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© 2023. Also edited by: Maria Zulema Cabail, Patrick Cadet, William Gillis, Manya Mascareno, Fernando Nieto, Jillian Nissen, Christos Noutsos and Joanne Spadaro.
1 - CELLULAR RESPIRATION

Background

Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

All living cells need energy for cellular processes, such as pumping molecules into or out of the cell, DNA duplication, synthesizing proteins, and even muscle contraction. Adenine triphosphate, or ATP, is a special molecule which provides energy in a form that cells can use for cellular processes. This molecule is also known as the cell’s energy currency and is used by all living things.

Cellular respiration is the process by which organic molecules are oxidized and the released energy is transferred to form ATP. This process is essential for cell survival. The process begins in the cytoplasm and continues in the mitochondria. Mitochondria are essential organelles in this process and contain genetic information that codes for all of the proteins needed to undergo cellular respiration. The following equation summarizes the chemical changes that occur during cellular respiration of the monosaccharide glucose when oxygen is available.

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{ATP} \\
glucose + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}
\]

There are several steps in cellular respiration to maximize the amount of energy extracted from each glucose molecule in order to make as many ATP molecules as possible. Each oxidation step cleaves off one carbon molecule. The full oxidation of a 6-carbon-glucose molecule will result in the production of 6-Carbon Dioxide molecules.

The first major step in cellular respiration is glycolysis:

\[
1 \text{ glucose} \rightarrow 2 \text{ pyruvate} + 2 \text{ ATP}
\]

What happens next depends on whether or not oxygen (O\textsubscript{2}) is available to the cells. When oxygen is available, the cell will continue on to the Krebs cycle and the electron transport chain to make up to 32 ATPs (30 in eukaryotes because 2 ATP molecules are used to shuttle pyruvate into the mitochondria).

\[
2 \text{ pyruvate} + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 30\text{ATP}
\]
Cellular respiration that uses $O_2$ as the final electron acceptor is called **aerobic respiration**. Most of the time, the cells in our bodies use aerobic respiration.

When oxygen is not available, cells use **anaerobic** processes to produce ATP. Under anaerobic conditions, many cells use a process called **fermentation** to make ATP. As shown in the figure above, there are two types of fermentation: **lactate fermentation** (in muscles) and **alcoholic fermentation** (by yeast to make bread).

Fermentation has two disadvantages compared to aerobic respiration. Fermentation produces much less ATP (only 2) than aerobic respiration (compared to 30-32 ATP), and fermentation...
produces a toxic byproduct (either lactate, which becomes lactic acid, or alcohol). However, fermentation is very useful if oxygen is not available. *For more details on cellular respiration and the mitochondria, please review the additional readings provided by your instructor.*

Use the above information to create a flow chart in the space below on cellular respiration pathways, reactants used during cellular respiration, and products forms, including waste products and total energy production. Include where in the cell each step takes place. Be thorough in the details, as this information will be used to justify your hypotheses in the experiments.
Part 1. What is yeast and what are some common uses of yeast?

Yeast is used to make bread and it can also be used to brew beer or alcohol (you can bake bread, but don’t try the latter at home; improper alcohol brewing can produce acetaldehyde and is fatal when ingested!). The yeast you buy from the supermarket has been desiccated (dried) and when placed in water with sugar, the yeast will carry out the process of cellular respiration and grow. The CO₂ bubbles formed during cellular respiration is what causes the dough to rise, giving you delicious bread! Under anaerobic conditions, yeast will carry out alcoholic fermentation (we call this ethanol in the lab).

\[
C_6H_{12}O_6 \rightarrow 2 CO_2 + 2 C_2H_5OH \text{ (Ethanol)} + 2 \text{ ATP}
\]

Part 2. GERMINATING SEEDS

In order for a dormant seed to become a plant, the plant embryo within the seed must create energy to support growth. To do this, the embryo will use its nutrient stores to carry out cellular respiration and create ATP. This ATP will then allow the embryo to continue the cell division process and grow. Seeds respond to environmental cues to stimulate growth. Some seeds need to be frozen prior to starting their metabolism while others do not. For some seeds, freezing results in damage to the embryo and may slow growth.

Objectives
1. Examine the process of cellular respiration in two ways:
   a. Using yeast, measure the products of aerobic and anaerobic respiration (CO₂ and ethanol); and
   b. Examine the effects of aerobic and anaerobic conditions on the growth of yeast by estimating the concentration of yeast cells.

2. Examine the rate of cellular respiration in germinating seeds in previously frozen and normal seeds by measuring levels of oxygen use.
**Hypotheses**

**Yeast:**
1. Which culture will produce the most CO₂? Why? Use your knowledge as evidence to back up this hypothesis.

2. Which culture will produce the most ethanol? Why? Use your knowledge as evidence to back up this hypothesis.

3. Which culture will produce the most cells? Why? Use your knowledge on cellular respiration to back up this hypothesis.

**Germinating seeds:**
1. What condition (cold-treated vs untreated) would result in a larger metabolic rate in seeds? Why?
**Materials**

Part 1:
- Yeast experiment already set up (to CO₂ gas sensor)
- Ethanol strips
- pH strips
- Beaker
- Test tubes
- Test tube rack
- Spectrophotometer
- Cuvettes

Part 2:
- Weight balance scale or digital scale
- Lab quest unit and O₂ gas sensor
- 250mL respiration chamber
- Cold-treated and untreated seeds
- Parafilm
Instructions

Part 1: Yeast

1. The yeast cultures have been created approximately 3 hours prior to the start of class. Please note the results in the table below.

<table>
<thead>
<tr>
<th>Observation (Is it cloudy or clear? How many bubbles?) + Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Control</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>B. Aerobic</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>C. Anaerobic</td>
</tr>
</tbody>
</table>

2. After the demonstration, you will now use these cultures to measure ethanol. Label 2 tubes, A (for control), B (for aerobic), and C (for anaerobic).

3. Take a small amount of each culture (~1mL) and place it into the appropriate test tube. Be sure to replace the stopper on the demo cultures.

4. Carefully open and take out the ethanol strips and the pH strips. On the opposite site of the test site, label each strip either A, B or C (for each yeast condition).
5. Briefly dip the ethanol strip into the corresponding bottle to measure the percent of ethanol. Keep the packet so that you can compare the color results to determine % ethanol. Record your results in the table below.

6. Repeat this procedure with the pH strips. Record your results in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Ethanol Color</th>
<th>% Ethanol</th>
<th>pH Color</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Aerobic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Anaerobic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. You will now use your test tubes to estimate the amount of yeast cells in each culture.

8. Turn on the spectrophotometer.

9. Using water, you will zero the unit.

10. Adjust the wavelength of the spectrophotometer to 600nm.

11. Gently swirl the yeast in your test tube. Take the yeast and place it into a cuvette.

12. Place the cuvette into the spectrophotometer with the clear sides facing the beam (look for the open square) and record the absorbance.

If the optical density of the sample is greater than 1.0, dilute the sample 1:10 with deionized water and read the optical density again (Add 9 mL of water to your 1mL culture).

**Be sure to DILUTE THE SAME NUMBER OF TIMES FOR ALL SAMPLES. Repeat the process until your reading is less than 1.0.**

Dilution: Yes or No  How many times did you dilute? ________________

<table>
<thead>
<tr>
<th></th>
<th>Abs (600nm)</th>
<th>Calculated cell density (# cells X dilution factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaerobic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
13. Calculate an approximate cell density for each sample, assuming that an OD 600 nm of 1.0 corresponds to approximately $1.3 \times 10^7$ cells / mL. Use only data where the OD 600 nm is less than 1.0 for these calculations. If you used a dilution factor, multiply your final result by the dilution factor.


14. You have now completed the yeast experiments. Turn on your sink and while the water is flowing, carefully pour the yeast cultures down the drain.
POST-LAB QUESTIONS:

1. Did the CO₂ results match your hypothesis? Why or why not?

2. Which yeast culture(s) produced more ethanol? Why do you think this happened?

3. What pH values did you measure in each culture? What does this tell you about the levels of CO₂?

4. Which yeast culture yielded the highest density in cells? Why do you think this happened?
5. Based on this yeast experiment, why is it important to test hypotheses-driven experiments in multiple ways? What would the outcome be if we used only one of these tests to study cellular respiration? Would your predictions and outcomes be more or less accurate?
Part 2: Germinating seeds
You will now measure the rate of cellular respiration in germinating seeds. There will be two sets of seeds, one that has been given a low temperature shock (frozen) while the other set has not been given any treatment. The germinating seeds use oxygen to carry out their metabolism (cellular respiration) to multiply the number of cells in the embryo found within the seed. You will examine which condition produces that largest effect in metabolism (cellular respiration) in the treated vs untreated seeds by measuring levels of O₂ consumed by the germinating seeds.

1. Using a balance scale or digital scale, measure an equal weight of cold-treated and non-treated seeds for this experiment. Use ~15-25 seeds.

2. Take 2 respiration chambers and label one with A (cold-treated) and the other with B (non-treated).

3. Place the O₂ gas sensor over the respiration chamber. Wrap parafilm around the mouth of the chamber and the O₂ gas sensor to seal the unit and prevent leakage of gases.

4. Plug in the O₂ gas sensor to the lab quest unit.

5. You will now take O₂ measurements every 2 minutes over the course of 10 minutes. Fill in your readings in the table below.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Cold-treated</th>
<th>Non-treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Using a graphing program (e.g. excel), you will now plot your data using a linear function. The x-axis is the time and the y-axis are your measurements. See if you can replicate the rate provided by the Vernier Probe.
POST-LAB QUESTIONS:

1. Which seed had the faster metabolism? Why do you think this happened?

2. How is this experiment important for farmers in the real world?
2 – PHOTOSYNTHESIS

Background

Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

Photosynthesis is the process by which certain living organisms can turn the sun’s radiant energy into chemical energy. This chemical energy is then used to produce organic molecules such as carbohydrates from carbon dioxide. While the process of cellular respiration breaks down organic molecules to produce chemical energy in the form of ATP, photosynthesis is the exact opposite in using chemical energy to build up organic carbon molecules. Organisms that can produce their own organic compounds (food) using the energy from the sun are called photoautotrophs and includes plants and certain bacteria called cyanobacteria

*FIGURE 1.* The cycle of cellular respiration and photosynthesis.
The complex chemical reaction of photosynthesis is described by the equation below:

\[
6\text{CO}_2 + 6\text{H}_2\text{O} \overset{\text{Sunlight}}{\longrightarrow} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

**Carbon dioxide**  **Water**  **Sugar**  **Oxygen**

*FIGURE 2.* The photosynthesis equation.

Photosynthesis in plants takes place on a cellular level. Within plant cells, there are organelles called **chloroplasts**. Inside of chloroplasts are stacks of circular structures called **thylakoids**. The thylakoids themselves are sitting in a space inside of the chloroplasts called the **stroma**. The stroma houses all of the enzymes needed to convert CO\(_2\) into sugar molecules in the **Calvin Cycle**, or the **light-independent reactions**. The **thylakoid membrane** divides the outside of the thylakoids from the inside of the thylakoid. Embedded within the thylakoid membrane are **pigment molecules** responsible for absorbing light energy. These pigment molecules include **chlorophyll a**, **chlorophyll b**, and **carotenoids** that make up a larger complex of proteins called **photosystems**. While the chlorophyll within photosystem I and photosystem II absorb light energy, this energy is then used to extract electrons from water molecules that are eventually used to produce NADPH and FADH\(_2\). When water is split, the remaining protons (H\(^+\)) are used to produce a proton gradient to power ATP synthase to produce ATP. The remaining oxygen (O) molecules will combine to form atmospheric oxygen (O\(_2\)) as a waste product. This process makes up the first part of photosynthesis called the **light-dependent reactions**. The second part of photosynthesis utilizes these energy carrying molecules (NADPH, FADH\(_2\) and ATP) to catalyze the **carbon fixation** process, or the **light-independent reaction (the Calvin Cycle)**. This process uses 6 molecules of CO\(_2\) to build the basic sugar unit, which can then be converted to carbohydrates.
FIGURE 3. The structure of chloroplasts.

After completing the background reading on your Labxchange.org account, create a flow chart in the space below on the process of photosynthesis, including the reactants used and the products formed. Draw where photosynthesis takes place. Be sure to use the underlined vocabulary above.
Objectives
1. Determine the photosynthesis rate of a plant as a function of distance.
2. Determine the absorption spectra of different photopigments.
3. Examine the number of chloroplasts in different plant samples.

Hypotheses
1. How does light intensity affect photosynthesis rates? Which condition will yield the greatest amount of O$_2$ product (and use the most CO$_2$)? Why?

2. What do you expect the absorption spectra of chlorophyll or carotenoids to look like? Why?

3. How does the number of chlorophylls differ between different plant samples and parts of the plant? Where do you expect to see the most chlorophyll? Where do you expect to see the least? Why?
Materials

Part 1:
- Lab quest unit and O₂ gas sensor
- Spinach leaves (or whatever is assigned by your instructor)
- Light source
- 1 Large tank of water (heat filter)
- 2 Respiration Chambers
- 1 Meter stick

Part 2:
- 1 Spectrophotometer
- 2 Cuvettes (ask instructor if this is needed)
- 1 Sample of photopigments
- 1 Sample of pure petroleum (Blank)

Part 3:
- Light microscope
- Plant samples
Instructions:

Part 1: Rate of Photosynthesis. The experimental setup should look like the following picture:

Figure 4. Setup for photosynthesis experiment.

1. Take a handful of spinach leaves and make sure that the leaves are dry. Moisture on the leaves will affect O₂ measurements.

2. Take a respiration chamber and place several pieces of spinach leaves into it.

3. Place the O₂ gas sensor on the respiration chamber.

4. Seal the probe onto the chamber with parafilm. If you do not, you will risk gas exchange with the room air.

5. Plug the gas sensor line into the Lab quest unit.

6. Repeat steps 1-7 with an empty respiration chamber as your control.

7. Wait until the % O₂ on the lab quest unit begins to increase for the plant chamber (this shows that photosynthesis is occurring and that your chamber is sealed tightly). Also check that the % O₂ from the control chamber is steady. This may take up to 10 minutes.

8. Place the large tank of water in between the light source and the plant (see Figure 4 above).

9. Using the meter stick, you will place both the plant tube and the empty tube at the distances outlined in the chart below. Start with 25 cm. After you have completed your measurements, you will move to 50 cm.

10. You will now proceed to take measurements of % O₂ production every 2 minutes over the course of 10 minutes for each distance. Fill in your values in the table below.
11. When you are done with the experiment, you will use a graphing program (such as excel) to plot the data. The x-axis is the time and the y-axis is your measurement. You must fit to a linear plot for each distance and determine the slope of the line. The slope will tell you the rate of the reaction for each distance. (Hint: you can create one graph for all 5 distances or 1 separate graph for each distance)

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty tube</td>
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<td></td>
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<tr>
<td>Plant tube</td>
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<td>50</td>
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<tr>
<td>Empty tube</td>
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<tr>
<td>Plant tube</td>
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<td>75</td>
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<td>Empty tube</td>
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<tr>
<td>Plant tube</td>
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<td>100</td>
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<td>Empty tube</td>
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<tr>
<td>Plant tube</td>
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<tr>
<td>125</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Empty tube</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Plant tube</td>
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</tr>
</tbody>
</table>
POST-LAB QUESTIONS:

1. What is the purpose of the tube without a plant sample?

2. Why is it important to have a large tank of water in between the light source and the plant sample?

3. Based on your graph and the calculated slope, what is your conclusion about the rate of respiration as a function of distance to the light source?
Part 2: Measuring absorption spectra.

1. Plug in and turn on your spectrophotometer. Wait for it to warm up.

2. Using the dial, bring the wavelength to the first measurement in the table below (400nm).

3. Carefully transfer petroleum ether into a cuvette. Place the cuvette into a spectrophotometer and use it to zero / blank the machine.

*NOTE: ask the instructor if you should be removing the samples. Sometimes the samples are already prefilled for you and you can place the glass tubes directly into the spectrophotometer.

4. Once the machine has completed its cycle, you should see a measurement of 0.0. If the reading is higher or lower than 0.0, press the zero/blank again. When the cycle is complete, remove the cuvette with the petroleum ether.

5. Take a new cuvette and add in the photopigment sample that has been assigned to you.

6. Place the photopigment sample in the spectrophotometer.

7. You will now measure the absorbance of your sample across the visible spectrum. Adjust the spectrophotometer to the following wavelengths in the table (next page). You will record your output readings in the table. Also note the color that each wavelength corresponds to.

*NOTE: If the readings are bouncing between numbers, reperform the blank / zero your unit with the petroleum ether and take the reading again.

