1. Understand cephalopods with respect to:
   a. Body plan
   b. Locomotion
   c. Respiration
   d. Circulation
   e. Digestion

2. Dissect and identify parts of a squid

INTRODUCTION

Form and function

Before you begin examining the anatomy of each organism, the manual will give a little background on each animal and you should also look it up on your own. Where do they live? What do they eat? What eats them? What are the biggest challenges in surviving? In reproducing? Look at how each organism has adapted to its environment.

Form is believed to follow function, meaning that the form of a body part or structure is related to the function it carries out. Think about how the form of each body part you examine today aids in its function. How does it compare to body parts from closely related organisms? How different are they? How similar are they?

Metazoan Phylogeny

The metazoans, or multicellular animals, are most likely derived (evolved) from a common single-celled eukaryotic organism that lived about 700 million years ago. Since then, the metazoans have undergone periods of mind-boggling diversification. Some paleontologists estimate that more than 100 different phyla have existed at one point or another; fewer than half of those survive today.

If you accept the theory that all animals have a common ancestor, then it seems logical that all animals should have some traits or characteristics in common with one another. However, as you look at the diversity of life, you will recognize that certain groups of organisms share more similarities to each other than others. Shared traits may indicate that organisms are more closely related to each other than to a third organism who does not share that trait.

For example, worms and insects have segmented bodies, whereas starfish do not have segmented bodies. Worms and insects are thought to be more closely related to each other sharing a common ancestor, than they are to starfish. A cladogram is a diagram which depicts the relationships between different groups called clades. By depicting these relationships, cladograms reconstruct the evolutionary history (phylogeny) of the taxa. Cladograms are constructed by grouping organisms together based on their shared derived characteristics. As
you move up the cladogram towards the branches, a line that diverges into two lines symbolizes where a common ancestor diverged into two evolutionary lines now differentiated by a certain characteristic. Cladograms can also be called **phylogenies** or **trees**.

The evolutionary relationships among the metazoan can be estimated by examining the presence (or absence) of shared traits or characters. Imagine four phyla of animals designated A, B, C, and D (Figure 6-1a). All four phyla share trait a, phyla B, C, and D share the trait b, and phyla C and D both share the trait c but do not share the trait d (only possessed by phylum D). An analysis of these phyla with regard to these characters would lead us to construct a phylogenetic tree (or cladogram) that may represent their evolutionary lineage or relationship.

Refer to Figure 2 for an example of a cladogram. According to this example, birds are most closely related to crocodiles and they share the characteristic of producing eggs with shells.

As already mentioned, shared characters suggest common ancestry. The more characters shared, the closer the relationship between organisms. As one moves up from the base of the phylogenetic tree, one moves through the evolutionary history of this group of organisms.
TRUE TISSUES
The animal kingdom is divided into Parazoa (Sponges) and Eumetazoa. Eumetazoa possess true differentiated tissues while sponges do not. Eumetazoans have distinct groups of cells that are arranged for specific purposes. Refer to Figure 3 to see phyla that fall into the Eumetazoa group.

BODY SYMMETRY
The Kingdom Animalia can be divided into two broad groups based on morphological symmetry. Animals such as worms and insects are said to exhibit bilateral symmetry (see Figure 4). Imagine a plane that has divided the organism right down the middle creating symmetrical right and left sides.

Animals that do not have obvious left and right sides, like sea anemones and starfish, are examples of animals with radial symmetry in their adult form. The body is usually cylindrical or disk shaped (possible with radiating arms) and multiple planes can be passed through the organism to create symmetrical halves.

Looking at Figure 3, which phyla exhibit radial symmetry? What body symmetry do you exhibit?

Generally, radially symmetrical animals are sessile or slow moving while bilateral animals tend to be more motile. The
following orientation/directional terms are used for animals with bilateral symmetry:

- **Anterior**: the end where the head is
- **Posterior**: the rear end
- **Dorsal**: the top surface, the back
- **Ventral**: the bottom surface, underside
- **Lateral**: surfaces on the side

Because of the way most animals move, the anterior end of an animal is the end that normally encounters the animal’s environment first. So the anterior end tends to be concentrated with a variety of sense organs and nervous tissue, a phenomenon known as **cephalization**.

