Life in the Fast Lane: From Hunted to Hunter

Lab Investigation: Class Cephalopoda *High School Version*

Lesson by Kevin Goff

Shape of Life

Squid and octopi are **cephalopods**. The name means "head-foot," because these animals have gripping, grasping arms that emerge straight from their heads. At first glance, they seem like an animal group all to themselves, utterly different from every other creature on Earth. But in fact, they are **molluscs**, belonging to the same phylum as snails and slugs (**gastropods**), as well as clams, oysters, mussels, and scallops (**bivalves**). Like all modern day molluscs, cephalopods evolved from simple, snail-like ancestors that crept sluggishly on the Cambrian seafloor over 500 million years ago. These ancient snails had shells resembling an umbrella, probably to shield them from the sun's intense ultraviolet radiation. When all sorts of new predators appeared on the scene, with powerful jaws or crushing claws, a thin shell was no match for such weapons. Over time, some snails evolved thicker shells, often coiled and spiky. These heavy shells did a better job of fending off predators, but they came with a price: They were costly to build and a burden to lug around. These snails sacrificed speed for safety.

> **VIDEOS TO WATCH**
>
> **Get familiar with basic molluscan anatomy by watching this short clip on the *Shape of Life* website:**
>
> - **"Mollusc Animation: Abalone Body Plan" (under Animation; 1.5 min)**
>
> **Take special note of the abalone's foot, radula, and shell-making mantle. These traits were present in the snail-like ancestor of all molluscs.**

This lifestyle worked fine for many molluscs. Still today, nearly 90% of all molluscan species are heavily armored **gastropods** that crawl around at a snail's pace. Most are grazers or scavengers, a lifestyle that doesn't require speed. About 10% of molluscs – the **bivalves** – have adopted an even less active lifestyle: They are filter feeders who sit still and simply wait for food to come to them. But the remaining 1% of molluscs – the **cephalopods** – have abandoned such lifestyles. They are active predators who stalk, chase, and kill live prey. And they do it not by scuttling across the seafloor but by swimming in open water with remarkable speed.

> **VIDEOS TO WATCH**
>
> **Now watch this *Shape of Life* clip:**
>
> - **"Mollusc Animation: Squid Body Plan"(under Animation; 1.5 min)**
>
> **Note how the ancestral snail's foot, mantle, shell, body shape, and other traits have radically changed in squid.**

Now, it may be hard to imagine snails evolving into sleek and speedy squid, built for hunting on the high seas. It would help if we had a "transitional form" that exhibits intermediate traits between snails and squid. And luckily, we do! The beautiful chambered nautilus has a heavy, coiled shell like a snail. Yet its body is squid-like, with many tentacles and big eyes. These rare "living fossils" give us a glimpse of early cephalopods – first the nautiloids, later the ammonoids – that used to swarm the ocean. Some had coiled

> **VIDEOS TO WATCH**
>
> **See how the nautilus represents a transition from sluggish snail to speedy swimmer in this Shape of Life clip:**
>
> - **"Mollusc Animation: Nautilus Body Plan" (under Animation; 2.5 min)**

shells, ranging from the diameter of a nickel to bigger than a truck tire. Others' shells were straight cones, sometimes as long as a small airplane! They left life on the seafloor by storing buoyant gas in their shells, like the living nautilus. In those days, early fish were also slow swimmers, weighed down by heavy, bony plates. But in time, fish lost their bony armor and got much faster. And to keep pace with their fishy competitors, cephalopods evolved bodies built for greater and greater speed, too …as you'll soon see!

In this lab activity you'll dissect *Loligo*, a genus of squid that swims in the open ocean. In this environment, there is nowhere to hide, and success depends on raw speed. Fast, strong, and intelligent, a squid's body is well built for hunting and escaping. They may seem light years away from slow-moving slugs and other all-but-brainless gastropods, yet when you examine them closely you can still see the shadow of snails past.

> **YOUR MISSION:** As you dissect your squid, make a running list of as many adaptations for an ***open-water, predatory niche*** as possible. For each, write a sentence describing HOW that trait helps the animal capture, subdue, or consume its prey, and/or escape other open water predators. As you do so, keep the ancestral snail in mind. List at least 10 EXTERNAL adaptations and 5 INTERNAL adaptations. Turn these in on a separate sheet of paper.