8. After you have completed your experiment, you will graph your results. The x-axis is the wavelength, and the y-axis is the absorption.
<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Absorbance (abs)</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>420</td>
<td></td>
<td></td>
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<tr>
<td>440</td>
<td></td>
<td></td>
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<tr>
<td>460</td>
<td></td>
<td></td>
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<tr>
<td>480</td>
<td></td>
<td></td>
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<tr>
<td>500</td>
<td></td>
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<tr>
<td>520</td>
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<td>540</td>
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<td>560</td>
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<td>580</td>
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<td>600</td>
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<td>620</td>
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<td>640</td>
<td></td>
<td></td>
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<tr>
<td>660</td>
<td></td>
<td></td>
</tr>
<tr>
<td>680</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
POST-LAB QUESTIONS:

1. What is the purpose of the pure petroleum? Why do we use this instead of water?

2. What do the wavelengths on the spectrophotometer correspond to?

3. What does the absorbance value at each wavelength correspond to?

4. Based on the absorbance spectra, what type of photopigment do you most likely have?

5. Which wavelengths of light produce the highest rates of photosynthesis? The lowest?
Part 3: Chloroplast counting

1. Take three different samples of plants that are available to you. Be sure that one of the samples is a stem. If the tissue is thick, try to cut a thin piece.

2. Place your sample of plant tissue on a microscope slide.

3. Add a drop of water to the slide.

4. Add a coverslip.

5. Using a microscope, visualize a single plant cell and count the number of chloroplasts you see (they should be green and round). Record your counts in the table below. Repeat this count in two other cells. Each sample should have 3 cell counts.

6. Calculate the average number of chloroplasts for each sample and the standard deviation for each count (See Appendix for calculation).

<table>
<thead>
<tr>
<th>Sample (type of plant and tissue)</th>
<th>Chloroplast count</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Average</td>
<td></td>
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<tr>
<td>SD</td>
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<td>1</td>
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<td>2</td>
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<td>3</td>
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<tr>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td></td>
</tr>
</tbody>
</table>
POST-LAB QUESTIONS:

1. Why does the density of chloroplasts vary between different plants?

2. Why does the density of chloroplasts vary between different plant parts?
3 – PLANT STRUCTURES

Background

Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

Plant cells have special organelles with specialized function, such as chloroplasts for photosynthesis, vacuoles for water storage and turgidity, and a cell wall for strength. The vacuoles, when filled with water and ions, push outward towards the cell wall to create a “turgid”, or rigid cell, while the cell wall contains and prevents the plant cell from bursting. In many plants, there are two layers of cell walls, primary cell wall and secondary cell wall, that reinforce the structure of the plant cell and provide additional support. There are two major meristematic tissues that give rise to all plant tissue. The three main plant tissue are: Vascular, Ground and Dermal tissue.

Meristematic Tissue: there are two types of plant stem cells that play a role in primary and secondary plant growth. Primary plant growth is performed by the apical meristem that is found at the tip of the shoot, and the root meristem that is found in the roots. Secondary growth occurs in eudicots and is involved in forming woody stems. Secondary growth is performed by the lateral meristem and includes the vascular cambium and the cork cambium. The vascular cambium can be found in between the vascular tissue bundles while the cork cambium is found in the outer wall of wood and eventually forms the bark (Figure 1).

FIGURE 1. Image from Biology 2e by OpenStax is licensed under CC BY 4.0. In woody plants (eudicots), primary growth is followed by secondary growth.
Vascular Tissue (Figure 2): there are two types of vascular tissue. Xylem is responsible for transporting water and inorganic ions from the roots to the shoots of a plant while phloem is responsible for bidirectionally transporting nutrients and water throughout the plant.

Ground Tissue (Figure 3): primarily involved in the structural support of a plant and acts as nutrient storage. The three types of cells that make up ground tissue are collenchyma (structural support), sclerenchyma (structural support), and parenchyma (nutrient storage).
**Dermal Tissue (Figure 4):** forms the outer covering of the plant. The epidermal cells of plants can form specialized cells, such as trichomes, guard cells, and root hairs.

![Dermal Tissue](image)

**FIGURE 4.** *Image from Biology 2e, provided by OpenStax is licensed under CC BY 4.0.* Guard cells form stomata pores on the underside of leaves. (credit a: modification of work by Louisa Howard, Rippel Electron Microscope Facility, Dartmouth College; credit b: modification of work by June Kwak, University of Maryland; scale-bar data from Matt Russell)

The cells from these 4 tissue types make up all plant structures to create the root and shoot system. The roots are usually found in soil and absorbs minerals and water. Roots usually have root hairs to increase the surface area for water and mineral absorption. The water and minerals are transported to the shoot system through the xylem. There are several types of roots, but two main ones of focus in the lab are tap roots and fibrous roots.

The shoot system includes stems, leaves, and flowers. At the ends of shoots and roots, you will find the apical meristem and the root meristem. The leaves of plants are usually thin to allow sunlight to penetrate into the cells of the leaves. The plant cells of leaves generally have abundant levels of chloroplasts. The underside of plant leaves has guard cells that form stoma (stomata – plural).

There are two types of angiosperm plants, monocots and eudicots. The anatomical structure of the plant tissue within monocots and eudicots differs. By examining the structure of an angiosperm, you can differentiate between a monocot and a eudicot. For example, tap roots are generally found in eudicot plants while fibrous roots are found in monocot plants. Other differences include the vein patterns on the leaves, flower petal number, and the arrangement of vascular tissue in the stem, roots, and leaves. Leaf veins in monocots are parallel while they are branched in eudicots. Flower petal number in monocots are in multiples of 3 while eudicots are in multiples of 4 or 5.
Can you guess the difference in arrangement of the vascular tissue in roots, stems and leaves of monocots and eudicots?

**Objectives**
1. Examine plant structures and learn about the anatomy and physiology of plants.
2. Distinguish the basic cell and tissue types in plants and the function of each of these cells and tissues.
3. Based on the anatomical characteristic of plants, understand the differences in structure between a monocot and a eudicot plant.

**Hypotheses**
1. How does the structure of plant cells support its specific function? What do you expect the cells from dermis, ground, vascular and meristematic tissue to look like?

2. Which plant is the monocot and eudicot? What evidence do you have to support this?
Materials

- *Two flowering plants (available during the Plant Reproduction lab)
- African violet (or other similar plant; trichomes)
- Zebrina leaf (or other similar plant; chloroplast)
- Celery (in blue dye): DEMO
- Potato
- Onion
- IK2I
- Razor blades
- Glass slides
- Wood examples
- Root examples

Slides of (Subject to change: check with your Instructor):

- Persimmon (cell wall)
- Animal cell slide
- Eudicot + monocot cross section of root
  - Ranunculus mature root
  - Ranunculus young root
  - Corn prop root
- Eudicot + monocot cross section of stem
  - Tilia stem young
  - Tilia stem old
  - Ranunculus stem
  - Corn stem
- Eudicot + monocot cross section of leaf
  - Coleus leaf
  - Corn leaf
  - Lilac leaf
- Root tip
  - Radish root tip
  - Alium root tip
- Apical meristem: coleus stem tip
Instructions

1. Examine the prepared slide of the persimmon for an example of a cell wall. Also look at a prepared slide of an animal cell. Can you see the difference in cell structure between the two? Describe + draw what you see.

2. Examine the prepared slides on the cross sections of a monocot and eudicot root. How are the vascular bundles arranged? Describe + draw what you see in the space below.

3. Examine the prepared slides on the cross sections of a monocot and eudicot stem. How are the vascular bundles arranged? Describe + draw what you see in the space below.
4. Examine the prepared slides on the cross sections of a monocot and eudicot leaf. How are the vascular bundles arranged? Describe + draw what you see in the space below.

5. Examine the prepared slides of the apical meristem and root meristem. Describe + draw what you see. Can you see root hairs?

6. Find a tap root and a fibrous root. Describe + draw what you see.
7. Take a glass slide and prepare a small sample of the African violet. Using a dissecting microscope, see if you can find the trichomes. Describe what you see in the space below.

8. Take a glass slide and prepare a small sample of a leaf from the Zebrina plant. Place the leaf bottom side up and add a small drop of water. Using a microscope, see if you can find the guard cells and stomata. Describe what you see in the space below.

9. Take a razor blade and very carefully cut a thin piece of the potato and place it on a glass slide. Examine the potato under the microscope. Describe and draw what you see in the space below.
10. Take a drop of IK₂I and place it on the potato and view under the microscope again. What do you see? (NOTE: this will stain starches brown-black) Describe and draw what you see in the space below. What type of plant cell stores the starch in a potato?

11. Cut a thin piece of the onion and place it on a slide. Describe and draw what you see in the

12. Go up to the front of the classroom and find the piece of wood trunk. Examine the circles. What tissue types do they represent?
13. Go up to the front of the classroom and find the celery sitting in the blue dye. Closely examine and stem and the leaves of the celery. What do you see? Why do you think this happened?

14. You must start this section with the plant reproduction lab. Take your two plant samples and physically examine the leaves, stem, and flowers. What differences can you see between the two plants?
**POST-LAB QUESTIONS:**

Using the materials from this week and next week’s lab, fill in the table below with the differences in structure between monocot and eudicot plants.

<table>
<thead>
<tr>
<th></th>
<th>Monocots</th>
<th>Eudicots</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roots</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Roots</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vascular</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>tissue</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stem</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(vascular</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>tissue)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaves</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(veins)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaves</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(vascular</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>tissue)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong># Flower</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>petals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Seeds:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cotyledons</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4 – PLANT REPRODUCTION

Background: prelab reading
Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

FLOWERS & THEIR REPRODUCTIVE PARTS:

Angiosperms are plants that form flowers and later fruit for reproduction. Flowers are modified leaves organized around a central stalk. All flowers contain the same structures: sepals, petals, carpels (gynoecium), and stamens (androecium) (Figure 1). The sepals form a whorl or ring-like structure at the base of the stalk that surrounds a flower bud. Petals are located inside this whorl of sepals and are often colorful to attract pollinators. Flowers pollinated by wind are usually small, feathery, and visually inconspicuous. The sexual organs (carpels and stamens) of a plant are usually located at the very center of the flower.
The style, stigma, and ovary compose the female reproductive organ and is collectively called the gynoecium or carpel. Within the ovary are the ovule(s), which are small sacs that contain the female reproductive cells. Within the ovule, the megaspores undergo a process of meiosis (2n à n chromosomes) and mitosis to form the female gametophyte (dominant megaspore). The female gametophyte (egg) is protected by the wall of the ovule and the carpel. A long, thin structure called a style leads from the sticky stigma, where pollen is deposited, to the ovary. The ovary houses one or more ovules, each of which will develop into a seed upon fertilization.

The male reproductive organ consist of the stamens (androecium). The stamens are long stalk-like structures that surround the central carpel. Stamens are composed of two parts: a thin stalk called a filament and a small sac-like structure called the anther. The anther contains male reproductive cells called microspores, which undergo meiosis (2n à n chromosomes) followed by mitosis to form pollen grains that contain sperm cells.

When a pollen grain lands on the stigma, a pollen tube forms from the pollen to deposit the sperm cell into the ovule. Postfertilization, the embryo within the ovule forms the seed. As the seed develops, the walls of the ovary thicken and form the fruit.

**PAUSE to complete the following:**

*In the space provided below, draw and label the parts of a flower:*
In the space below, draw and label the male and female reproductive organs of a flower carpel (gynoecium) and stamens (androecium):
The ovule contains the megasporangium that is protected by the integument and the ovary wall. Within each megasporangium, a megasporocyte undergoes meiosis, generating four megaspores—three small and one large. Only the large megaspore survives. The megaspore divides three times to form eight haploid cells. 1 is the dominant megaspore egg; 2 fuse to form a...
2n (diploid) **polar nucleus**; three cells form antipodals, and the two cells closest to the egg become the **synergids**.

The anthers contain the microsporocyte that undergoes meiosis to form 4 haploid cells. Each cell then undergoes one round of mitosis to generate a **microspore** with two haploid cells (1 more round of mitosis) and a tube cell.

Pollen brought to the stigma will form a **pollen tube** that will elongate until it enters the ovary. From here, it will enter the **micropyle**, which is an opening in the integument of the ovule.

A double fertilization event then occurs. One sperm and the egg combine, forming a diploid **zygote**—the future embryo. The other sperm fuses with the diploid (2n chromosomes) polar nuclei, forming a triploid (3n chromosomes) cell that will develop into the **endosperm**, which is tissue that serves as a food reserve. The zygote develops into an embryo with a radicle, or small root, and one (monocot) or two (eudicot) leaf-like organs called **cotyledons**. This difference in the number of embryonic leaves is one of the identifying hallmarks for the two major groups of angiosperms: the monocots and the eudicots. Seed food reserves are stored outside the embryo, in the form of complex carbohydrates, lipids or proteins. The cotyledons transfers nutrients from the endosperm to the developing embryo. The outer shell of the seed is formed from a structure called the **integument**, that prevents dessication of the internal embryo and the endosperm. The ovary itself will develop into the fruit.

**PAUSE to complete the following:**

*In the space provided below, create a flow chart of the process of male and female gametophyte formation:*
Objectives
1. Understand the reproductive cycle in an angiosperm and how male and female gametophytes are produced.
2. Observe the structures of an angiosperm via dissection of a flower and using microscopy.
3. Distinguish the characteristics that are common to monocots and eudicots.

Hypotheses
1. From quickly looking at the two plant samples, can you guess which one is the monocot and eudicot? What evidence do you have to support this?

2. What do you think is the function of each of these plant parts:
   a. Petals
   b. Sepals
   c. Stamens
   d. Pistil / carpal


**Materials**

- Short movie “Sexual Encounters of the Floral Kind”, or other video (Instructor assigned)
- 2 different plant species
- Scalpel or razor blade
- Glass slides
- Examples of seeds: Corn vs Bean
- Examples of fruit (there may be apples, peach, orange, bell pepper, tomato, etc)

Slides of (Subject to change: check with your Instructor):

- Zea Mays kernel (corn)
- Bean
- Flower bud
- Lily Anther
- Lily megasporocyte (ovary)
- Lily pollen tube
Instructions

1. Take your flower samples and note the physical characteristics of each plant. Fill in the table below of the visible characteristics that you observe.

<table>
<thead>
<tr>
<th></th>
<th>Plant 1 Name:</th>
<th>Plant 2 Name:</th>
</tr>
</thead>
<tbody>
<tr>
<td># of petals</td>
<td></td>
<td></td>
</tr>
<tr>
<td># of sepals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf vein shape</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Final Conclusion on type of plant</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Add a drop of water onto a glass slide. Take an anther from your assigned flower and gently rub it onto the drop of water. Carefully view the slide under the microscope. Describe and draw what you see from each plant in the space below.

3. Carefully cut the ovary from each plant in half. What do you see inside? How many ovules are found inside? What does each ovule correspond to?
4. There are several examples of fruits for this lab. Examine some of these fruits and fill in the table below.

<table>
<thead>
<tr>
<th>Name of fruit</th>
<th>Describe the fruit</th>
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<tbody>
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</tbody>
</table>

What does each part of the fruit correspond to in the flower?

a. Seed:

b. Flesh of fruit:

5. Take a **bean** seed and cut it in half. Can you distinguish the endosperm from the embryo? Do the same to a corn seed. Fill in the table below with your observations.

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Bean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape of seed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(describe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td># of cotyledons</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. For the corn seed, place one drop of I$_2$KI on each side to stain the endosperm so that you can distinguish the embryo’s food source from the embryo. Write + draw your observations below.

7. Use the remaining time to examine the pre-prepared microscope slides of the following and draw + describe what you see:
   a. Anther
   b. Pollen tube
   c. Ovary/embryo.
POST-LAB QUESTIONS:

1. What is the process of male and female gametophyte production in angiosperm plants?

2. How do differences in the structure of floral parts result in evolutionary favorability (video)?

3. What are the differences between the bean and corn seeds?
5 – POPULATIONS

Background: prelab reading
Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

A population is an important functional unit in biology, defined as groups of organisms that are genetically and spatially distinct from other such groups. It is also the fundamental unit of evolution. Populations are dynamic, they grow, decline, colonize new populations, and go extinct. Understanding how and why populations change over time is critical to such wide-ranging practical issues as pest control, endangered species protection, and even human population growth.

In order to study populations, scientists must be able to track living things over time and estimate their size numbers. In doing so, scientists can determine correlations and factors concerning population growth within a species. An example of this is human population growth in different environments. Human lifespan in the 1800’s compared to the present time was a lot shorter and was affected by many extrinsic (environmental) factors.

In the absence of extrinsic and intrinsic factors, populations can grow exponentially. However, real life is filled with obstacles and thus as competition for resources increase, the exponential growth is limited. This type of limited logistic growth can be described by the following equation:

\[
\frac{dN}{dt} = rN \left( K - N \right) / K
\]

Where:
\( N \) = population size
\( r \) = intrinsic growth rate
\( K \) = carrying capacity
Objectives
1. You will estimate population growth using an online simulator.
2. You will estimate population size of moving organisms in a simulated lab setting.

