The Blue Mussel: A Not-So-Typical Mollusc

Lab Investigation: Class Bivalvia *High School Version*

Lesson by Kevin Goff

Shape of Life

Overview: Through a sequence of engaging laboratory investigations coupled to vivid segments from the acclaimed *Shape of Life* video series, students explore the fascinating structural and behavioral adaptations of modern molluscs. But rather than study these animals merely as interesting in the here-and-now, students learn to view them as products of a 550 million year natural history. Students interpret their diverse adaptations as ancient solutions to the challenges of life in a dangerous world, while using Phylum Mollusca as the occasion to discern three major macroevolutionary patterns: divergent evolution, convergent evolution, and coevolution.

NEXT GENERATION SCIENCE STANDARDS

MS-LS1-4 Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.

MS-LS2-2 Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

MS-LS2-4 Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

MS-LS4-1 Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.

MS-LS4-2 Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.

MS-LS4-6 Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.

MS-ESS1-4 Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.

HS-LS1-2 Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

HS-LS2-2 Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

HS-LS4-1 Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

HS-LS4-2 Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

HS-LS4-4 Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

HS-LS4-5 Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Cross-Cutting Concept #1: Patterns

Cross-Cutting Concept #6: Structure and Function

Scientific and Engineering Practice #4: Analyzing and Interpreting Data

Scientific and Engineering Practice #7: Engaging in Argument from Evidence

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Grades: 7-12. The lesson plans below primarily target high school audiences, but there is a middle school version of each lab activity, and the lessons are adaptable for younger students.

Subjects: Biology, Earth science, ecology, paleontology, evolutionary science

Key Concepts / Unifying Theme: Three recurring patterns of long-term macroevolution: divergence, convergence, and coevolution

Essential Skills / Scientific Process: Interpreting biological adaptations as instances of "form follows function." Analysis of graphs and time series.

Instructional Approach: In general these lessons ply an "explore-before-explain" pedagogy, in which students make and interpret observations for themselves as a prelude to formal explanations and the cultivation of key scientific concepts. There are splashes of inquiry and scientific process using authentic data, and students are pressed to think at higher cognitive levels. Instruction is organized around three unifying themes – the macroevolutionary patterns of divergence, convergence, and coevolution – and students learn to interpret diverse biological phenomena of these patterns.

Common Core State Standards for Literacy in Science and Technical Subjects supported in this module:

Writing Standard 1.b, 6-8 Write arguments focused on discipline-specific content: Support claim(s) with logical reasoning and relevant, accurate data and evidence that demonstrate an understanding of the topic or text, using credible sources.

Writing Standard 1.b, 9-10 Write arguments focused on discipline-specific content: Develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns.

Writing Standard 1.b, 11-12 Develop claim(s) and counterclaims fairly and thoroughly, supplying the most relevant data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form that anticipates the audience's knowledge level, concerns, values, and possible biases.

Writing Standard 2, 9-12 Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

Writing Standard 4, 9-12 Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Common Core State Standards for Mathematics supported in this module:

8.SP.A.1 Statistics & Probability – Investigate patterns of association in bivariate data: Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities.

HSS.ID.B.6 Statistics & Probability – Interpreting Categorical and Quantitative Data: Summarize, represent, and interpret data on two categorical and quantitative variables.

HSS.IC.B Statistics & Probability – Making Inferences & Justifying Conclusions: Make inferences and justify conclusions from sample surveys, experiments, and observational studies.

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Shape of Life

The earliest animals on Earth had either irregular, **asymmetrical bodies** or **radial symmetry**, with a body shaped like a merry-go-round. Animals with these body plans usually sit still on the seafloor – like sponges, coral, and sea anemone. Others – like jellyfish – just drift along on ocean currents. These animals do not actively forage for food. Instead, they wait for food to come to them. Their body shape lets them collect food from any direction. Eventually, though, a line of worm-like animals evolved **bilateral symmetry**, with a body bearing two sides – left versus right – that are mirror images of each other. This body plan is an adaptation for **directional movement**. To understand why, just imagine a car with monster truck tires on one side and little red wagon wheels on the other. It would go in circles! Having identical left and right halves enables an animal to track in a straight line.