EXTERNAL ANATOMY

1. Position your squid in a dissecting tray as diagrammed. ***Make sure the funnel is facing the ceiling!*** Rinsing your specimen under a faucet will help diminish preserving fluid fumes.

2. **Cephalopod** means "head-foot," and for good reason: The tentacles extend straight from the head! Distinguish the head-foot region from the **mantle**. In snails, clams, oysters, mussels, etc., the mantle is a soft and flimsy internal tissue that produces the shell. But notice the squid lacks an external shell, and its mantle has become thick, muscular, and streamlined, with a pair of **fins**. By undulating its fins, the squid can cruise slowly through the water, but it uses its funnel to jet propel when it needs speed. The fins also act as keels for balance and rudders for turning.

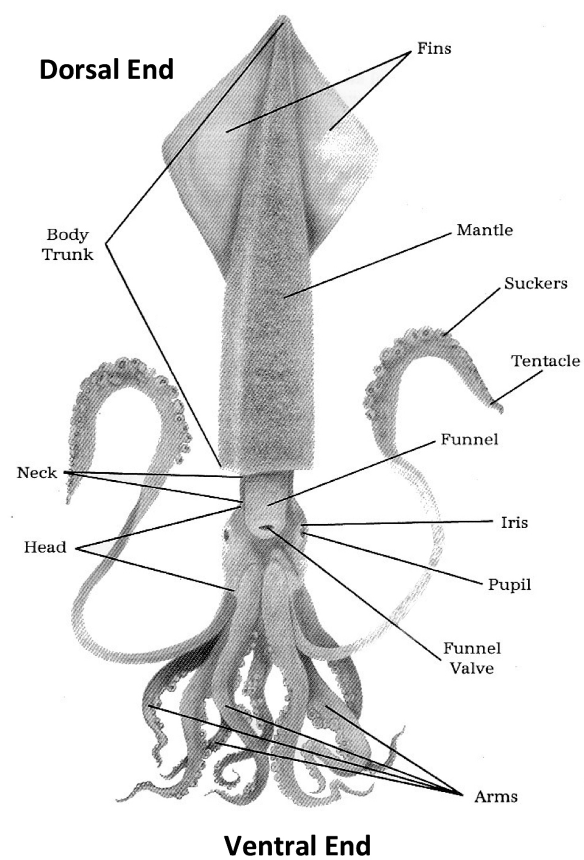

Diagram by Glen Folsom, from David Hall's *An Illustrated Mini Dissection Guide to the Squid*

3. Lift the rim or "collar" of the mantle and peek underneath. This is where water enters the **mantle cavity** and washes over the gills (you'll see these later). Wedge open the nozzle-like **funnel** with forceps or a probe. This is where water is flushed from the mantle cavity. By rhythmically inflating and deflating its mantle cavity, the animal can squirt pulses of water from the funnel. (By the way, the funnel is probably all that remains of the ancestral snail's foot.) The result is rapid **jet propulsion**. Squid swim like torpedoes, with the funnel hanging underneath. They can aim the funnel forwards or backwards, allowing them to swim with arms leading the way (for hunting) or arms trailing (for escape).

4. Examine the ten **arms**, whose function is to seize live prey (usually fish). Notice that the two tentacles are longer and flattened near the tips. Both the arms and tentacles are covered with **suckers**. Snip off a piece of an arm or tentacle and examine the suckers with a magnifying glass or binocular microscope. Look carefully and you'll see that the suckers have jagged "teeth" for improved grip! Snip off a piece of an arm and examine the suckers with a magnifying glass or binocular microscope. Look carefully and you'll see that the suckers have jagged "teeth" for improved grip!

5. Check out the **eyes** on either side of the head. These are advanced "camera" eyes very much like our own, complete with **pupil**, **lens**, and **retina**. (Later you can dissect an eye, but not yet.) Unlike the simple eyes of snails, slugs, and scallops, the cephalopod eye generates crisp images with excellent resolution. Indeed, squid and octopi have the keenest eyesight of any invertebrate.

6. Spread the arms and find the squid's mouth in their midst. Use a probe to poke around inside and you'll feel the hard, sharp **beak** within. (Later you'll remove this and dissect it.) The saliva of many cephalopods contains a **venom** that stuns their prey. The small blue-ringed octopus, which lives in shallow tide pools along the coast of Australia, packs the most potent venom of all, quite able to kill a human. The blue-ring's bite usually isn't felt, but within minutes the paralyzing neurotoxin causes the victim to collapse, his chest muscles lock up, and he suffocates.