Hypotheses
1. How do intrinsic (organisms internal biological processes) and extrinsic (environmental) factors affect population growth?
2. How do initial values in the capture and mark technique affect population size estimates?
Materials

Part 1:
- Computer for simulation

Part 2:
- 2 different colored beads
- Containers with lids
**Part 1: Population growth Simulation**

The first experiment will use a computational simulation of population growth under a carrying capacity.

Launch the simulation of population growth here:
[http://virtualbiologylab.org/NetWebHTML_FilesJan2016/LogisticGrowthModel.html](http://virtualbiologylab.org/NetWebHTML_FilesJan2016/LogisticGrowthModel.html)

To start the simulation, hit “Go”. To stop, hit “Go” again. In your trials, run the simulation at least until the first graph “Population Size” reaches stability, which is when the curve becomes flat (shows a plateau). After you adjust the parameters, hit “Setup” to reset the results and the simulation will be ready to begin. You can adjust the speed bar to let the simulation run faster.

You can separately change three parameters for the red and blue populations. “N-Zero” is the population size (N) at time 0. “K” and “r” are the parameters carrying capacity (K), and intrinsic growth rate (r) from the logistic regression model, respectively. After running a simulation, three plots will be reported at the bottom. In all the graphs the red and blue populations are represented by traces of their respective colors. “Population Size” is a plot of overall population sizes over time. “Population Growth Rate” is the growth rate of the overall population (dN/d10-ticks) for a given population size. “Per Capita Growth Rate” is the amount by which a particular individual is changing the population for a given population size.

Complete the following three trials and answer the questions for each simulation.

1. **Simulation 1.** Set N-Zero = 5 and r =1 in both populations. Adjust “K” to be 1000 for the red population and 500 for the blue populations. Hit “Setup” and “Go”.

2. In simulation 1, which population had a higher population size (N, left figure) at the end?

3. In simulation 1, which parameter of the logistic model controls the maximum population size?

4. **Simulation 2:** Set r =1 and K = 1000 for both populations. Adjust “N-Zero” to be 10 in the red population and 100 in the blue population. Hit “Setup” and “Go”.

5. In simulation 2, what is affected by changing N-Zero?
6. In simulation 2, why is the relationship between population growth rate and population size (the center graph) the same?

7. In simulation 2: looking at the center plot (“Population Growth Rate”), when is the population growth rate highest?

8. In simulation 2: Looking at the center plot (“Population Growth Rate”), when population size is getting very close to the carrying capacity, what happens to the population growth rate?

9. Based on the logistic regression model, what would happen if the population size is higher than the carrying capacity?

10. Simulation 3: Set up the simulation to test your prediction from the previous question.

11. Did your simulation support your prediction from question 9? Why or why not?
Part 2: Mark and recapture

This second experiment will simulate the Mark and Recapture method in a lab setting. This method allows you to estimate a moving population size. The first step is to capture and mark a sample of individuals. Marked individuals are immediately released as close as possible to the collection site. After giving the animals time to recover and to mix randomly with the whole population, a second sample of the organisms is collected. The assumption behind mark-recapture methods is that the proportion of marked individuals recaptured in the second sample represents the proportion of marked individuals in the population as a whole. The size of the population can then be estimated from the number of marked individuals recaptured on the second day using the following equation:

Lincoln-Peterson Index:

\[ N = \frac{M \cdot S}{R} \]

- \( N \) = population size estimate
- \( M \) = marked individuals released
- \( S \) = size of second sample
- \( R \) = marked animals recaptured

1. You will split up your different colored beads using the following table for each trial. Start with the trial 1, do not move on to trial 2 and trial 3 until you have completed the next steps.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Bead color 1 (population size)</th>
<th>Bead color 2 (MARKED (M) individuals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>175</td>
<td>25</td>
</tr>
<tr>
<td>Trial 2</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Trial 3</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

2. Add the beads from trial 1 into a container with a lid. Close the lid and shake the beads.

3. Blindly grab out 40 beads (S) and record the number of MARKED (bead color 2) that you grabbed. These beads from your second trapping are the RECAPTURED individuals. Place all the beads back and repeat this for a total of 3x’s and fill in the table below.
4. You will now blindly collect 80 beads (S) and record the number of MARKED (bead color 2) that you grabbed. These beads from your second trapping are the RECAPTURED individuals. Place all the beads back and repeat this for a total of 3x’s and fill in the table below.

5. Repeat the experiment for trials 2 and 3 and fill in the information in the table below (this table is a compilation for ALL TRIALS):

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Averaged R</th>
<th>Calculated N</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S = 40, M = 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S = 80, M = 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S = 40, M = 50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S = 80, M = 50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S = 40, M = 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S = 80, M = 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Use the Lincoln-Peterson Index equation to estimate your population size. Add the values to the table above.

7. Calculate the % error for your estimates using the following equation and add it to the table above:

\[
\% \text{ Error} = \frac{(Estimated \ N - Actual \ N)}{Actual \ N} \times 100
\]
POST-LAB QUESTIONS:

1. What is the relationship between the initial captured sample (M), the recapture sample size (S) and your % error?

2. If you were conducting this experiment to determine the # of chipmunks at our college, how could you ensure a more accurate estimate of population with a lower % error?
6 – ANIMAL PHYLA

Background: Pre-lab reading
Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

The animal kingdom is composed of organisms which are not capable of manufacturing their own food and dependent on the producers (photosynthetic organisms) for their supply of energy. It is a very diverse group consisting of animals of different size, shape, and form, and from very simple to extremely complex, organisms. All the members of the animal kingdom are multicellular with most having specialized cells that are differentiated and organized into complex tissues, organs, and organ systems. This results in an increased efficiency to carry out basic processes and helps animals to adapt to different types of evolutionary stresses. Animals have been thought to have originated from colonial flagellated protists and have the following characteristics which distinguish them from other living beings:

1. Animals are multicellular and eukaryotic organisms.
2. Most animals are bilaterally symmetrical.
3. Animals are heterotrophic with extracellular digestion.
4. Animal cells have more mitochondria and do not have cell walls and chloroplasts.
5. Animals have greater degree of specialization of cells and differentiation into tissues, organs, and organ systems.
6. Most members of the animal kingdom are motile at some stage of their life cycle (e.g., larval stages of some sedentary animals)
7. Most animals have a complex developmental stage (embryonic or larval stage).
8. Most animals have excitable tissues that allow coordinated movements.
9. Most animals reproduce sexually with predominant diploid phase in the life cycle.
10. Animals share similar genes for rRNA and embryonic development regulation.
11. Most animals exhibit social and emotional behaviors which are essential for their survival.

Currently, there are 35 phyla under the kingdom Animalia but the following 9 are most extensively studied:

- Phylum Porifera (Sponges)
- Phylum Coelenterata or Cnidaria (Hydra)
- Phylum Platyhelminthes (Flatworms)
- Phylum Nemathelminthes (Roundworms)
- Phylum Annelida (Earthworms and Leeches)
- Phylum Arthropoda (Insects)
- Phylum Mollusca (Snails)
- Phylum Echinodermata (Sea Stars)
- Phylum Chordata (Humans) ---------------------> VERTEBRATES

INVERTEBRATES
These phyla have been created on the basis of the following features: **the animal tissues, symmetry, embryonic development, presence or absence of body cavity (coelom)** and molecular characteristics (nucleotide or amino acid sequences). The animal exhibiting similar features or characteristics are grouped in one phylum. The simplest way of classifying animals is as invertebrates and vertebrates. Vertebrates are the animals that have a backbone and make a small fraction of the animals in the Kingdom Animalia. These include most familiar animals like frog, fish, reptiles, birds, and mammals. Invertebrates lack the backbone and include most of the animals of the Kingdom Animalia.

In this lab, we will be concentrating on three phyla of the invertebrates: *Porifera, Cnidaria and Platyhelminthes*.

**Phylum Porifera:**
Phylum Porifera is a group of around 9,000 simplest and most primitive multicellular animals with no tissues or internal organs and organ systems. The word *Porifera* means ‘the one with pores’ or ‘pore-bearing’. The members of this phylum have spongy appearance and are therefore also called sponges.

All the members of the phylum *Porifera* are aquatic, mostly marine but some are found in freshwater as well. The sponges are sessile or sedentary but do have free-swimming larval stages in their life cycle. The sponges lack a definitive symmetry and therefore have an [asymmetrical body plan](#). These can grow as crusts, globular aggregations, or form vase like structures that are often brightly colored due to the presence of pigmented endosymbiotic dinoflagellates, algae and cyanobacteria present in the surface cells. Most of the sponges are colonial and the colonies are formed by the process of budding (asexual reproduction).

The body of sponges is a network of pores and canals (passageways) and it lacks a mouth. One end (**base**) of the body is closed and attached to the substratum while the other end has an opening called **osculum** which acts as an exit for water that enters the body of the sponge through numerous pores. The water carries the food particles and oxygen and enters the body cavity called the **spongocoel**.
- **Cell types**: Although sponges have a few cell types, but they are specialized to carry out certain functions and can change form and function if needed. Starting from the outside to the inside, the following cells and structures can be seen in body wall of sponges:
  1. **Pinacoderm**: The pinacoderm cells are found on the outermost surface of the sponge. These are thin, flat cells loosely held together and have no cell junctions.
  2. **Porocytes**: These are tubular or cylindrical cells and form the pores by creating a fold in the body wall of the sponge. Water current enters the body of the sponge through these pores.
  3. **Mesohyl**: Mesohyl is the gel like matrix lying beneath the pinacoderm. It contains freely moving amoeboid cells or amoebocytes that receive food particles from the choanocytes for digestion. Amoebocytes can differentiate into sclerocytes to secrete spicules, spongocytes to secrete spongín and collencytes to secrete collagen.
  4. **Choanocytes**: Are cells that function in respiration and excretion. The free end of these cells has a moving flagellum that creates a water current through the porocytes. This directs water into the spongocoel.
Feeding and Digestion: Sponges are filter feeders as they capture the food from the water current passing through the spongocoel. The food particles are captured by the mucus secreted by the choanocytes. Digestion is completely intracellular, and the undigested matter leaves the spongocoel through the osculum with outgoing water current.

Respiration and Excretion: The water current created by the choanocytes brings dissolved oxygen into the spongocoel. Oxygen diffuses into the cells lining the spongocoel and metabolic wastes like ammonia and carbon dioxide diffuse from the cells into the exiting water current.

Reproduction and Development: Sponges reproduce both asexually and sexually.

- Asexual Reproduction: Fragmentation and budding are two modes of asexual reproduction in sponges.
- Sexual Reproduction: Most sponges are hermaphroditic and produce sperm and egg at different times to prevent self-fertilization. Sperm are produced by the choanocytes which undergo meiosis whereas the eggs are produced by the amoebocytes. Sperm are released as a cloud and leave the body of the sponge with the exiting water current through the osculum and enter the body of another sponge through the feeding water current. These are captured by the choanocytes and transferred to the eggs in the mesohyl to bring about fertilization to produce a free-swimming larva. It stays motile for a few days and eventually settles down to develop into an adult.
Phylum Cnidaria:
The Phylum Cnidaria includes around 10,000 invertebrate species of soft-body and stinging animals such as jellyfish, sea anemone and corals. The members of the phylum are mostly marine and colonial with very few freshwater species. Cnidarians exhibit radial symmetry, are diploblastic (tissues derived from two embryonic germ layers; endoderm and ectoderm), have two adult forms (polyp and medusa) and a larval stage. These animals have a digestive system for extracellular digestion. For the first time in animal kingdom, the development of simple hairnet like nervous system is seen in cnidarians but there are no nerve tracts or brain. The members of the phylum have unique stinging cells called cnidocytes which contain nematocysts (stingers) which are used to capture the prey.

Cell and Tissues: The Cnidarians shows slightly more organized body plans and presence of tissues but no organs. The epidermis is the outer layer and has mucus producing cells and cells that help the animal capture the prey. The gastrodermis is the inner layer that lines the digestive system. At the center, enclosed by these layers, is the hollow central cavity called the gastrovascular cavity.

Body Plans: Cnidarians exhibit three basic body forms (polymorphic), polyp, medusa, and a larval stage.
- Polyp: It is the sessile (sedentary) body form that is shaped like a hollow cylinder with one opening at the top with the other end attached to the substratum. The open end has mouth with a ring of tentacles around it and leads into the gastrovascular cavity.
• **Medusa**: Also called a jellyfish, it is the free-swimming body form of the cnidarians. Medusa body form is shaped like an umbrella with a mouth called manubrium in the center and tentacles on the periphery. Just like polyp, mouth in the medusa leads into the gastrovascular cavity.

• **Larva**: The free-swimming larva of the jellyfish is formed as a result of sexual reproduction.

**Feeding and Digestion**:
Cnidarians are carnivorous predators and catch their prey from drifting water with the help of tentacles. The tentacles contain the stinging cells, **cnidocytes**, which in turn have a capsule called **nematocyst**. Cnidarians discharge this nematocyst to sting the prey to immobilize it. The tentacles then grab the prey and move it into the mouth and gastrovascular cavity where extracellular digestion takes place with the help of the digestive enzymes secreted by the gastrodermis cells lining the gastrovascular cavity. Since cnidarians have only one opening, anything that is not digested is regurgitated through the mouth.
**Respiration and Excretion:** Since cnidarians lack a circulatory system, oxygen and carbon dioxide exchange takes place by diffusion directly between cells in the epidermis and water in the environment, and between cells in the gastrodermis with water in the gastrovascular cavity. Similarly, nitrogenous wastes exit the body via diffusion from the cells and the water outside the animal or in the gastrovascular cavity.

**Response System:** The cnidarians are the first animals to have a primitive nervous system in the form of nerve net. There is major nerve tract or formation of an integrating center. The nerve cells are scattered throughout the body and may form aggregates in the form of **nerve plexi** or nerve cords. The nerve cells have mixed properties of motor and sensory neurons that help the animals with coordinated movements of tentacles, ingestion and digestion of the food and elimination of undigested matter.

**Reproduction and Development:** The cnidarians reproduce both asexually and sexually. The asexual reproduction takes place by the process of budding where buds are formed as outgrowths on the parents’ body walls. In solitary polyps (e.g., Hydra), the bud breaks off and develops into an independent animal whereas in colonial polyp forms (e.g., Obelia), the individuals formed from budding are attached to the parent. The progeny so produced is genetically identical to the parent.

![Hydra budding](https://example.com/hydra_budding_image)

*FIGURE 6. Hydra budding by Michael J. Gregory, Ph.D. provided by Lumen Learning is licensed under CC BY-NC-SA 4.0.*

Sexual reproduction is carried out differently in polyp and medusa forms and usually triggered by adverse environmental conditions. The species that only have polyp body form produce gametes in temporary gonads that can be seen as a node in the body wall of the animal. There is no definitive distinction between the male and female gametes, but the ones towards the mouth of the animal produce the sperm whereas the ones towards the base of the body produce eggs. The sperm are free-swimming due to the presence of flagella and swim towards the non-motile eggs to fertilize. Fertilization results in the formation of a free-swimming larva that is released from the parent body through the mouth. The larva swims along the water current for some time (few hours to few days) and eventually settles on a favorable substratum to develop into a new polyp colony. Sexual reproduction increases the chances of genetic outcrossing and results in the formation of individuals with different genetic makeup than their parents.
Phylum Platyhelminthes:
As the evolutionary pressure increased, the animal body plans underwent dramatic changes from the ones seen in the phylum Cnidaria. The phylum platyhelminthes consists of more than 20,000 species of animals which are commonly called as flatworms and are mostly parasitic with some being carnivorous. These animals exhibit bilateral symmetry and have a dorsoventrally flattened body. The members of the phylum are triploblastic (tissues derived from three embryonic germ layers: endoderm, mesoderm and ectoderm). The size of these worms can vary from a few millimeters (Planaria; 0.1 inch) to few meters (tapeworms; 3 meters). These animals also show the development of true muscle, connective tissue, and nervous system. We will study the phylum under three different classes due to the differences in the morphology and adaptations of animals to different habitats.

Class Turbellaria: The representative member of the class we will study is Dugesia (commonly known as Planarians). Most planarians are free-living flatworms found in freshwaters, but some may also be found in marine habitats.

- **Nervous System:** A very peculiar feature of the planarians is the presence of eyespots (ocelli) on the dorsal surface at the anterior end of the body. These eyespots are light sensitive and determine the direction of the light but cannot form an image. As the planarians live in dark, they move away from the direction of light. There is a primitive integrating center as brain (ganglion cell) along with the nerve cords arranged in a ladder-like manner that run along the length of the body of the planarians.
• **Feeding and Digestion:** The planarians are carnivorous scavengers and bottom-feeders. These animals have a single-opening digestive tract, which consists of a mouth, pharynx, and gastrovascular cavity. The food is digested in the gastrovascular cavity and nutrients are absorbed by simple diffusion because of the lack of circulatory system. Any undigested matter is expelled through the mouth (no anus).