Video Titles:

For dazzling displays of how asymmetrical and radial animals can harvest food from any direction, visit the Shape of Life website and watch these two clips (under "Behavior"):

- *Sponges: Filter Feeding Made Visible (2.5 min)*
- *Cnidarians: Anemone Catches Goby (2.5 min)*

To see how a bilateral, cephalized body lets an animal actively seek food watch these two Shape of Life clips:

- *Flatworm Animation: Body Plan (under "Animation"; 2.5 min)*
- *Flatworm: An Invasive Flatworm Hunts Earthworms (under "Behavior"; 2.5 min)*

Become familiar with the basic mollusc body plan – and its capacity for directional movement – by watching these two Shape of Life clips:

- *Mollusc Animation: Abalone (under "Animation"; 1.5 min)*
- *Molluscs: Pycnopodia Chases Abalone (under "Behavior"; 2.5 min)*

Animals with bilateral symmetry also usually have a distinct **head** at one end, where the **mouth** and **sense organs** are concentrated. We say they are **cephalized**, meaning "head-having." In contrast, animals with radial symmetry are not cephalized: They have no head, just a mouth in the middle. Being both bilateral and cephalized permits an animal to move in one deliberate direction – headfirst – letting their sense organs lead the way, like floodlights through a fog. Such animals can actively seek out the things they need. They can forage for food, track live prey, seek better habitat, or search for a mate.

In time, that first line of bilateral, cephalized, worm-like animals branched into most of the animal groups we see today, from penguins to porcupines, scorpions to squid, ants to alligators, and bullfrogs to bull sharks. Among the earliest bilateral animals to appear in the fossil record are the **molluscs**: soft-bodied animals that grow a calcified shell on their backs. The first molluscs were simple snails with a shell shaped like a dome or umbrella – probably to protect them from the sun's intense ultraviolet radiation, or perhaps predators. But in time these simple animals would diversify into a spectacular variety of forms, each adapted for a different lifestyle. In today's lab we'll dissect a member of a molluscan line that took some very radical turns away from the ancestral snail: **Class Bivalvia** – the **bivalves**, like clams, oysters, mussels, and scallops. Our specimen, the blue mussel *(Mytilus edulis)*, is an oddball, quite different from its cephalized, bilateral ancestors. But as you study it, keep in mind that it descended from a crawling, grazing snail with an umbrella on its back!

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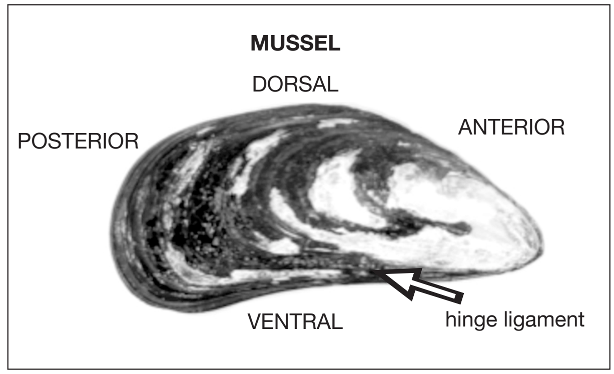
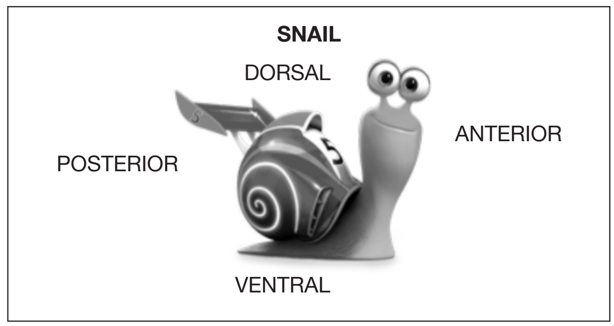
Floor and Roof

Line a dissecting tray with paper towels and get a mussel and dissecting tools. If your mussel is pickled in preserving fluid, rinse it under a faucet to diminish the odor.

ALERT! You MUST situate your specimen correctly in your tray, as shown in the diagram. If you fail to do this, you'll get inside and find everything backwards from your diagrams! The leathery **hinge ligament**, which joins the two shells, should be on the upper right.





(Images: Rainer Zenz and Icon Archive)

A mussel's shell is split into two **valves**. The way it's lying in your tray makes it seem like one valve is the floor, the other the roof. But this is misleading, for inside the shell is the ghost of a **bilateral** snail from the mussel's past. Hold it up and look at it end on, with the hinge ligment facing skyward. ***Does it have bilateral symmetry? Explain:***

To orient yourself, compare the mussel and snail diagrams. Note that the mussel has a **left** and **right** flank – same as the snail – and four main body surfaces: **dorsal** (its back), **ventral** (belly), **anterior** (head), and **posterior** (tush). ***On the diagram, mark where you think the mussel's mouth and anus will be once we get inside.***