7. Notice the dark spots on the mantle. These are **chromatophores**, tiny organs that enable squid to quickly change color. Each chromatophore is a pool of dark pigment surrounded by muscle fibers and nerves. To turn darker the squid expands the pools of pigment, and to turn lighter it contracts them. Most squid and octopi use camouflage to make up for the absence of a shell. What's more, many octopi

VIDEOS TO WATCH

For dazzling displays of octopus color-changing and shape-shifting, watch these *Shape of Life* clips (under "Behavior"):

- **Molluscs: Octopus Camouflage (2 min)**
- **Molluscs: Blue-Ringed Octopus Warning Coloration (1 min)**

can dramatically alter the texture of their skin to mimic rocks, coral, and seaweed! Deep sea squid have glow-in-the-dark **photophores** that create "living light," or **bioluminescence**. Besides the light-producing tissue, these complex little organs are often equipped with shutters, lenses, and internal reflectors, just like a signal beacon. Extraordinary!

INTERNAL ANATOMY

8. Lay your specimen in the dissecting tray, funnel side up. Use scissors (blunt tip down) to make a long cut along the length of the squid's mantle, from funnel to the dorsal tip. Pin the mantle open to reveal the **mantle cavity** and internal organs (see diagram below).

   Valuable dissecting hint: The organs are held in place by thin, semi-transparent sheets of **mesentery**. By peeling and cutting these membranes away, you can get a much better view of the organs underneath.

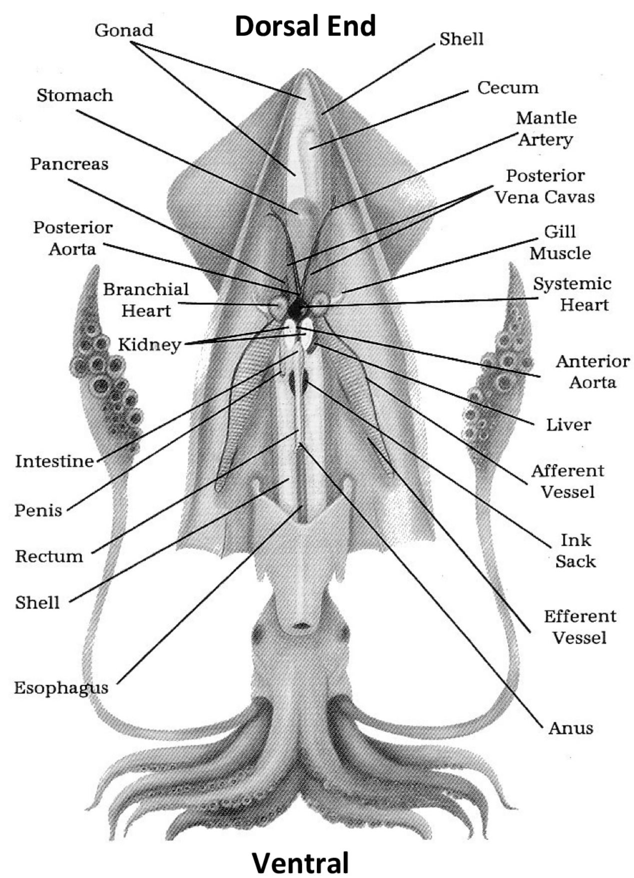

Diagram by Glen Folsom, from David Hall's *An Illustrated Mini Dissection Guide to the Squid*

9. The **gonad** usually occupies the dorsal region of the body cavity. This reproductive organ produces **gametes** (sex cells). Is your squid male, with a smooth, whitish **testis** for producing sperm? Or is it female, with an **ovary** and perhaps a mass of orange or yellowish eggs? If female, your squid will also have a pair of large, long, cream-colored **nidamental glands** between the gills. These produce the egg casing. In males, packets of sperm are ejected through the **penis**, which you may be able to find beside the gills. During mating season, squid gather in huge shoals, with males battling over females. A successful male wraps his arms around a female. He then uses one of his tentacles to transfer a sperm packet to his mate's mantle cavity. The packet ruptures, releasing sperm to fertilize the eggs. Later, the female expels them through her funnel and attaches them in clusters to something solid on the seafloor. They hatch out as small yet well-developed juveniles, with eyes, arms, jet propulsion, color-changing chromatophores, and all!