• **Respiration:** Since planarians lack the respiratory and circulatory system, they obtain oxygen from their surrounding through simple diffusion across the body surface.

• **Excretion:** The excretory system consists of tubules connected to a branched network of ducts throughout the body of the animal. These tubules have pores along the sides of the body to excrete the waste. The tubules are formed by specialized cells called protonephridia or **flame cells** with cilia on one end. It is the movement of these cilia that moves the waste material into the tubule and out of the body.

• **Reproduction and Development:** Planarians can reproduce both asexually and sexually. Asexual reproduction is achieved via fission. Sexual reproduction takes place by the formation of male and female gametes. All the planarians are hermaphrodites, so they possess both testicles and ovaries in the same individual. During sexual reproduction, one animal transfers its sperm to another. The fertilized egg goes through many larval stages.
and is eventually released from the parent animal which hatches into a new worm in a few weeks.

**Class Trematoda**: The members of this class are commonly known as flukes and are all parasites living in the digestive system of the vertebrates. Currently, about 20,000 species of trematodes are known out of which around 40 are human parasites. The body of these flatworms is flat leaf like. The anterior end has a blunt triangular projection having a cup-shaped sucker which has an oval mouth in the middle. The anterior sucker is used by the fluke to latch onto the host to feed.

![Stained and preserved liver flukes](image)

**FIGURE 11.** Left: stained liver fluke. Right: Preserved liver fluke. Image by Michael J. Gregory, Ph.D. provided by Lumen Learning is licensed under CC BY-NC-SA 4.0.

- **Nervous System**: Being parasitic, the flukes have lost the eyespots seen in planarians but do have a ganglionated nerve ring (brain) surrounding the esophagus at the anterior end.

- **Feeding and Digestion**: The flukes use their anterior sucker to ingest blood from the bile duct of the host. The mouth leads to the pharynx followed by esophagus and the gastrovascular cavity. The gastrovascular cavity consists of intestines extending on both sides of the body. The intestines end blindly with no anus suggesting that flukes have an incomplete alimentary canal.

- **Respiration**: Being parasitic, flukes lack respiratory system. They obtain oxygen from the host bile and eliminate carbon dioxide via exosmosis.

- **Excretion**: Just like planarians, flukes have a very well-developed excretory system consisting of flame cells and protonephridia.

- **Reproduction and Development**: Flukes are hermaphroditic, but self-fertilization does not take place in these flatworms because of the way the male and female parts are located in the body. The paired testes are located in the posterior part of the body while the ovaries are located anteriorly. The eggs produced by the ovaries pass into the uterus located in the middle of the body where they are fertilized by the sperm from another fluke. The fertilized eggs are released from the body of the fluke through the genital opening. One fluke can produce a large number of fertilized eggs. Each egg once released from the body of the host enters its intermediate host and goes through a series of larval stages before it again enters its definitive host (human).
**Class Cestoda:** Commonly known as tapeworms, class Cestoda is composed of over 4,000 species. Cestodes are endoparasites of small intestines and just like flukes require more than one host for their complex life cycles. Unlike flukes, cestodes are characterized by their long flat bodies that can grow up to 18 meters long and consists of many reproductive segments known as proglottids. The body of these organisms is divided into scolex or head that contains the suckers and hooks. They lack organs for digestion, respiration and circulation. The surface of their body is covered by small microvilli-like projections that help with the absorption of nutrition from the intestinal fluids of their hosts.
• **Nervous System**: The nervous system in tapeworms consists of only a pair of lateral nerve cords which arise from a nerve mass in the scolex and extend in the length of the body of the worm.

• **Excretory system**: Just like other flatworms, the tapeworm also uses flame cells for excretion and the protonephridial system also runs the length of the body.

• **Reproduction and Development**: tapeworms are hermaphroditic and contain both male and female reproductive structures. Self-fertilization or internal fertilization is very common in tapeworms. A single tapeworm can produce up to 100,000 eggs. Just like flukes, the fertilized egg is encased in a shell and go through a series of larval stages.
FIGURE 16. Life cycle (sexual reproduction) of Tapeworm.
Objectives
1. Examine the anatomy and life cycles of three representative basal animal phyla.
2. Examine how embryonic development determines adult form.
3. Determine the organizational differences between animals without and with true tissues.
4. Understanding body symmetry.

Materials

- Light microscope

Slides of (Subject to change: check with your Instructor):
- Metridium (Porifera)
- Leucosolenia (Porifera)
- Grantia (Porifera)
- Spicules (Porifera special feature)
- Hydra (Cnidarian)
- Obelia (Cnidarian)
- Nematocyte (Cnidarian special feature)
- Dugesia (Platyhelminthes: Planaria)
- Taenia Pistiformes (Platyhelminthes: Tapeworm)
- Other parasites: Clonorchis Sinesis (Platyhelminthes: Trematode)

Fresh samples of:
- Dugesia (planaria)
- Hydra
- Daphnia

Preserved specimens of:
- Tapeworm
- Fluke
- Leucosolenia
- Assorted sponges
- Jellyfish
**Instructions**

1. Examine the preserved structures of Porifera, Cnidarians, and Platyhelminthes. What can you surmise with regards to the anatomy of the preserved organisms (body structure, special characteristics, organ systems, etc)?

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<tr>
<th>Organism (and Phyla)</th>
<th>Description</th>
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2. Examine the fresh samples of Hydra and Planaria. Describe and/or draw what you see below. How do their sensory systems allow these organisms to find food or escape from potential predators? (Hint: read the background info!)
3. Using a light microscope, examine the slides in the materials section. Using the space below, provide descriptions of the features in the slides corresponding to Porifera, Cnidarians, and Platyhelminthes.

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<tr>
<th>Slide</th>
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**POST-LAB QUESTIONS:**

Using the specimens you observed during the lab, please fill out the table below.

<table>
<thead>
<tr>
<th>Common name of organism</th>
<th>Phylum</th>
<th>Body Symmetry</th>
<th>Does it have true tissues? If yes, what embryological germ layers?</th>
<th>Types of feeder (filter, predator, etc)</th>
<th>Does it have organ system? If yes, which ones? Any other special characteristics? (Use additional paper if necessary)</th>
</tr>
</thead>
</table>
Background
Please read assigned background readings, watch the dissection video and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

Fetal pigs are unborn pigs used in biology laboratories and are a by-product of the pork industry. Fetal pigs are used in biology labs because of their similarities in their physiological systems to humans and other mammalian vertebrates. For this lab, the fetal pig will be used as a representative of all the major organs found in mammalian vertebrates.

Orientation terms: Know the following terms of orientation before you begin this lab:

- **Anterior end**: refers to the head end. If a structure is anterior to another, it is closer to the head.
- **Posterior end**: refers to the tail end. If a structure is posterior to another, it is closer to the tail.
- **Dorsal side**: refers to the back side, where you would find the vertebrae.
- **Ventral side**: refers to the belly side; it is opposite to the dorsal side.
- **Lateral**: Towards the sides of the body.
- **Medial**: Towards the middle of the body.
**Objectives**
1. Examine the anatomical and physiological systems of vertebrates using the fetal pig as the model organism.
2. Distinguish the different organs systems of the fetal pig.
3. Know the pathway and the parts of the digestive system in the fetal pig and the function of each part.

**Hypothesis**
1. Do you expect the digestive system of the fetal pig to be similar to humans? Why and in what aspects?
**Materials**

**Part 1:**
Fetal Pig Dissection:
- Preserved fetal pig
- Dissecting pan
- Dissecting tools
- Dissecting t-pins
- Plastic bag
- Metric ruler
- Paper towels
- Gloves
- String
- Bag tag (to label your pig)
- Humectant (Preservative for the pig)
- Disinfectant (Staphene)

**Before you start, keep in mind the following SAFETY information:**
- **NEVER** point sharp objects at yourself or others
- Properly mount specimens to the dissection pan
- Wash hands at the end of each class period
- Properly dispose of any materials
- Clean up area

**Part 2:**
- Light Microscope

**Slides of (Subject to change; check with your Instructor):**
- Esophagus
- Stomach
- Intestine: Duodenum, Jejunum, Ileum
- Colon
- Pancreas
- Liver
Instructions

Part 1: Fetal pig dissection instructions:

1. Obtain a bag with a fetal pig. Cut open the bag and pour out the excess liquid in the sink prior to removing the pig from the bag.

2. Try your best to rinse off any excessive preservative by holding it under the running water.

3. Place the pig in the dissecting tray. Examine the pig to determine its sex using the following pictures.

Female pig-Posterior, ventral

Image by Michael J. Gregory provided by Lumen Learning is licensed under CC BY-NC-SA 4.0

Male- Posterior, ventral side up

Image by Michael J. Gregory provided by Lumen Learning is licensed under CC BY-NC-SA 4.0
Do you have a male or female pig? How do you know?

4. The approximate gestational age of a fetus can be estimated by measuring its size in length. Using a piece of string, measure your pig's length from the tip of its snout to the base (start) of its tail (do not measure the tail). The pig may be curved due to the fixation process, so try your best to follow the curve of the pig. Next, place the string next to a ruler to determine the length in cm. Use the length/age chart below to determine the age of your fetal pig:

<table>
<thead>
<tr>
<th>Length of Fetus (cm)</th>
<th>Gestation Age (Days)</th>
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<tr>
<td>2</td>
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<td>4</td>
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<td>100</td>
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What is the approximate gestational age of your pig?

5. Examine and check the following external structures of your pig. Be sure to check off each box as you make your way through this list.

- **Snout**: The snout of the pig has a blunt tip composed of cartilage and is strengthened by bone. It is used by the pig to push, lift, and dig.

- **External nares**: These are the nostrils of the snout and open into the nasal cavity where the inhaled air is warmed, filtered, and moistened.

- **Pinna or external ear**: Flap-like composed of cartilage, just like the human ear; helps collect sound waves.

- **Eyes**: Closed in fetal pigs; have the upper and lower eyelids.

- **Appendages (forelimbs and hindlimbs)**: Take a note of the positions of the knee, the elbow, the ankle, and the wrist.
□ Digits: Pigs have four digits on each foot, so a pig has a total of sixteen digits.

□ Umbilical cord: This extends from the abdomen of the fetus to the placenta of the mother. The main function of the umbilical cord is to transport the food and oxygen to the fetus and remove waste. The exchange takes place via diffusion from one blood system to the other. With scissors, cut across the cord about 1 cm from the body. Examine the 3 openings in the umbilical cord. The largest is the umbilical vein, which carries blood from the placenta to the fetus. The two smaller openings are the umbilical arteries which carry blood from the fetus to the placenta.

□ Anus: Lift the pig's tail to find the anus.

□ Mammary papillae: These are tiny bumps on the ventral surface of the pig and are present in both males and females. In the female these structures connect to the mammary glands.

□ Urogenital opening: This is an opening through which liquid wastes and reproductive cells pass (in the males). In the male, the opening is on the ventral surface (belly) of the body, just posterior (behind) to the umbilical cord. In the female, the opening is ventral (just below) to the anus.

6. Draw and label the parts from #5 here.
7. Place the fetal pig ventral side up in the dissecting tray/pan.

8. Take a long piece of string and tie it to one forelimb. Pass the string UNDER the tray and tie it to the other forelimb. Make sure it’s nice and tight otherwise you will have difficulty completing the dissections.

***TIP: First pass use a loose knot. As you dissect and loosen the limbs, go back, retie the string and double knot it.***

9. Repeat the same process with the hind legs.

10. Using a scalpel, cut the sides of the mouth (through the muscles and the joints) to open the lower jaw (be careful of the sharp canines) to view the structures inside the mouth. Open the jaw wide enough to expose glottis and epiglottis. The epiglottis is a cartilaginous flap that extends up through the soft palate into the nasopharynx and keeps the food from entering the trachea (windpipe).

11. Examine the hard palate and the soft palate. This separates the nasal cavity from the oral cavity. Note the big muscular tongue which has numerous papillae on the surface. These papillae contain the taste buds.

12. Locate the sublingual salivary glands (under the tongue). Check off all the parts of the mouth after you identify them.

   - Glottis
   - Epiglottis
   - Soft palate
   - Hard palate
   - Tongue
   - Sublingual salivary glands

13. Draw and label the parts from the checklist in #12 in the space below.
14. Next, refer to the diagram below, which illustrates the order number of incisions you will make to open the body cavity and using the instructions below.

***NOTE: You will have to retighten your string as you cut***

![Diagram of incisions](image)

a. With your fingertips, locate the lower edges of the ribs.

b. Starting with number 1, use a scalpel to make an incision from anterior to posterior end. Start gently so that you do not puncture the organs underneath the ribcage. The sternum is made of cartilage, so you may also use a small scissor to cut along the sternum.

c. Continue with incision number 2. Be extremely careful not to apply too much pressure to the scalpel. Directly underneath this soft tissue are the organs. This will bring you just above the umbilical cord. Cut around the cord to avoid injury to other structures and extend incision number 4 to the rear body wall.

   i. ***NOTE: If you have a male pig, when you reach the umbilical cord, continue your incision towards the hindlimbs.***
d. Along the rib cage, use pointed scissors to cut along the midline of the ribs. This will reduce the chance of you cutting the organs directly underneath the ribcage.

e. After incisions number 4 through the body wall, you will be able to see the peritoneum, a thin layer of tissue that lines the body cavity. Cut through the peritoneum along the incision lines.

f. Spread the flaps of the body wall apart. Cut the umbilical vein which extends through the liver.

g. Once the vein is cut, carefully pull the flap of skin, including the end of the umbilical cord between the hind legs. Now you should be able to see the organs of the abdominal cavity.

h. Finally, make the incision following number 3 to expose the diaphragm.

i. If there is an excess of preservative fluid and clotted blood, rinse the abdominal cavity gently under running water. Dab lightly with paper towels to soak up extra water.

15. Now that you have opened up your pig, you will identify the following organs of each physiological system (for more details on the function of each organ, please refer to the assigned Labxchange readings):

a. *Respiratory system:* In the thoracic cavity, you will find the lobes of the **lungs**. Follow the lobes anteriorly midline and see if you can spot the **trachea**. Around the neck region in front of the trachea sits the **thyroid gland** (part of the endocrine system). The posterior end of the thoracic cavity (end of the ribs) is the **diaphragm**.
   - Lungs
   - Trachea
   - Thyroid gland
   - Diaphragm

b. *Circulatory system:* **Veins** are dyed blue, and **arteries** are dyed red. In the thoracic cavity surrounding the lungs is the **heart**. Can you find the **right atrium**? The **thymus gland** (immune system) can be found either on top of the heart or near the thyroid gland.
   - Veins
   - Arteries
   - Heart
   - Right atrium
   - Thymus gland
c. **Digestive system:** Underneath the trachea lies a smooth circular tube. This is the *esophagus*, which travels behind the heart to lead to the *stomach*. The stomach is found directly underneath the *diaphragm*. The *liver* is also directly underneath the diaphragm and in front of the stomach. Gently flip to the underside of each lobe of the liver until you find a small blueish looking bag like structure. This is the *gallbladder*. Flip the stomach up and examine the *pancreas*. It will look beige or yellow in color and is bumpy looking. Next to the left side of the stomach (your right) you will find a long, flat, and thin light brown structure. This is the *spleen* (immune system). Go back to the stomach and find the end of it. This is where you will find the start of the *small intestine*. The first part of the small intestine is the *duodenum*, where digestive enzymes enter from the gallbladder, liver, and pancreas. Next, find the larger diameter intestine. This larger diameter intestine is the *large intestine* (hence the name). The large intestine is considerably shorter; follow it until you reach the end. This structure is the *rectum*. The rectum then leads to the *anus*.

- Esophagus
- Stomach
- Liver
- Pancreas
- Gallbladder
- Spleen
- Small intestine
- Large intestine
- Rectum
- Anus

***NOTE: Be sure to complete the background reading via labxchange on the function of each of these organs; the digestive system is covered during this lab!***

d. **Endocrine system:** thyroid, thymus, and pancreas, have been covered in the above a-c.

e. **Excretory system:** Move the intestines to the side. Along the lateral dorsal sides of the pig you will find the *kidneys*. Identify the *ureters* and follow the ureters to the *bladder*, which can be found in the section of the umbilical cord that you folded back. It is a rubbery, white colored structure.

- Kidneys
- Ureters
- Bladder
16. In the space below, draw and label all the parts on the checklist from #15. You may make more than one drawing as needed.
17. Once you are finished observing all the structures, please store your pig. Take paper towels and saturate it with humectant spray. Using the humectant-soaked paper towels, carefully cover the pig. Place the pig with the tray into a plastic bag. Write your names, date, and semester on a label and use the tag to seal the open end of the bag. Place the trays with your pigs on the designated shelf.