**CELL LAYERS**
The animals that we will be studying the rest of this semester are **triploblastic**. This means that they are composed of three types of embryonic tissue or **germ layers**:

- **Ectoderm**: this embryonic tissue develops into the skin and nervous tissue
- **Mesoderm**: this gives rise to most muscles and organs
- **Endoderm**: this makes up much of the gut

The **coelom** is a fluid or air-filled internal cavity which separates the gut from the body wall (refer to Figure 5). This body cavity suspends the body organs and can act as a shock absorber. It is considered a **true coelom** if it is lined entirely with mesodermal tissue and a **pseudocoelom** if the lining is of mixed dermal origin. An animal without a coelom is called an **acoelomate** while animals with a coelom is considered a **coelomate**. A flatworm is an acoelomate while an earthworm is considered a coelomate. In an earthworm, the coelom is filled with fluid that acts like a skeleton.

![Figure 5. Types of body cavities](image)
PHYLUM MOLLUSCS

Most members of the Phylum Mollusca (Latin: *mollis*, soft) are included in one of the four major clades:

- **Polyplacophora** (chitons)
- **Gastropoda** (snails, slugs and limpets)
- **Bivalvia** (clams, oysters and related forms)
- **Cephalopoda** (squids, cuttlefish and octopods)

In this lab, you will be studying the online dissection of a squid, *Loligo pealei*.

BODY PLAN

Molluscs are bilaterally symmetrical and are believed to have evolved from annelid-like ancestors. Although their mode of development is similar to annelids, molluscs completely lack segmentation and have greatly reduced the size of their coelom. The Phylum Mollusca is one of the most morphologically diverse animal groups. The adaptations that members of the different clades possess have allowed for their great success in many different environments. Despite this diversity, all molluscs are derived from a general body plan with three main body regions:

- **A head-foot**
  The head-foot region is primarily responsible for sensory and locomotion.

- **A visceral mass**
  The visceral mass is located atop the head-foot and contains the digestive, circulatory, reproductive and excretory organs.

- **A mantle**
  The mantle covers the visceral mass and assumes a variety of functions, including secretion of the calcareous shell and respiration.

In each of the four major clades, these three body regions vary in their dominance.

![Figure 6. Variance in three major body regions in molluscs](image)
Squids belong to the class, Cephalopoda, alongside octopus and cuttlefish. In cephalopods (Greek; “kephalo”- head, “pod” - foot), the head-foot region dominates the body. The “head” of cephalopods are highly cephalized with a well-developed nervous system. In addition, the foot has been modified into arms and feeding tentacles. The visceral mass is surrounded by a muscularized mantle, which is the fleshy cover that protects the soft body. The openings of the digestive, reproductive and excretory systems, and most importantly, the ctendidia or gills, are all found within the mantle cavity. The shell is reduced and is either internal or completely absent, except in ancient cephalopods (e.g., Nautilus), which possess an external chambered shell.

**SUPPORT & MOVEMENT**

Unlike other molluscs, most cephalopods, such as the octopus, entirely lack external shells for support. The squid, on the other hand, has an internal remnant of the shell known as the gladius, or pen, which is a hard feather-shaped structure that runs along the length of the mantle. Why might a reduced or internal shell be advantageous for the squid?

Locomotion in cephalopods is unique and involves not only the eight arms, but also the mantle, which has become highly muscular. Although cephalopods can move by swimming or crawling with their arms, most cephalopods primarily move by a type of jet propulsion. Water is taken into the mantle cavity and expelled forcefully through a long tube-like structure called the siphon by contractions of the muscular mantle walls. By rapidly opening and closing its mantle, cephalopods can rapidly eject water through its siphon and create short jets of water to propel itself. The flexible siphon and the arms can even be angled to control the direction of movement and allow for cephalopods to rapidly change its course in the water. Some cephalopods, like squids, have also paired paddle-shaped fins that extend from the mantle to help steer and aid in forward or backward movement. Altogether, this special type of movement makes cephalopods the fastest marine invertebrates!