10. If your squid is female, you'll want to remove the two large nidamental glands, being careful not to damage the organs underneath. Now explore the structure of the two feathery **gills** with a probe. They are much more branched, and bushy than the plate-like gills of ancestral snails and most modern molluscs. Moreover, each gill has its own heart! Called **branchial hearts**, they pump blood in and out of the gills to absorb oxygen. In between the branchial hearts is a third heart, the bigger and more muscular **systemic heart**, which pumps oxygen-rich blood to the rest of the body. Squid have evolved a **closed circulatory system**, which pipes blood directly to all body tissues through pressurized arteries. This is a major advance over gastropods and bivalves, whose circulatory system is "open," with blood weakly soaking into the animal's spongy tissues. A squid's blood is colorless until exposed to oxygen, which turns it blue because it's copper-based. (Our own blood is iron-based, which makes it red.)

11. Near the hearts look for a pair of small, triangular, whitish organs: the **kidneys**. These filter nitrogen wastes from the bloodstream and excrete them into the mantle cavity.

12. Identify the digestive organs. Remember that the mouth is in the head, amidst the arms. The **beak** bites off chunks of meat, which travel up the **esophagus** and into the **stomach**. The stomach is just above and behind the hearts, often slightly left of center. It can be hard to find, but if you use your fingertips, it may feel firmer and more muscular than other organs. Slice it open to reveal hard internal ridges that grind food mechanically, while enzymes break it down chemically. These enzymes are secreted by two organs: (1) the **liver**, a long whitish organ against the back wall, stretching along the midline from the head to the stomach; and (2) the **pancreas**, which is small and nestled amidst the kidneys, hence hard to find. Nearby, locate the **cecum**, a big flimsy pouch adjoining the stomach where food is further digested and nutrients are absorbed into the blood. Anything undigested passes down the **intestine** and out the **anus**, to be flushed out through the funnel. This compartmentalized digestive system is more complex than that of grazing gastropods and filter feeding bivalves. It can handle a large mass of food at once and process it quickly.

13. Find the **ink sac** under the intestine. Puncture it with a probe. When threatened, the squid releases clouds of dark, noxious ink to confuse the enemy and screen its escape. Some deep sea squid startle attackers by squirting out glow-in-the-dark bioluminescent ink!

14. Against the back wall you can find the squid's **pen**. This thin, lightweight plate is all that remains of the ancestral shell. It's internal now and offers no protection – just a bit of support for the streamlined body. See if you can remove the entire pen without breaking it. Why do you think it was nicknamed a "pen"? If

you're ever stranded on a desert isle and need to put a note in a bottle, but don't have a writing utensil, just dissect the nearest squid and you'll have both pen and ink!

15. Now cut away the squid's arms and carefully remove the **beak**. It's packed in powerful jaw muscles. Strip away the outer tissue and you'll see it resembles a parrot's beak (but upside down). Open the beak to find a toothy tongue – the **radula**. Study its hook-like teeth under a magnifying glass or binocular microscope. Can you see how they're arranged for rasping meat off their prey?

16. With a sharp scalpel and a careful hand, you can expose the squid's **brain**, which is encased in a "skull" of cartilage between the eyes. Slice at an angle to avoid damaging it. This is by far the most advanced brain of any invertebrate. Squid and octopi can quickly process complex sensory information, including the "imaging" of data from the eyes. At the same time, they can control eight to ten different arms with exceptional speed and dexterity. They are capable of learning and can even be trained!

17. Finally, dissect the **eye**. Light enters through the **pupil**, the hole at the front. Around it is an **iris** that dilates and contracts to control brightness. The hard nugget inside is the **lens**, which focuses light on a dark, light-sensitive **retina** at the back of the eye. It's the same design as your own eye, yet the cephalopod eye evolved quite independently of our vertebrate eyes!