**Part 2: Microscopy slides**

1. You will now examine the microscope slides of the digestive system. Please draw and describe what you see.

   □ Esophagus

   □ Stomach

   □ Small Intestine

   □ Colon

   □ Pancreas

   □ Liver
Post-lab Questions:

1. List the function of each organ below:
   a. Stomach
   b. Esophagus
   c. Small Intestine
   d. Large Intestine
   e. Pancreas
   f. Liver
   g. Gallbladder
2. What structure separates the thoracic cavity from the abdominal cavity?

3. List two organs found in the thoracic cavity.

4. Describe the pathway of food through the digestive system beginning with the oral cavity.
8 – MUSCULOSKELETAL, NERVOUS & SENSORY SYSTEMS

Background reading:
Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

The Muscular System:
Triploblastic animals develop with three embryonic germ layers (ectoderm, mesoderm and endoderm) that give rise to all tissues in the body. Almost all triploblastic animals depend upon muscular systems for movement and the nervous system to control that movement. Muscle cells contain high concentrations of contractile proteins called actin and myosin that interact with each other to contract muscles. Approximately 80% of body mass in mammals is composed of skeletal muscles that are closely associated with the skeletal system. Other than skeletal muscles, vertebrates also have cardiac and smooth muscles.

The characteristic features of three types of muscle are outlined in the table below:

<table>
<thead>
<tr>
<th>Skeletal Muscle</th>
<th>Cardiac Muscle</th>
<th>Smooth Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Associated with the skeletal system, hence the name</td>
<td>• Associated with the heart, hence the name</td>
<td>• Associated with the walls of viscera, blood vessels, iris, erector muscle of hair follicles</td>
</tr>
<tr>
<td>• Long thread like fibers</td>
<td>• Short, branched cells</td>
<td>• Short, fusiform cells</td>
</tr>
<tr>
<td>• Striated</td>
<td>• Striated</td>
<td>• Non-striated</td>
</tr>
<tr>
<td>• Multinucleate</td>
<td>• Single nucleus</td>
<td>• Single nucleus</td>
</tr>
<tr>
<td>• Abundant sarcoplasmic reticulum</td>
<td>• Moderate sarcoplasmic reticulum</td>
<td>• Scanty sarcoplasmic reticulum</td>
</tr>
<tr>
<td>• No intercalated discs, no gap junctions</td>
<td>• Intercalated discs containing gap junctions</td>
<td>• No intercalated discs; gap junctions present</td>
</tr>
<tr>
<td>• Voluntary</td>
<td>• Involuntary (autorhythmic)</td>
<td>• Involuntary (autorhythmic)</td>
</tr>
</tbody>
</table>

The Skeletal System:
The skeletal system is the framework that the entire body is constructed around. Bones are the main component of the skeletal system. Exoskeletons are external skeletal systems while endoskeletons are internal skeletal systems. Cartilage is dense connective tissue found at the joints and provides a smooth surface for the movement of bones. A ligament is a band of fibrous connective tissue connects bones together by attachment points directly on bone. A tendon is a tough connective tissue that is connected to a muscle and attaches to a bone.
Bones have several distinct regions composing its structure. The diaphysis is the central shaft of the bone and the internal cavity of the diaphysis is called the medullary cavity. Within the medullary cavity is either red (red blood cells) or yellow (fat) bone marrow. The outside covering of the diaphysis is called the periosteum and covers the compact bone. The rounded ends forms the epiphysis. In juvenile bone, the epiphyses of long bones are filled with spongy bone, which contain stem cells for bone growth. In adults, the spongy bone of the epiphysis becomes compact bone.

![Figure 1. Structure of bone. Long Bone from Biology2e, by OpenStax is licensed under CC BY 4.0.](image)

**The Nervous System:**

The nervous system is divided into two parts, the central nervous system and the peripheral nervous system (FIGURE 2). The central nervous system consists of the brain and spinal cord. The peripheral nervous system consists of all the nerves that are outside of the brain and spinal cord. The peripheral nervous system is further divided into the somatic nervous system and the autonomic nervous system. The somatic nervous system controls skeletal muscles. The autonomic nervous system controls smooth and cardiac muscles, and other involuntary muscle contractions, such as digestion. The autonomic nervous system is further divided into the sympathetic nervous system and parasympathetic nervous system.
The divisions of the nervous system are outlined in Figure 2 below:

![Figure 2. Divisions of the nervous system.](image)

In the central nervous system, there are several important regions in the brain. The brain is covered by the three membranes called **meninges**. The **dura mater** is the outermost, the **pia mater** is the inner membrane, and the **arachnoid mater** lies in between the two.

At the anterior end of the brain is a small structure called the **olfactory lobe**. These lobes receive nervous stimuli from the nose and are involved with the sense of smell.

Above the olfactory lobes is the **cerebrum**. The cerebrum has a folded surface and is divided into two cerebral hemispheres (left and right) by a deep groove called the longitudinal cerebral fissure. The cerebrum controls voluntary muscle movements, thinking, memory, judgment, and the senses. The cerebral cortex is divided into 4 lobes: **frontal**, **temporal**, **parietal**, and **occipital**. In between the frontal and the parietal lobes lie the **somatosensory motor cortex**, which is responsible for integrating information from the 5 senses (Figure 3).

Behind the cerebrum is the **cerebellum** which is principally a motor coordinating center. Behind the cerebellum is the **brainstem** which leads to the spinal cord. The respiratory and cardiac centers are located in this structure.
The structural and functional unit of the nervous system is a **neuron**. These cells receive sensory inputs from external environment, relay the signals to the central integrating unit (brain or spinal cord) and send motor commands to the effector organs.

**Figure 4. Parts of a neuron.**

Structurally, a neuron has three distinct parts. These include a cell body (soma), an axon and dendrites (Figure 4). The **cell body** is an enlarged region that contains the nucleus. Extending from the cell body are one or more cytoplasmic extensions called **dendrites** which carry nerve impulse towards the cell body. The dendrites receive all incoming signals from other neurons. The **axon** is a tube-like structure that carries impulses away from the cell body until it reaches the **axon terminal**. Neurons can be broadly divided into three categories: **sensory neurons**, **motor neurons** and **interneurons**. Sensory neurons (**afferent** – towards CNS) convert the
external stimuli from the environment into corresponding internal stimuli. Motor neurons (efferent – away from CNS) carry the nerve impulse from the integrating center to the effector organs (muscle or glands).

Neurons communicate with each other and the effector cells through a specialized intercellular junction called the synapse. A synapse can be chemical (where a neurotransmitter is released into the synapse) or electrical (where ions travel directly between the neurons).

An important aspect of the nervous system for proper functioning of the body is the reflex action. A reflex action is an instantaneous and involuntary response of the body to a stimulus and does not need conscious thought or awareness. It allows one to respond to adverse circumstances that could cause potential damage to the body. Some examples of reflexes include closing of the eyes when exposed to a bright light, a sudden withdrawal of hands when touching something hot, coughing or sneezing due to irritants in the airways, and the knee-jerk reaction. The neuronal pathway that the reflex action follows is known as the reflex arc. A reflex arc has five essential components (FIGURE 5):

**Sensory Receptor:** It receives the information and assists in generating impulses.

**Sensory Neuron / Nerve:** It carries information from the receptor to the interneuron in the spinal cord. Sensory neurons end in the dorsal horn of the spinal cord.

**Integrating center:** The interneurons in the spinal cord process the information and generate effective responses.

**Motor Neuron / Nerve:** It carries the information from the spinal cord to the effector organ. Motor neurons leave the spinal cord from the ventral horn.

**Effector Organ:** It receives information from motor neurons and results in the appropriate response (reflex).

![Figure 5. Reflex circuit.](image-url)
The Sensory System (the eye):
The sensory systems are pathways in the nervous system that are responsible for detecting, processing and perceiving internal and external stimuli. For example, internal stimuli includes changes to your blood pressure, while external signals include a sense of touch. The external stimuli that people are most aware of include vision (optic), smell (olfactory), hearing (auditory), taste (gustatory) and touch (tactile). This lab will focus on the structure and function of eye as an example of the sensory systems.

The eye is the organ of vision. The visible part of the eye has the following parts (FIGURE 6):

![Figure 6. Parts of the eye.](image)

### Structure
- Cornea
- Pupil
- Iris
- Retina
- Lens
- Ciliary Muscles
- Suspensory Ligaments
- Sclera
- Optic Nerve
- Blind Spot
- Aqueous Humor
- Vitreous Humor

### Function
- Refracts (bend) light into the eye.
- Allows the light to enter the eye. Changes size depending upon the brightness of the light.
- A circular muscle to control the size of the pupil.
- The structure where rods and cones are found.
- Focuses the light on retina to form an image.
- Change the shape of the lens for far and near vision.
- Attach the lens to the ciliary muscles.
- Tough and protective layer around the eye.
- Nerve that transfers the image formed on the retina to the brain.
- Part of the retina where optic nerve exits, point to no vision.
- Provides nourishment to the cornea and maintains pressure in the eye.
- Holds retina in place and maintains the shape of the eye.

The pathway of light through the eye goes through the following structures: Cornea, pupil, lens, vitreous humor, optic nerve, and retina. The retina is the site of the photoreceptors known as rods and cones. Activation of the rods and cones sends action potentials to the bipolar cells, of which the axons converge and form the optic nerve. The optic nerve then leads to the back of the
eye to send the images to the occipital lobes of the brain. The **ciliary muscles** surrounding the lens can contract or relax to change the shape of the lens so that light focuses on the retina (FIGURE 7).

**Figure 7. How light focuses on the retina.**
**Objectives**
1. Examine the microanatomical structure of muscles and neurons.
2. Examine the macroanatomical structures of muscle, neurons, and sensory systems.
3. Relate how the structure of cells found in the muscular, nervous, and sensory systems allow an organism to have specific physiological functions.
4. Perform self-tests to observe the function of these systems.

**Hypotheses**
1. How does the distinct structure of a cell allow for differentiation of function? (Muscle, nervous, bone cells)

2. How would stimulating a motor neuron in your arm affect your fingers?

3. Based on the structure of your eye, do you expect any ‘blind spots’ in your vision? Why or why not?
**Materials**

- Microscope
- Unit for muscle contraction (stimulator, force transducer, an interface unit)
- Sheep brain
- Dry long bones
- Fresh bones (cow)
- Model of reflex arc
- Medical hammer
- Model of brain
- Model of eye

**Slides of (Subject to change: check with your Instructor):**

- Striated muscle (skeletal muscle)
- Skeletal muscle
- Smooth muscle
- Cardiac muscle
- Bone
- Bone marrow
- Neuromuscular junction
- Spinal cord
- Dorsal Root Ganglion
- Optic nerve (eye)
- Retina (eye)
Instructions

Part 1: Musculoskeletal System

1. Obtain a microscope and slides of smooth, cardiac and skeletal muscle. Draw and describe what you see. What are the similarities and differences between the three types of muscle? (For example: How long are the muscle fibers? How many nuclei per muscle fiber? What is the pattern of striations? Are cells branched? Can you visualize intercalated disks?)

<table>
<thead>
<tr>
<th>Skeletal</th>
<th>Smooth</th>
<th>Cardiac</th>
</tr>
</thead>
<tbody>
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<td></td>
</tr>
</tbody>
</table>

2. Obtain the unit of muscle contraction equipment (*Please see Instructor for demonstration of how to use the unit*).

3. Make sure the knobs on the transducer are set to 0 and that the wires are connected to the unit.

4. Place a pad on the stimulator wire.

5. Remove the sticker. Place a dab of the green gel onto the center of the pad and stick the pad near the middle of your forearm.
6. Take another pad and place a dab of green gel onto the center of the pad. Place this second pad near your wrist.

7. Slowly turn up the voltage on the transducer until the muscle is stimulated. If there is no response, turn the voltage off and reposition the pad around your forearm and/or wrist.

8. Next, slowly turn up the frequency. What has happened? Why do you think increasing the frequency causes this effect? What physiological system is involved in causing the contraction of muscle (See REFLEX CIRCUIT)?

9. The patellar tendon is located just below your kneecap that attaches the quadriceps muscle to the tibia bone. There are afferent and efferent neurons found in this region. The patellar reflex test examines whether this circuit is intact. You will take turns testing the patellar reflex with your lab partner. Have your partner sit with their leg dangling and relaxed. Feel for your partner’s kneecap. The soft tissue under your kneecap is where you will perform the tap with the medical hammer (see figure below).

What happens when you tap the patellar tendon? Draw the reflex circuit that is activated in the space below.
Part 2: Musculoskeletal System

1. Examine the model skeletons that are provided in the lab. List below which organisms have an exoskeleton and which organisms have an endoskeleton.

<table>
<thead>
<tr>
<th>Endoskeleton</th>
<th>Exoskeleton</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Examine the long bone. Can you identify the major regions of bone structure covered in this lab? Draw and describe below.

3. Examine the fresh cow bones, if available. What structures can you identify?
Part 3: Nervous System

1. Obtain a pre-prepped microscope slide of a dorsal root ganglion, a spinal cord slide, and the neuromuscular junction (or whatever is available). What do the neurons look like? Draw and label what you see in the space below.

2. Examine the model of the motor reflex circuit. Draw and label the pathway of sensory-to-motor neuron activation in a reflex circuit. Use the following terms: motor neuron, sensory neuron, sensory receptor, effector (muscle), interneuron, dorsal root, ventral root.

3. Examine the plastic model of the brain. Can you identify the major lobes of the brain (frontal, temporal, parietal, occipital), the somatosensory cortex, the cerebellum, and the medulla)? Draw and label these lobes in the space below. Once you have done this, see if you can identify these same regions in the sheep brain (if available).
Part 4: Sensory Systems – The Eye

1. Examine the model of the eye. Can you identify the following parts: **lens, cornea, retina, optic nerve, iris**, and the **vitreous humor**? Draw and label these parts in the space below.

2. Where would the blind spot in the eye be located? Why?

3. You will now demonstrate the existence of the blind spot using this simple trick. Take a pen or a pencil and hold it with your right hand. Stretch out your right arm until the pencil is in front of your field of vision. Close your left eye but keep the right eye open. While keeping your right eye focused on the top of the pencil, very slowly move the pencil to the right. When the pencil seems to have disappeared, you will have found your blind spot. Do this very slowly because it is easy to miss the blind spot. Once you have done this, repeat the experiment with your left eye (close the right eye and move the pencil to the left).

4. (Optional) You may now take out your fetal pig and see if you can identify all of the structures that were covered in this lab.
POST-LAB QUESTIONS

1. What parts of the reflex arc are part of the central nervous system and what parts are part of the peripheral nervous system? (Hint: Review reflex circuit in the BACKGROUND)

2. What part of the long bone is responsible for growth in children? What happens to this region in adults?

3. Compare and contrast the musculoskeletal system of the human and pig. What is similar? What is different? (Please use background reading assigned to address this question; this will also address why we use fetal pigs as our example for vertebrate physiological systems)
9 – CIRCULATORY SYSTEM

Background reading:
Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

The Circulatory System:
The circulatory system in mammals consists of the heart, blood, and the blood vessels. This system allows blood, nutrients, oxygen and other gases, and hormones to circulate throughout the body. The exchange of gases to the tissues throughout the body is critical for maintaining life, while the exchange of nutrients, wastes, as well as hormones allows the body to maintain homeostasis. There are two main circuits of blood flow throughout the circulatory system: the pulmonary circuit and the systemic circuit (FIGURE 1). The pulmonary circuit pumps blood from the heart to the lungs while the systemic circuit pumps blood from the heart into the rest of the body.

![FIGURE 1. Image from Biology 2e by OpenStax is licensed under CC BY 4.0.](image)

The four chambers of the heart are the: right atrium, left atrium, right ventricle, and left ventricle. The four valves that can be found in the heart are the bicuspid (mitral) (between left atrium and left ventricle), tricuspid (between right atrium and right ventricle), pulmonary semilunar (between right ventricle and pulmonary artery), and aortic semilunar (between left ventricle and aorta). The atrioventricular valves are the bicuspid and tricuspid while the semilunar valves are the pulmonary and aortic semilunar valves. (FIGURE 2)
Deoxygenated blood that returns to the heart travels by way of the anterior (superior in humans) and posterior (inferior) vena cava. Follow the diagram (FIGURE 3) to examine the circulation of blood through a mammalian heart. Fill in the table with the parts of the heart that contain deoxygenated and oxygenated blood.

<table>
<thead>
<tr>
<th>Oxygenated</th>
<th>Deoxygenated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Blood traveling through vessels follows this order: **arteries (oxygenated), arterioles, capillaries (gas exchange), venules (deoxygenated), veins**, with the diameter ranging from large, small, and back to large as blood passes through these vessels. There are three layers of tissue that are arranged to form arteries and veins: **tunica intima, tunica media, and tunica externa**. Arteries have a thicker tunica media that is primarily composed of smooth muscle. This allows the arteries to contract and push blood in one direction. When observing an artery and a vein, the artery will appear much thicker because of the larger size of the smooth muscle. To keep blood continuously moving forward in veins, there are internal **valves** that open and close to prevent backflow of blood (FIGURE 4). Capillaries generally consist of only the tunica interna layer and do not perform this type of contraction. Capillaries are only one-cell layer thick (tunica intima or
endothelial tissue) so that exchange of gas, nutrients, and hormones can occur via simple diffusion through the thin capillary lining.