**RESPIRATION & CIRCULATION**

Cephalopods have paired gills called ctendidia in the mantle cavity that serve as the respiratory structure for gas exchange. Oxygen-rich water is drawn into the sides of the mantle cavity and as the mantle is filled, water slowly flows over the gills, allowing the exchange of oxygen and gases with the seawater to occur. The entrance of the mantle cavity then closes and forceful contractions of the mantle walls consequently eject deoxygenated water out the siphon. Therefore, cephalopods ventilate their gills by muscular contractions of the mantle. Water flow is

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maintained by the repetitive filling and emptying of the mantle cavity as the cephalopod jet-propels through the water.

As the water passes over the ctenidia, oxygen diffuses into a large blood vessel on the outer edge of each gill. Carbon dioxide is also released from the blood into the water. The veins in the gills carry oxygenated blood to the main **systemic heart**, which pumps blood to the rest of the body. Deoxygenated blood from the body is collected by the **posterior vena cava** and emptied into two hearts located at the base of each gill known as **branchial hearts**, which then pump blood via into the vessels of the gills to become re-oxygenated.

Cephalopods are the only molluscs that have all of their blood contained in vessels in a **closed circulatory system**; all other members of the Phylum Mollusca have open circulatory systems, in which the blood empties from vessels into body cavities (**hemocoels**) directly bathing the organs within. In general, all molluscs have a respiratory pigment called **hemocyanin**, a copper-containing protein, to transport oxygen. Interestingly, the presence of hemocyanin in the blood of molluscs causes blood to turn from colorless to blue when exposed to air.

**FEEDING & DIGESTION**

While certain molluscs, such as bivalves and some gastropods, are filter feeders that use their ctenidia to trap food suspended in water, cephalopods are active carnivores. Squids feed a variety of prey, such as small fish, crabs, shrimps, and even other smaller squids. A squid uses powerful sharp-toothed **suckers** on its two longer feeding **tentacles** to capture its prey and drag it towards the mouth, where the other eight **arms** manipulate the prey for consumption. Squids actually have eight arms and two feeding tentacles whereas
octopuses only have the eight arms. Furthermore, the mouth, which is contained in the muscular **buccal mass**, is equipped not only with sharp chitinous jaws or **beak** used for tearing prey, but also with the **radula**, a tongue-like organ inside the beak that is covered with rows of tiny teeth. 

*What do you think is the purpose of the radula?*

Once the prey is secured at the mouth, cephalopods also contain **salivary glands** that can release poisonous secretions to kill the prey or liquefy any soft body parts. Food passes from the mouth in the buccal mass to a thin esophagus before entering a thick-walled stomach lined with rough ridges to grind up the food. Unlike squids, octopods also have a section of the esophagus that is enlarged to form a crop for storing food before it enters the stomach. Food is further processed in the stomach with the aid of digestive enzymes secreted by a cream-colored **digestive gland**. Partially digested food is next passed into a larger pouch-like organ called the **cecum**, where digestion is completed and nutrient absorption primarily occurs. The walls of the cecum consist of ciliated folds to sort minute food particles and any indigestible material is passed up to the intestine, where they are compressed into excrement. Waste is discarded into the rectum that leads to the anus and is ultimately directed out of the **siphon**, where all the waste products exit into the water.

**REPRODUCTION**

Cephalopods are **gonochoristic**, either male or female, and engage in internal fertilization. Females possess large ovaries and a prominent pair of white **nidamental glands**, which secrete the outer covering of the eggs. Males have a large testis and package their sperm into complex structures called **spermatophores**. During copulation, males directly deposit their spermatophores into the female. Some species, such as squids, use a specially modified arm to deliver their spermatophores to the female, while other species use an elongated penis at the end of the vas deferens to transfer their spermatophores. Following fertilization, the female attaches gelatinous masses of fertilized eggs to objects underwater or releases them into the water column, where the offspring must fend for themselves after they hatch.

Because cephalopods lack external sexual characteristics, they engage in courtship rituals that involve elaborate color changes using concentrated pigmented cells in the mantle known as **chromatophores**. Cephalopods can remarkably control their chromatophores to produce complex chromatic displays, which also helps them camouflage to hide from predators or communicate with each other.