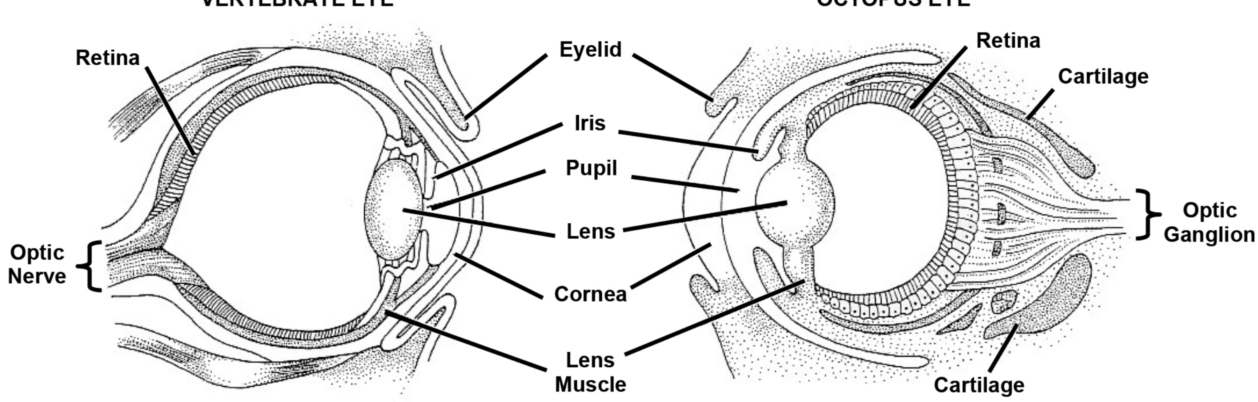

Image: Futuyma's *Evolutionary Biology*, 3rd ed

POST-LAB ACTIVITIES AND DISCUSSION

- Visit the ***Shape of Life*** website and watch one of these two segments:
    - "Peter Ward, Paleontologist: The Ancient Nautilus" (under Scientists; 8 min)
    - "Molluscs: Nautilus Regulates Its Buoyancy" (under Behavior; 2 min)

Discuss with your teacher and classmates how the nautilus represents the evolutionary transition from sluggish snails to speedy squid.

- Share and discuss your list of squid adaptations for a predatory, open water lifestyle.
- A "big pattern" that we often see in the fossil record is **co-evolution**. Co-evolution occurs when different plant and animal lines adapt to EACH OTHER, back-and-forth, reciprocally. Very often, coevolution is an "**arms race**" between predators and prey. For example, rabbits gets faster to outrun foxes, then foxes get faster in response, so rabbits get even faster …and so on. Watch the ***Shape of Life's*** "Molluscs: The Survival Game" (under Phyla; 15 min). Discuss the 500+ million year history of molluscs as a never-ending co-evolutionary arms race.
- Another "big pattern" is **divergent evolution**. This occurs when one group of organisms splits into several new and different groups with new habitats and lifestyles. Similarities reflect common ancestry. Differences reflect later adaptation of body parts and behaviors for new functions. Discuss how the following traits "diverged" over the long history of molluscs:
    - Shells (remember: the ancestral mollusc had a thin umbrella shell on its back)
    - Foot (the ancestral mollusc crawled on a single muscular foot)
    - Gills (the ancestral mollusc had simple plate-like gills)
- The last "big pattern" is **convergent evolution**. It's sort of the opposite of divergent evolution, but not exactly. Convergence occurs when organisms that are NOT closely related evolve similar body features to serve similar functions for similar lifestyles or similar habitats. In other words, they evolve similar adaptations separately and independently of one another. They're alike, but not akin. The most remarkable case of convergence is the "camera eye" of squid and octopi. It's incredibly similar to our own eyes. Like our eyes, it's round and filled with fluid to bend light. The eye is encased in a socket of bone or cartilage. It's shielded by an eyelid and transparent cornea. The eye has an iris for adjusting the pupil to regulate the amount of light. And it has a lens for focusing images on a dark retina packed with photoreceptors, all

wired to the brain by way of an optic nerve. What's most amazing is that these two organs did NOT evolve from a shared ancestor who had a camera eye. Nor did one evolve from the other. There are a few telltale differences between the two eyes. The photoreceptors are arranged quite differently on the retina, and an octopus's lens slides forward and backwards to focus, while our lens focuses by changing shape. Yet overall, the likeness is astonishing. Natural selection fashioned the same exquisite device twice!

With your classmates, brainstorm examples of NON-molluscs whose traits "converged" with these other squid traits: (1) **sharp beak**, (2) **venomous saliva**, (3) **streamlined mantle**, (4) **supportive inner shell** ("pen"), and (5) **grasping arms**.