FIGURE 4. Image from Biology 2e, by OpenStax is licensed under CC BY 4.0. (credit: modification of work by NCI, NIH)
Objectives
1. Learn the parts of the mammalian heart, the chambers, and the valves.
2. Know the direction of blood flow through the circulatory system into the heart and what parts carry deoxygenated and oxygenated blood.
3. Understand the difference between the pulmonary circuit and the systemic circuit.
4. Understand the differences between arteries, veins and capillaries.

Hypotheses
1. What is the function of valves in the mammalian heart?

2. How does separating the circulatory system into the pulmonary and systemic circuit more efficient than having a single, unidirectional circuit?

3. How does the structure of arteries, veins and capillaries specific to its function? (Hint: what is the function of arteries, veins, and capillaries?)
Materials

- Microscope
- Stethoscope
- Sphygmomanometer
- Sheep heart

Slides of (Subject to change: check with your Instructor):
- Artery
- Vein
- Blood
- Aorta
**Instructions**

**Part 1: Microscopy**

1. Examine the slides of the artery and vein. What differences can you see between the two structures? Draw and label what you see in the box below.

<table>
<thead>
<tr>
<th>Artery</th>
<th>Vein</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Examine the slide of blood. What type of blood cells do you see (erythrocytes and leukocytes)? Draw and describe what they look like.

3. Examine the model of the heart and see if you can identify the following parts of the heart: **superior + inferior vena cava, right atrium, left atrium, right ventricle, left ventricle, pulmonary artery, pulmonary vein, tricuspid, bicuspid, aortic semilunar valve, pulmonary semilunar valve**. Draw and label the parts of the heart in the space below.
Part 2: Measuring blood pressure

1. Blood pressure can be measured from the brachial artery located in the upper arm and is measured by systolic and diastolic pressure. Systolic pressure typically ranges from 100 to 140 mm Hg, with an average near 120. Diastolic pressure typically ranges from 70 to 85 mm Hg, with an average near 80. Blood pressure is reported as systolic pressure/diastolic pressure (120/80), or "120 over 80".

2. Blood pressure is measured with a stethoscope and a sphygmomanometer. A stethoscope is used to listen for the thumping of the contracting artery. To measure blood pressure, the cuff of the sphygmomanometer is tightened with pumped air until blood flow through the artery stops, or when thumping sounds are no longer detected. Then, the pressure of the cuff is slowly released until thumping sounds resume, indicating that blood flow has resumed through the artery. The pressure at which the first beat is heard corresponds to the systolic pressure, and the pressure at which the beat stops is the diastolic pressure.

3. Do all the following experiments in pairs, alternately serving as subject and experimenter.
   i. Prep your stethoscope by wiping the ear-piece and the chest piece (circle part) with ethanol to clean it for use.
   ii. Have your lab partner sit in a relaxed position for 2 min and breathing normally. Attach the cuff around his/her arm above the elbow.
iii. Place the chest piece of the stethoscope (circle part) under the cuff and over the brachial artery just above the elbow (near the end of your biceps). Make sure you can hear the brachial artery prior to moving on to the next step.

iv. Inflate the cuff to about 200 mm Hg, which will stop blood flow through the artery, or whenever you stop hearing the brachial artery. Be sure to check with your partner for any pain or discomfort.

v. Slowly release the pressure in the cuff and listen for when you can hear the artery again. Note this number on your sphygmomanometer.
   a. When the pressure falls below the systolic pressure, blood spurts through the artery. This flow of blood occurs quickly and produces vibrations and turbulence that can be heard with a stethoscope as loud, tapping sounds. The pressure at which you hear these sounds is the systolic pressure.

vi. Continue to slowly release pressure from the cuff and listen for when you can no longer hear the artery. Note this number on your sphygmomanometer.
   a. As the pressure drops, the sounds become louder and more distinct as more blood flows through the artery. This is due to the cuff still occluding part of the artery, creating whooshing sounds as blood flows. When the cuff pressure reaches the diastolic pressure (fully opened artery), blood flow is normal and the sounds disappear. The pressure at which the sound disappears is the diastolic pressure.

vii. Release all remaining pressure from the cuff. Record your blood pressure in the table below:

<table>
<thead>
<tr>
<th>Person 1 – Sex:</th>
<th>Person 2 – Sex:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

viii. We will now tally the class average and compare male vs female blood pressure values.

<table>
<thead>
<tr>
<th>Female: Average BP</th>
<th>Male: Average BP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. (Optional): You can take out your fetal pig to observe all the structures covered in this lab.
POST-LAB QUESTIONS

1. What are the structural differences between arteries, veins and capillaries that affect how blood travels through these blood vessels?

2. What are some factors that could affect blood pressure?

3. Starting from the vena cava, describe the flow of blood through the pulmonary and systemic circuits.
10- RESPIRATORY SYSTEM

Background
Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

The function of the respiratory system is to provide oxygen to body tissues for cellular respiration (ATP production), remove the waste product carbon dioxide, and to maintain acid-base balance of fluids. The respiratory system of a human is similar to that of the fetal pig.

![Major Respiratory Structures](image)

**FIGURE 1. Major Respiratory Structures.** The major respiratory structures span the nasal cavity to the diaphragm. *Major Respiratory Structures* by OpenStax from *Anatomy and Physiology* is licensed under CC BY 4.0.

The pathway of respiration begins in the **nostrils** and **mouth** (FIGURE 1). The air then passes through the **pharynx** in the back of the throat to enter the **larynx**. A structure called the **epiglottis** is situated anterior to the larynx that closed the path to the trachea when swallowing.
food (see Digestive System). From here the air moves into the **trachea**, which is composed of **cartilaginous rings** that are connected by dense connective tissue. The trachea then branches into two **primary bronchi** that enters the left and right lung. The bronchi further branch into **secondary bronchi**, which branch even further into **bronchioles** (FIGURE 2). At the end of bronchioles are small and thin air sacs called **alveoli**. The very thin alveoli are surrounded by small **capillaries** where gas exchange (oxygen and carbon dioxide) occurs (FIGURE 3).

**FIGURE 2.** The respiratory organs include the lungs. Air travels past the larynx, into the trachea where it branches into the primary bronchi, which further branches into secondary bronchi. From here, the air will travel until it reaches the terminal bronchi that is attached to small air sacs called the **alveoli**.
FIGURE 3. Alveoli. Bronchioles lead to alveoli, which are air sacs. Alveoli are surrounded by capillaries, where gas exchange occurs. Respiratory Zone by OpenStax from Anatomy and Physiology is licensed under CC BY 4.0.

During **inhalation**, the **diaphragm** and the **external intercostal muscles** contract (FIGURE 4 and FIGURE 5) to lift the ribs upward and expand the diaphragm downward, increasing the volume in the thoracic cavity. This causes the chest cavity to expand to create a negative internal pressure in comparison to the environmental air. Like a vacuum, the air is sucked into the respiratory passage due to the difference in pressure between the body wall and the environment. During **exhalation**, the **internal intercostal muscles** contract to bring the ribs downward while the diaphragm and external intercostal muscles relax. This causes a decrease in lung volume that pushes the air out of the lungs.

Breathing can be passive or active. **Passive breathing** does not require energy to force air out of the lungs and is controlled by the autonomic nervous system. **Active breathing** requires active manipulation of muscle contractions by the central nervous system to control the muscles of the diaphragm and the intercostal muscles to allow for deep inhalation, and may also use other muscles, such as the neck muscles, to further expand the thoracic cavity. Deep exhalation may use abdominal muscles to push the organs into the diaphragm to further compress the thoracic cavity.
FIGURE 4. Thoracic muscles, the intercostals and the diaphragm, contract and relax during inhalation and exhalation. *Parietal and Visceral Pleurae of the Lungs by OpenStax from Anatomy and Physiology* is licensed under CC BY 4.0.

FIGURE 5. *Inspiration and Expiration* by OpenStax from Anatomy and Physiology is licensed under CC BY 4.0.
The respiratory volume during the breathing cycle can determine the air capacity and health of the lungs. There are four major types of respiratory volumes: tidal, residual, inspiratory reserve, and expiratory reserve (FIGURE 6). Tidal volume (TV) is the volume of air that can enter and exit the lungs at rest, and is approximately 500 mL. During active breathing, the inspiratory reserve volume (IRV) is additional volume that occurs during a deep inhalation beyond the tidal inspiration. This is the extra volume of air that can enter the lungs during a forced inspiration (when you take a deep breath). The expiratory reserve volume (ERV) is the volume of air that can be forcefully exhaled beyond the resting tidal expiration. The residual volume (RV) is the air left in the lungs if you exhale as much air as possible and is also known as the ‘dead space’. The residual volume keeps the alveoli slightly inflated to prevent them from collapsing. This is because the alveoli are coated with mucus to enhance gas exchange with the capillaries. Deflated alveoli can collapse and become difficult to reinflate. Respiratory volume is dependent on a variety of factors (genetic, lifestyle, etc) and measuring these volumes can provide important information on the health of a person’s lungs.

For this experiment, you will perform a pulmonary test of respiration to determine lung capacity as a function of physiology factors. See the table below for measurements.
<table>
<thead>
<tr>
<th>Pulmonary function test</th>
<th>Instrument</th>
<th>Measures</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spirometry</td>
<td>Spirometer</td>
<td>Forced vital capacity (FVC)</td>
<td>Volume of air that is exhaled after maximum inhalation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forced expiratory volume (FEV)</td>
<td>Volume of air exhaled during one forced breath</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forced expiratory flow, 25–75 percent</td>
<td>Air flow in the middle of exhalation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Peak expiratory flow (PEF)</td>
<td>Rate of exhalation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum voluntary ventilation (MVV)</td>
<td>Volume of air that can be inspired and expired in 1 minute</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow vital capacity (SVC)</td>
<td>Volume of air that can be slowly exhaled after inhaling past the tidal volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total lung capacity (TLC)</td>
<td>Volume of air in the lungs after maximum inhalation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Functional residual capacity (FRC)</td>
<td>Volume of air left in the lungs after normal expiration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual volume (RV)</td>
<td>Volume of air in the lungs after maximum exhalation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total lung capacity (TLC)</td>
<td>Maximum volume of air that the lungs can hold</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expiratory reserve volume (ERV)</td>
<td>The volume of air that can be exhaled beyond normal exhalation</td>
</tr>
<tr>
<td>Gas diffusion</td>
<td>Blood gas analyzer</td>
<td>Arterial blood gases</td>
<td>Concentration of oxygen and carbon dioxide in the blood</td>
</tr>
</tbody>
</table>

TABLE 1. Pulmonary Function Testing by OpenStax from Anatomy and Physiology is licensed under CC BY 4.0.
**Objectives:**
1. Examine the structures of the respiratory system and how each component contributes to breathing and gas exchange.
2. Examine how the respiratory capacity is unique to each individual based on lifestyle and physiological differences.

**Hypothesis:**

1. After taking a poll in the class comparing sex, age, height, and smoker status, etc., decide as a class what you want to compare. You will create your own hypothesis relating respiratory capacity to each of these categories. Write the categories here and your hypotheses for the outcome of the following measurements: breathing frequency, tidal volume, inspiratory reserve, expiratory reserve, and vital capacity.
Materials

- Microscope
- Example of cow lungs (if available)
- Model of respiratory tract
- Biopac: bacteriological filter
- Biopac: disposable mouthpiece
- Biopac: air transducer
- Spirometer

Slides of (Subject to change: check with your Instructor):
- Lung
- Bronchioles
- Trachea
Instructions

Part 1: Examination of respiratory structures
1. Examine the microscope slide of the lung. Draw + write your observations in the space below.

2. Examine the microscope slide of the bronchiole. Draw + write your observations in the space below.

3. Examine the microscope slide of the trachea. Draw + write your observations in the space below.
4. Examine the dried cow lung samples (please be gentle with the lungs to prevent damage). How does it look and feel?

5. Examine the model of the human respiratory system. Draw and label all the parts of the respiratory system.
Part 2: Respiratory Capacity

1. You will now decide as a class which factors you want to compare during the respiratory capacity test. Note the factors below. The instructor will assist in compiling the table which you will then add in data as each student tests their respiratory volume (see Step 20 for the table). Write in the space below what groups you will be comparing (ex: male vs female, tall vs short, etc.)

2. You will now go to a Biopac station (there are only 4 stations so each group will have to take turns performing this experiment). Check that the airflow transducer is plugged into the system and that a NEW disposable mouthpiece is connected to the transducer for each person (See FIGURE below).

*****NOTE: ALWAYS USE A NEW FILTER AND DO NOT SHARE MOUTHPIECES!!*****

3. Start the Biopac Student Lab program on the computer.

4. Choose “L08 – RESPIRATORY CYCLE I” and click ok.

5. Type in a unique filename and click ok. This will be your group’s data files.
6. Choose the subject and have them sit in a chair in a relaxed position. The subject should be facing AWAY from the monitor.

7. The subject will hold the Airflow Transducer vertically in their hand (see picture above).

8. You will hit the record button.

9. The subject will place the mouthpiece in their mouth. The subject will breathe normally through their mouth for 60 sec (have a group member perform the timing). The subject should hold their nose or use the nose clips if they are naturally trying to breathe through your nose. This is your TIDAL BREATHING. (Please see figure on PAGE 6)

10. Have a group member instruct the subject to take a very deep breath through their mouth (inhale as much as you can), hold their breath for 2 seconds, and then expel as much air as possible (exhale as deeply as you can).

11. Instruct the subject to breathe normally for 20 sec.

12. Instruct the subject to take a very deep breath (inhale as much as you can), hold their breath for 2 seconds, and then expel as much air as possible (exhale as deeply as you can).

13. Instruct the subject to breathe normally for 20 sec.

14. You may now stop the recording.

15. Hit done on the recording and select data analysis.

16. On the right-hand side of the program, choose the typing cursor icon (I).

17. Highlight a region of interest to determine the volumes, frequencies, etc.

18. Count the number of breathes in 60 sec to determine the breathing frequency. Please add this data to the table below. Use additional paper if you do not have enough space.

****Use FIGURE 6 on page 117 and TABLE 1 on page 118 to guide you through the analysis****
19. Determine the **average TIDAL VOLUME** from 6 breaths. Use the chart below to fill in your values (units = mL).

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Category of Subject (from STEP 1)</th>
<th>Tidal Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
20. Calculate the **volume of gas** you move in and out of your lungs during 1 minute of tidal breathing. (Tidal volume / minute = tidal volume X breathing frequency (units = breaths/min))

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Category of Subject (from STEP 1)</th>
<th>Rate of tidal volume in 1 min (mL / min)</th>
</tr>
</thead>
<tbody>
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</table>

21. Determine your **inspiratory reserve**. It is calculated by subtracting the volume of the maximal inspiration (deep inhale) minus the preceding normal tidal breathing volume.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Category of Subject (from STEP 1)</th>
<th>Inspiratory Reserve (mL)</th>
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</thead>
<tbody>
<tr>
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</table>
22. Determine your **expiratory reserve**. It is calculated by subtracting the volume of the minimal exhalation (deep exhale) minus the preceding normal tidal breathing volume.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Category of Subject (from STEP 1)</th>
<th>Expiratory Reserve (mL)</th>
</tr>
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23. Determine your **vital capacity**. This is the total lung capacity and it the sum of the tidal volume, inspiratory reserve, and expiratory reserve.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Category of Subject (from STEP 1)</th>
<th>Vital Capacity (mL)</th>
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24. Repeat steps 6 – 19 for the class factors that were decided earlier and fill in the two tables below with the results. Use additional paper if necessary. Calculate the average and standard deviation for each demographic that you chose and compare the two data sets (use excel to calculate this or see APPENDIX).

<table>
<thead>
<tr>
<th>Category 1:</th>
<th>Breathing frequency</th>
<th>Tidal Volume</th>
<th>Inspiratory Reserve</th>
<th>Expiratory Reserve</th>
<th>Vital Capacity</th>
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<tbody>
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</table>

**AVERAGE**

**STANDARD DEVIATION**
25. If time permits, you will perform a standard student’s two-tailed t-test to determine if there was significance between the two groups. Enter the data in a graphing software (such as excel or google sheets) to perform this calculation. (See the APPENDIX for hand-calculation).
POST-LAB QUESTIONS

1. Define the measures that you took to perform this experiment and what in terms of lung function: breathing frequency, tidal volume, inspiratory reserve, expiratory reserve, vital capacity.

2. Based on your results, can you make any conclusions between the two groups that you chose to examine?
3. How does the class average compare to your individual result?

4. What does the standard deviation suggest regarding your experimental results? Are your results reliable? Why or why not?

