complex that functions as a transcriptional coactivator in all eukaryotes

Mineralization - a process where an inorganic substance precipitates in an organic matrix

Nicotinamide Adenine Dinucleotide - Ribosylnicotinamide 5'-phosphate (NMN) and adenosine 5'-phosphate (AMP) linked by the two phosphoric groups; binds as a coenzyme to proteins, serves in respiratory metabolism (hydrogen acceptor and donor).

Phenylpyruvate - An intermediate in the biosynthesis of phenylalanine, formed by the decarboxylation of prephenate with loss of hydroxyl

Pyruvate - a salt or ester of pyruvic acid

Vocabulary

Redox Reaction - is a type of chemical reaction that involves a transfer of electrons between two species.

Rhizosphere - the region of soil in the vicinity of plant roots in which the chemistry and microbiology is influenced by their growth, respiration, and nutrient exchange.

Scalability - the capacity to be changed in size or scale.

Semiconductor - a solid substance that has a conductivity between that of an insulator and that of most metals, either due to the addition of an impurity or because of temperature effects.

Solderless - any of various alloys fused and applied to the joint between metal objects to unite them without heating the objects to the melting point.

Solenoids - a cylindrical coil of wire acting as a magnet when carrying electric current

Trophic - relating to maintenance or regulation of a bodily organ or function, especially by a hormone

Valine - an amino acid that is a constituent of most proteins. It is an essential nutrient in the diet of vertebrates.