5. What other possible comparisons could you make in this experiment?
11 – Excretory and Reproductive Systems

Background reading:
Please read assigned background readings and prepare notes prior to coming to class. There are many figures in the background reading that will help you to complete this lab.

Recommended: bring a device so you can refer to the online background reading + figures.

The Excretory System:

The excretory system plays an important role in maintaining body fluid homeostasis and consists of the kidneys, ureters, urinary bladder, urethra, and a urogenital opening. The excretory system eliminates fluid solute wastes from the body, regulates blood pH, fluid volume and pressure, and controls levels of electrolytes. Wastes from the blood are brought to the kidneys for filtration, reabsorption and secretion. The kidneys are a bean shaped organ situated against the dorsal body wall (back) and the final excretory products are transported to the bladder by tubes called ureters. The urinary bladder narrows posteriorly to form the urethra, which enters the pelvic cavity to carry the urine outside of the body through the urogenital opening (FIGURE 1).

FIGURE 1. Image from Biology2e, by OpenStax is licensed under CC BY 4.0. (credit: modification of work by NCI)
Blood from the abdominal artery flows into the **renal arteries**, which further branches into several segmental arteries in the kidneys. These arteries eventually branch into numerous **afferent arterioles** that form capillaries that innervate the **nephrons**, including the **glomerulus** (FIGURE 2). Blood exiting the kidney leaves by the **renal veins** to join the inferior vena cava, and back to the heart.

![Diagram of kidneys](image)

**FIGURE 2.** Structure of kidneys. Image provided by OpenStax from Biology2e is licensed under CC BY 4.0. (credit: modification of work by NCI)

Each kidney contains over one million **nephrons**. There are two types of nephrons—**cortical nephrons**, which are found deep in the **renal cortex**, and **juxtamedullary nephrons**, which extend into the **renal medulla**. Cortical nephrons compose the majority of nephrons in the kidneys (85%) while the juxtamedullary nephrons are responsible for creating concentrated urine. The pathway of glomerular filtration once it leaves the glomerulus and into the nephron is as follows: **Bowman’s capsule, proximal convoluted tubule, descending loop of Henle, distal convoluted tubule**, and the **collecting duct**. All ‘urine’ will converge into the ureters once it leaves the collecting duct (FIGURE 3).

The network of capillaries within Bowman’s capsule, is called the glomerular capillary bed, or **glomerulus**. Once the efferent arteriole exits the Bowman’s capsule, it branches to form the **peritubular capillary network**, which surrounds and interacts with the renal tubule. All solutes and water that are reabsorbed will move into the peritubular capillary network or secreted back into the nephron from the peritubular capillary network.
Male Reproductive System:

In the male reproductive system, the scrotum houses the testicles or testes, and provides the passage for blood vessels, nerves, and muscles related to testicular function. The testes are a pair of male reproductive organs that produce sperm and some reproductive hormones, such as testosterone and estrogen. Within the testes are the seminiferous tubules that produce sperm.

When the sperm have developed flagella and are nearly mature, they leave the testicles and enter the epididymis, where sperm will mature. The sperm will leave the epididymis and enter the vas deferens, which carries the sperm behind the bladder to the ejaculatory duct. From here, sperm will be pushed through the urethral opening (FIGURE 4).

FIGURE 3. Structure of nephrons. Image by OpenStax from Biology2e is licensed under CC BY 4.0.
As sperm leaves the urethra, it is mixed with fluids that are released from accessory glands. This forms the semen. These accessory glands are the **seminal vesicles**, the **prostate gland**, and the **bulbourethral gland**. The seminal vesicles are a pair of glands that is found posteriorly (behind) to the urinary bladder and anterior to the rectum. The walnut-shaped prostate gland is below the urinary bladder and surrounds the urethra. The prostate has a series of short ducts that connect directly to the urethra to release fluids. The bulbourethral gland releases its secretion prior to ejaculation to neutralize any acids that are in the urethra from urine.

The table below summarizes the function of the male reproductive parts:

<table>
<thead>
<tr>
<th>Organ</th>
<th>Location</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrotum</td>
<td>External</td>
<td>Houses testes</td>
</tr>
<tr>
<td>Penis</td>
<td>External</td>
<td>Exit for urine, also copulating organ</td>
</tr>
<tr>
<td>Testes</td>
<td>Internal</td>
<td>Produces sperm and male hormones</td>
</tr>
<tr>
<td>Seminal Vesicles</td>
<td>Internal</td>
<td>Produces fluid found in semen</td>
</tr>
<tr>
<td>Prostate Gland</td>
<td>Internal</td>
<td>Produces fluid found in semen</td>
</tr>
<tr>
<td>Bulbourethral Glands</td>
<td>Internal</td>
<td>Produces fluid to neutralize acid in urethra at ejaculation</td>
</tr>
</tbody>
</table>
Female Reproductive System:

The female reproductive structures include the ovaries, oviducts/fallopian tubes, uterus, and the vagina/vaginal canal. The ovaries are the site for egg (follicle) development and hormone production, such as estrogen and progesterone. The ovaries contain follicular cells that can give rise to eggs. In humans, several follicular cells develop at the beginning of the menstrual cycle. At ovulation, only one follicle ruptures and one egg is released. The remainder of the menstrual cycle is used to thicken the uterine wall for possible implantation of a fertilized egg. Unfertilized eggs will degenerate and the uterine lining is shed at the end of the menstrual cycle, which marks the beginning of a new cycle.

There are two oviducts, or fallopian tubes, connecting from each ovary to the uterus. At the anterior end of the oviducts, you can find flared, finger-like ends called fimbriae that open towards the ovaries. On the posterior end, the fallopian tubes / oviducts connect directly to the uterus. When an egg is released at ovulation, the fimbriae movements direct the egg into the fallopian tube, where the egg will travel until it enters the uterus. Any present sperm will navigate to the anterior section of the fallopian tube to meet and fertilize an egg. If fertilized, the egg will travel through the rest of the fallopian tube to reach the uterus for implantation. If fertilization is unsuccessful or if there is no sperm present, then the egg will slowly degenerate as it moves towards the uterus.

The uterus is a structure about the size of a female’s fist. The posterior part of the uterus, called the cervix, extends into the top of the vagina. The vagina is a muscular tube that leads to the vaginal opening (FIGURE 5). The uterus supports the developing embryo and fetus during gestation. The thickest portion of the wall of the uterus is made up of smooth muscle. Contractions of the smooth muscle in the uterus aid in passing the baby through the vagina during labor.
FIGURE 5. Structure of the female reproductive system. Image provided by OpenStax from Biology 2e is licensed under CC BY 4.0. (credit: a: modification of work by Gray’s Anatomy; credit b: modification of work by CDC)
**Objectives:**
1. Examine the renal system and understand how the kidney contributes to maintaining fluid osmolarity.
2. Examine the male and female reproductive systems and how the structures contribute to the function of reproduction.

**Hypotheses**
1. How does the distinct structure of the kidney allow the filtration of fluid wastes from the circulatory system?
Materials

- Models of: kidneys and nephrons
- Models of: male and female reproductive systems

Slides of (Subject to change, check with your Instructor):
- Urethra
- Ureter
- Urinary bladder
- Kidney with blood vessel
- Kidney
- Testes (mammal)
- Ovary
- Fallopian tube
**Instructions**

1. Examine the model of the kidneys. Draw and identify the structures and the pathway of urine production.

2. Examine the model of the nephrons. Draw and identify the regions of the kidney (cortex vs medulla), and the parts of the nephron. Describe the pathway of solute movement through a nephron below.
3. Examine the slide of the kidney and kidney with blood vessels under the microscope. Draw and label what you see. What does the structure of the nephron look like?

4. Examine the slides of the testes and the ovaries. Draw and label what you see. What are the similarities? What are the differences?
5. Examine the model of the female reproductive system. Draw and identify the structures. Identify the pathway that an egg travels through the female reproductive system. Where would fertilization occur?

6. Examine the model of the male reproductive system. Draw and label the structures. What is the pathway that a sperm travels during ejaculation?

7. What glands contribute to the production of semen to support the sperm?
12 – PLANT PROJECT

Background:

Plants are a part of the ecosystem that provides many functions for the planet. They provide food, shelter, and cycle CO\textsubscript{2} back into O\textsubscript{2}. Plants utilize radiant energy from the sun to convert CO\textsubscript{2} into carbohydrates in a process called photosynthesis. The formula for the process of photosynthesis is below, where 6CO\textsubscript{2} molecules are needed to make one sugar molecule:

\[
6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

Although there are different types of terrestrial plants, the process of photosynthesis remains the same. A limiting factor in plant growth is the amount of light that is available to a plant.

Angiosperms are flowering plants that produce seeds and fruits. The purpose of flowering is to produce new progeny through fertilization. Flowering angiosperms may house both male and female parts for the purpose of fertilization. Pollen released from anthers can land on the stigma of a flower and will then form a pollen tube that will make its way through the style and into the carpel / ovary of the flower. Sperm will then travel through the pollen tube and into the ovule to fertilize the egg and the polar nuclei in a process called double fertilization. The developing ovary becomes fruit while the seeds are formed from the ovule that contains the fertilized egg, which will eventually become the embryo. Contained within seeds are dormant embryos that are protected by the seed coat. The fruit itself varies with the plant species and aids in seed dispersal.

There are two types of angiosperms, monocots and eudicots, and special characteristics that allow us to differentiate the two. You will find these differences in seedlings, the newly germinated plant, adult plant, and flowers. Below are tables and spaces for you to describe the general characteristics of seeds, flowers, and differences between monocots and eudicots. Use the information provided from your lecture class and labs 2, 3, and 4 to complete the sections below.
In the table below, summarize the differences between monocots and eudicots. Include a drawing.

<table>
<thead>
<tr>
<th></th>
<th>Monocots</th>
<th>Eudicots</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roots</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaves</strong></td>
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<tr>
<td><strong>Flowers</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Seeds</strong></td>
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</tr>
<tr>
<td><strong>Vascular tissue:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stem</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Roots</strong></td>
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</tr>
</tbody>
</table>
Using the space below and the background information from Week 3 and 4 labs, draw and label a diagram of the major parts of a flower. Be sure to add: **sepals, petals, carpals, stigma, style, ovary, ovule, stamen, anther, filament**.
Using the space below, and the background information from Week 4 lab, draw and label a diagram of the major parts of a seed. Be sure to have the following: \textit{embryo, endosperm, cotyledon, seed coat, radicle, hypocotyl}
OBJECTIVES
There are two objectives to this lab.
1. You will examine using two different types of seeds how the absence of light effects germination and the growth of plants. You will be doing this by planting monocot or eudicot seeds under conditions of light or dark and measuring time for germination and determining the rate of growth after germination. The following measurements will be taken daily:
   a. # of days until germination
   b. Once germinated, daily growth measurements
   c. Statistical analysis of a + b and comparison between light vs dark conditions and comparison between monocot and eudicot seeds and plants.
2. Once plants have sufficiently grown, you will compare the two types of plants to determine the type of angiosperm you have planted.

HYPOTHESIS
1. a. Under which conditions (light or dark) do you believe will affect the rate of germination (which one will germinate first)? Why?

2. Under which conditions (light or dark) do you believe will affect the rate of plant growth (which plant will grow taller or bigger)? Why?

3. What type of angiosperm are the corn and radish seeds? Why? What observations will help you to determine this?
MATERIALS

- 4 pots
- Sunflower seeds
- Corn seeds
- Soil
- Small sticky labels
- Ruler
- Spoon
- Toothpicks
- Permanent marking marker
INSTRUCTIONS

1. Take 1 corn and 1 radish seed. Observe and take notes on the shape and size of your seeds. Use the chart below to describe the differences and similarities. Take each seed and soak it in water to soften the seed so that you can cut it in half and examine the interior. Continue to fill out the table below. Be sure to take pictures of your seeds before and after you dissect them.

<table>
<thead>
<tr>
<th></th>
<th>Physical characteristics of outside the seed</th>
<th>Physical characteristics of inside the seed</th>
<th>Additional observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radish</td>
<td></td>
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</tr>
</tbody>
</table>

2. Using a label, number each toothpick 1-20.

3. Take 4 pots and label each one as follows:
   A. Corn - Light
   B. Corn – Dark
   C. Radish – light
   D. Radish – Dark
4. Using the plastic spoon, fill each pot about ¾ of the way with soil. In pots A + B, place 5 corn seeds on top of the soil for each pot. Try to spread them out. In pots C + D, place 5 radish seeds into each pot and try to spread out the seeds. Insert your prelabeled toothpick into the soil and place it next to each seed so that you mark where your seeds are planted. The table below should describe each toothpick number and condition of each seed. Reference the table as needed to keep track of your experimental conditions.

<table>
<thead>
<tr>
<th>Seed #</th>
<th>Pot</th>
<th>Seed</th>
<th>Experimental Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>Corn</td>
<td>LIGHT</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>Corn</td>
<td>LIGHT</td>
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<tr>
<td>3</td>
<td>A</td>
<td>Corn</td>
<td>LIGHT</td>
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<td>4</td>
<td>A</td>
<td>Corn</td>
<td>LIGHT</td>
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<tr>
<td>5</td>
<td>A</td>
<td>Corn</td>
<td>LIGHT</td>
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<tr>
<td>6</td>
<td>B</td>
<td>Corn</td>
<td>DARK</td>
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<tr>
<td>7</td>
<td>B</td>
<td>Corn</td>
<td>DARK</td>
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<tr>
<td>8</td>
<td>B</td>
<td>Corn</td>
<td>DARK</td>
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<tr>
<td>9</td>
<td>B</td>
<td>Corn</td>
<td>DARK</td>
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<tr>
<td>10</td>
<td>B</td>
<td>Corn</td>
<td>DARK</td>
</tr>
<tr>
<td>11</td>
<td>C</td>
<td>Radish</td>
<td>LIGHT</td>
</tr>
<tr>
<td>12</td>
<td>C</td>
<td>Radish</td>
<td>LIGHT</td>
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<tr>
<td>13</td>
<td>C</td>
<td>Radish</td>
<td>LIGHT</td>
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<tr>
<td>14</td>
<td>C</td>
<td>Radish</td>
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<td>Radish</td>
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<td>Radish</td>
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<tr>
<td>20</td>
<td>D</td>
<td>Radish</td>
<td>DARK</td>
</tr>
</tbody>
</table>

5. Top off each pot with additional soil. Be careful not to knock over your toothpicks.

6. Water each pot until the soil is damp, but do not overwater or you will drown the seeds.

7. Place pots A + C in a bright spot. This can be near an open window or directly outside. Place pots B + D in the dark (an enclosed box, cupboard, closet, etc…)

8. Be sure to water daily (again, do not overwater) and check for growth. If the potting soil is still damp, you may skip watering for the day. You will be making measurements for 4 weeks (28 days). Create a chart using the tables below as an example to record your daily observations. You should use Excel or other software to track your daily data.
9. Take a picture of all four pots and make sure the labels on each pot can be clearly seen (A, B, C, D).

10. After your seeds germinate, begin to record the height of your plant (in the ex: table below).

<table>
<thead>
<tr>
<th>Day</th>
<th>Seed #</th>
<th>Germination?</th>
<th>Height (cm)</th>
<th>Width (cm)</th>
<th>What does it look like?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<th>Day</th>
<th>Seed #</th>
<th>Germination?</th>
<th>Height (cm)</th>
<th>Width (cm)</th>
<th>What does it look like?</th>
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<td>Day</td>
<td>Seed #</td>
<td>Germination?</td>
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<table>
<thead>
<tr>
<th>Day</th>
<th>Seed #</th>
<th>Germination?</th>
<th>Height (cm)</th>
<th>Width (cm)</th>
<th>What does it look like?</th>
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</table>
**DATA ANALYSIS**

At the end of 4 weeks (28 days) you will create a graph of germination rate vs time (simple bar graph on the number of days for germination). You will also create a graph of growth rate vs time for each seedling and each condition (light vs dark). From this graph, you will determine the rate of growth by fitting your plot to a linear fit ($y=mx+b$) and determining your slope (rate). The steps are below.

**Germination rate:**

1. For each condition, determine how many days it took for germination to occur and write it in the table below. and then average those values.

<table>
<thead>
<tr>
<th>Pot A</th>
<th>Pot B</th>
<th>Pot C</th>
<th>Pot D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed #</td>
<td>Days to Germination</td>
<td>Seed #</td>
<td>Days to Germination</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>12</td>
<td>17</td>
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<td>8</td>
<td>13</td>
<td>18</td>
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<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

Average days:

Average days:

Average days:

Average day:

Standard deviation

Standard deviation

Standard deviation

Standard deviation

To calculate the average: $(\text{Sum of days}) / 5 = \text{Average # of days to germination}$
You may use excel or other software to determine the standard deviation or you may calculate the standard deviation by hand by filling in the table below for each sample:

<table>
<thead>
<tr>
<th>Seed #</th>
<th>Days to Germination (X₀)</th>
<th>(X₀-Average)</th>
<th>(X₀-Average)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tbody>
</table>

\[ SD = \sqrt{\frac{(X₀-\text{Average})^2}{n-1}} \]

2. Using excel or other graphing program, plot the germination time (y-axis) versus the condition (x-axis). Add in error bars using your standard deviation values. Be sure to properly label your axes and give your graph a title.

**Critical thinking**

What does the graph tell you about the germination rate between light and dark, and between corn and radish? If there is a difference in the rate, what factors do you think may have contributed to the germination rate?
**Growth Rate:**

1. For each condition, determine the average growth (cm) rate per day. Use the table below as an example for how to determine your average growth rate for each day. Repeat the calculation for each day of measurements for both height and width and for each pot. For each pot, you should have 28 days of data. Use the same formulas as above (germination rate) to determine average and standard deviation for each day and each pot. *(Hint: this will be much easier if you use excel to calculate your data)*

<table>
<thead>
<tr>
<th>Pot A – Day 1</th>
<th>Height (cm)</th>
<th>Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed #</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
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<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Using excel or other graphing program, create a scatter plot of the average height (y-axis) versus time (x-axis) for each pot. Add in error bars using your standard deviation values. Be sure to properly label your axes and give your graph a title.

3. You will fit your data points using a linear fit. Your software should have an option to display the equation. The slope of your line is your rate of height growth.

4. Create a scatter plot of the average width (y-axis) versus time (x-axis) for each pot. Add in error bars using your standard deviation values. Be sure to properly label your axes and give your graph a title.

**Critical thinking**

1. How does plotting the average height and width of the plant against time allow you to determine the rate of growth?

2. How does a large standard deviation affect the values you obtain for growth rates? What happens if your standard deviation for any data point is too large?

3. What does the graph tell you about the growth rate between light and dark? What factors may have contributed to any differences that you observed?

4. What does the graph tell you about the growth rate between corn and radish? If there is a difference in the rate, what factors do you think may have contributed to the germination rate?
13 – EXERCISE PHYSIOLOGY

Background
Mammalian physiological organ systems work together to maintain a state of homeostasis within the body. While each organ system has a distinct job, they each contribute to the proper functioning of the body. To summarize each of these organ systems, the digestive system is important for acquiring nutrition and is the provider of food energy for all the cells of the body. The musculoskeletal system allows an organism to physically move limbs to increase the chance of acquiring food in addition to escaping danger. The circulatory system pumps blood to all extremities and carries oxygen and substances that the cells of your body need to survive. The respiratory system works in concert with the circulatory system to reoxygenate blood and to release carbon dioxide, as well as remove wastes. The excretory system (renal system) maintains osmotic balance in the blood and bodily fluids by excreting excess salts, soluble wastes, and water. The endocrine system releases hormones to control organ function. The nervous system controls and coordinates all of the other systems and contains the central processor, the brain. For more information on each of these systems, please refer to the previous labs and the lecture materials. This project will require you to perform simple exercises and using your knowledge of physiological systems, describe how each system contributed to the changes you measured.

Objectives
1. Determine the lung capacity and pulse rate at rest of different people and compare this to factors such as age, sex, height and weight (optional).
2. Determine the breathing rate when at rest, after low physical activity, and vigorous physical activity.
3. Determine the pulse at rest, after low physical activity, and vigorous physical activity.
4. Determine the length of time it takes to fatigue under low and vigorous physical activity.

Hypotheses
1. How do you think a person’s size (height and weight) affects their lung capacity? What about other factors, such as fitness, smoking status, etc? Justify your answer based on your knowledge of physiological systems that you have learned in this course.
2. What do you think will happen to a person’s breathing rate when they begin to exercise? Justify your answer based on what you learned about the respiratory system.

3. What do you think will happen to the pulse rate as a person begins to exercise? Justify your answer based on what you learned about the circulatory and respiratory system.

4. What do you think will happen to your muscles if you continue to exercise vigorously?
Materials

- Biopac Airflow Transducer
- Biopac disposable mouthpiece
- Biopac electrode lead set
- Biopac electrode gel
- Biopac disposable electrode
- Biopac Temperature transducer
- Tape for temperature transducer
- Alcohol prep pads
- Stopwatch or timer (you may use your phone)
Instructions

1. Set up the Biopac unit as follows:
   a. Plug in the Airflow transducer to CHANNEL 1
   b. Plug in the Electrode Lead to CHANNEL 2
   c. Plug in the Temperature transducer to CHANNEL 3 (OPTIONAL)
   d. Start the Biopac Student Lab Program
   e. Choose Lesson “L15 – Aerobic Exercise Physiology” and click OK.

2. Each person from your group will take turns being subjects. Fill out the demographic information in the table below.

   *NOTE: Conversion from pounds to kilograms (kg): 1 lb = 0.454 kg
   *NOTE: Conversion from inches to centimeters (cm): 1 in = 2.54 cm

   ***NOTE: Do NOT choose a person with a history of heart or respiratory conditions, such as asthma! Choose someone who can perform moderate exercise for up to 10 minutes.

<table>
<thead>
<tr>
<th>Subject</th>
<th>AGE</th>
<th>HEIGHT</th>
<th>WEIGHT</th>
<th>SMOKER?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</table>

3. Prepare the airflow transducer with a disposable mouthpiece and give this to your subject.

4. You will tape the temperature transducer to the subject’s right fingertip according to the picture on the Biopac software (check the program for pictures).
5. You will attach the three electrodes to the subject according to the picture on the software (check the program for pictures).
   a. Please clean each spot with an alcohol pad.
   b. Place a small amount of electrode gel on the electrode pad.
   c. Stick the electrode pad on the three points below.
      i. Two on the bottom should be directly over the ribs.
      ii. The one on the top should be directly over the collarbone.
   d. Wait 5 minutes before starting measurements.
   e. Arrange all wires so that the subject can exercise comfortably without pulling off any of the wires.
   f. Follow the prompts on the program and be sure that all windows are consistently measuring blood pressure, breathing, and temperature. If one or more readings are not consistent, readjust the probes on the subject and try again.

6. While you are waiting, calculate the subject’s maximum heart rate at 80% max using this formula:

   \[
   0.80 (220 – \text{AGE}) = \text{MAX HEART RATE FOR SUBJECT}
   \]

   SUBJECT 1 Max Heart Rate = ____________________________

   SUBJECT 2 Max Heart Rate = ____________________________

   ***NOTE: MAKE SURE THE SUBJECT DOES NOT EXCEED THIS RATE DURING EXERCISE! ASK SUBJECT TO SLOWLY COOL DOWN

7. You will hit the record button on the computer.

   Use the following keys on the keyboard to label your points on the recording:
   F2: BEGIN EXERCISING
   F3: SUBJECT IS SWEATING
   F4: CHANGE IN INTENSITY
   F5: STOP EXERCISING

8. The subject will place the airflow transducer in their mouth and breath normally. This will be the data at rest. Check to make sure all the measurements are being displayed and that there are no blips in the recording. If there are, check your leads and try again.

9. Once you have confirmed that everything is running properly, record the subject for 2 minutes at rest.

   **NOTE: BEFORE YOU BEGIN THE NEXT STEP, MAKE SURE THE PERSON DIRECTING THE SUBJECT IS CHECKING THAT THE SUBJECT DOES NOT EXCEED THE CALCULATE MAX HEART RATE!**
10. Have the subject begin walking in place for 2 minutes. Hit the F2 key on the keyboard to mark when exercise started. If at any point the subject begins to SWEAT, hit the F3 key.

11. The subject will now jog in place for 2 minutes. Hit the F4 key on the keyboard to mark the change in exercise intensity. If at any point the subject begins to SWEAT, hit the F3 key.

12. The subject will now walk in place for 2 minutes. Hit the F4 key on the keyboard to mark the change in exercise intensity.

13. The subject will now stop exercising. Hit the F5 key and keep recording for up to 5 minutes while the subject is recovering from the exercise.

14. Stop the recording. Remove the electrodes from the subject and discard the disposable mouthpiece. You will now analyze your results.

15. Click done and analyze data. Choose the typing cursor on the right side of the program (I).

16. Examining the data from CHANNEL 1, you will now determine the breathing rate per minute at rest and the airflow amplitude during low impact exercise and moderate exercise. Highlight 60 seconds of data at rest (beginning of recording) and count the # of breaths. Do this for the walking, jogging, return to walking, and back to rest. Fill in your results in the table below (pg 142).

17. Examine the data from CHANNEL 2. You will determine the average HEART RATE per MINUTE during rest, low impact exercise and moderate exercise. Highlight 60 seconds of data at the appropriate points on the recording and count the # of heart cycles. Fill in your results in the table below (pg 142).

18. Examine the data from CHANNEL 3. You will determine the average body TEMPERATURE during rest, low impact exercise and moderate exercise. Highlight 60 seconds of data at the appropriate points on the recording and count the # of heart cycles. Fill in your results in the table below (pg 142).

19. You will now repeat STEPS 2 – 16 for SUBJECTS 2-4.

20. On a separate sheet of paper, using excel, or a photograph, gather the class data.

21. Separate the data based on the prediscussed groups (example: male vs female, short vs tall, etc…) and determine the average and standard deviation. Determine the statistical significance between the groups by performing a student’s two-tailed t-test (see APPENDIX or use excel).
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POST-LAB QUESTIONS

1. For each individual person in your group, what happened to the breathing rate, airflow amplitude, temperature and heart rate as exercise increased in vigorousness? What happened when the subjects slowly returned to rest?

2. After conducting the exercise trials, did the breathing and pulse rate recover to baseline levels (before exercise) after a 5-minute rest period?

3. What do you think would happen if you exercised vigorously for 1 hour? What would happen to your muscles? How would you feel? Use your knowledge regarding physiological systems to address this question.
4. What were the results of group comparison? Were the results significantly different? What does the standard deviation tell you about the experiment?

5. How does fitness level of an individual contribute to these measurements? What kind of measurements would you get if you were fit vs unfit?

6. What systems were involved in each aspect of breathing and pulse rate at rest, when walking, and when jogging? How did the body return each aspect back to baseline when you returned to rest? Use your knowledge regarding physiological systems to address this question. (Hint: all systems, the endocrine system in particular, are involved.)
14 – ANIMAL BIODIVERSITY SHOW AND TELL WORKSHEET

“Animal Biodiversity Show and Tell Worksheet” by Tin Chi ‘Solomon’ Chak is licensed under CC BY-NC. This work was adapted from “S3. Biodiversity Show and Tell Worksheet” by Sarah R. Stockwell and Jessica A. Davids, also licensed CC BY-NC.

Required readings: Biology2e Chapters 27.1 and 27.2.

Instructions:
1. Use a list of suggested websites to choose a species in the animal kingdom that you find interesting. Make sure enough is known about it to allow you to answer the questions below.

2. On Brightspace (or assigned LMS), go to the Google Slides document that has been set up for your discussion section. Check the Slides document to see if someone else in your section has already chosen the same species. If they have, you will need to choose something else. Once you have chosen a unique species, add a slide to the Slides document with your species’ common name, scientific name, and your name, along with a photo of the species. Complete the slide before the next lab.

3. Based on your species, answer the questions below. Complete the questions before the next lab and submit them online.

4. You will give a very brief presentation (about 1 minute) about your species in the following class. See the last page of this worksheet on what to prepare for the presentation.

Questions to submit on the LMS based on your unique species.
1. What is the Common and scientific name of your selected species?
2. Where on the animal tree of life is your species found? Phyla names are in the boxes.
3. What type of body symmetry does your species have (asymmetrical, bilaterally, radially, or rotational)?
4. Is your species diploblastic, triploblastic, or neither?
5. Does your species have a coelom?
6. Is your species a deuterostome, protostome, or neither?
7. How big is a typical individual of this species? If some individuals of this species are substantially larger than others (e.g., due to sexual dimorphism), please describe that as well.
8. What does this species eat? If it does not eat, how does it get energy?
9. In what ways do humans affect this species? In what ways does this species affect humans?
10. What other species eat your species? Is there another species that competes with your species for resources such as food or space?
11. Where does this species live (geography) and what is its natural environment like (habitat)?
12. Why is it important for people to know about this species?
13. Please list 3 additional facts about your species that you think your peers will find interesting. A good place to start is by asking yourself why this species is interesting to you. Why did you select it as your species? (Hint: “It was the top result on Google” isn’t a good answer.) Test out your fun facts on your friends!
14. List your sources here, including the URLs of websites you used. If you included the wording from a source verbatim in your answers above, make sure those words are in quotation marks and indicate the source.
What to do during the presentation?
Good news! Other than your answers to the questions above, you don’t need to prepare any other materials for the presentation. You should talk about these in your 1-minute presentation:

1. What is your species’ scientific and common name?
2. In which animal phylum is your species found?
3. What are three facts about your species that you found interesting (from question 13 or other questions above)?
(Note: There is no need to read these questions during your presentation. Talk through these points naturally as if you are introducing this interesting species to your friends.)

Reference:

15 - SECTIONS OF A LAB REPORT

Example of a lab report (NOTE: this is missing the abstract, citations and references):
https://courses.lumenlearning.com/suny-bio2labs/chapter/sample-lab-report/

***Refer to your instructor for additional information for the lab reports***

All statements from textbooks, lab manuals, and any outside sources MUST BE PROPERLY CITED. Do not use random websites as source material. The following sections must be included in your lab report and properly labeled:

**Abstract**
A brief summary (~1-2 sentences each) of your introduction, methods, results and discussion. While this section appears first in your lab report, it is generally written last.

**Introduction**
Begin the introduction by providing general background information relevant to understanding the experimental objectives. The background will become more specific and geared to the experiments. The introduction should end with a brief statement of the question(s) that is being addressed and the hypotheses for each objective. All statements from textbooks, lab manuals, and any outside sources MUST BE PROPERLY CITED.

**Methods**
The methods that are used to test the hypotheses must be clearly and concisely written. The purpose of the methods is to allow the reader to copy the experiment. Write in full sentences and in paragraph form. Methods are not written in bullet point format.

**Results**
All results, figures, and tables to depict the experimental outcome are placed into this section. Break each result into several parts so that the results can be clearly stated. Be sure to properly number each figure and/or table. Write specifically what your findings were in paragraph form and be sure to reference each figure or table as you write. Generally, the first sentence for each result will begin with: “This experiment examined X, and it was found that ____ occurred (Figure Y).” Be specific and detailed.

**Discussion**
This section includes a thorough discussion on why the results are the way they are, and whether the hypotheses were correct or not. Outside literature should be used to add further evidence to the reasoning. All statements from textbooks, lab manuals, and any outside sources MUST BE PROPERLY CITED.

**References**
Any information that is used from reputable sources (textbooks, peer-reviewed articles), need to be cited and compiled in a reference list. (Example: APA style or MLA style)
## 16 - LAB REPORT GRADING RUBRICS

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</table>

***Refer to your instructor for additional information on lab reports***
APPENDIX – Calculations and Graphs

1. How to calculate average or mean:

\[ Average = \frac{\sum X}{N} \]

Where:
\( X \) = value in data set
\( N \) = total number of data points

Example calculation:
Data set: 5, 6, 7
Average = \( \frac{5+6+7}{3} \)
Average = 6

2. How to calculate standard deviation of means:

\[ SD = \sqrt{\frac{\sum |X - \mu|^2}{N}} \]

Where:
\( X \) = value in data set
\( \mu \) = mean
\( N \) = total number of data points

Example calculation:
Data set: 5, 6, 7
Mean = 6
\( SD = \sqrt{\frac{[(5 - 6) + (6 - 6) + (7 - 6)]^2}{3}} \)
SD = 1.33
3. **How to calculate student’s t-test:**
   a. Calculate the t value using the equation below:

   \[ t = \frac{(X_1 - X_2)}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \]

   Where:
   - \( X_1 \) is the mean of sample 1
   - \( S_1 \) is the standard deviation of sample 1
   - \( n_1 \) is the sample size of sample 1
   - \( X_2 \) is the mean of sample 2
   - \( S_2 \) is the standard deviation of sample 2
   - \( n_2 \) is the sample size in sample 2

   **Example calculation:**
   Mean 1: 10
   Standard deviation 1: 1
   Sample size 1: 10
   Mean 2: 20
   Standard deviation 2: 3
   Sample size 2: 9

   \[ t = \frac{(10 - 20)}{\sqrt{\frac{1^2}{10} + \frac{3^2}{9}}} = 9.09 \]

   b. Determine the degrees of freedom (df) for the test by adding the sample sizes of both groups and subtracting 2.

   **Example continued:** df = 20 + 10 – 2 = 28

   c. Determine the Critical T-Value using the table below. Match the df with the t-value to determine the significance value. Any value of p that is 0.05 and lower is considered significant.
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Acknowledgements
This work was supported by a SUNY OER Services Impact Grant (2023).

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