Doors and Windows

A mussel sure doesn't look like a snail on the outside. To appreciate the family resemblance, you'll have to look under the hood. Its two shells – or **valves** – are joined by a tough yet-flexible, **hinge ligament** on the dorsal surface, which works like a door hinge. Slip a scalpel between the valves (not too deep!) and twist just enough to open a small crack. Observe the soft, ruffled fringes of the **mantle** around the perimeter. At the posterior end the mantle has two open windows called **siphons**. The more dorsal gap is the **excurrent siphon**; the more ventral gap is the **incurrent siphon**. Together, they let water circulate in and out. ***What two things does this water contain, necessary for survival?***

Now BEFORE opening your mussel all the way, **READ ALL FIVE STEPS BELOW.** You'll need to cut through the tough **adductor muscles**, but you want to avoid damaging the other soft tissues:

1. Study the diagram below to learn the location of the anterior and posterior adductors.
2. Slip your scalpel between the soft mantle and upper valve.
3. Gently peel the soft tissue away from the shell.
4. With luck, the adductors will now detach from the shell. If not, saw through them, as close to the shell as possible.
5. As you slowly pry open the mussel, peel the soft mantle away from the shell.

When a mussel is threatened, the adductors clamp the two shells together. The blue mussel is an **intertidal** species, often anchoring itself to a hard rock on the shoreline where the tide constantly rises and falls. ***Think! What events in the intertidal zone might provoke a mussel to slam shut and seal up for a while? Try to think of at least three:***

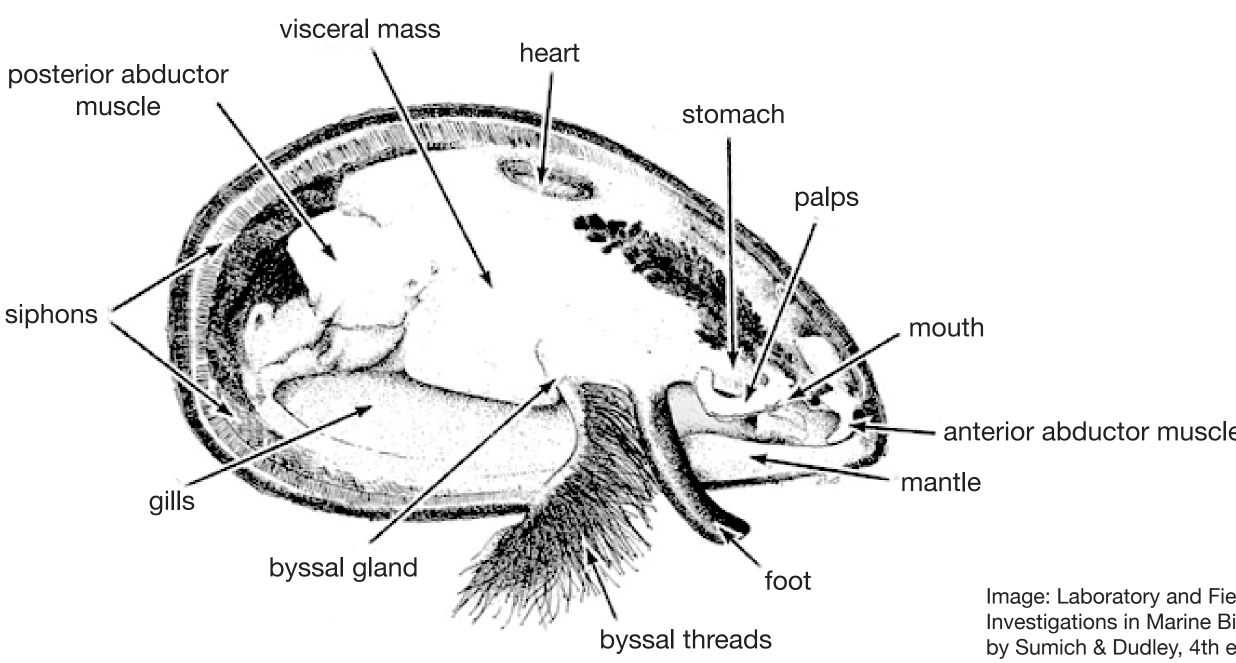


Image: Laboratory and Field Investigations in Marine Biology by Sumich & Dudley, 4th ed.

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Shape of Life

Sheetrock and Interior Trim

Detach the upper valve completely. The entire body is enshrouded in a thin, flimsy blanket of tissue – the **mantle**. The mantle might be tattered on top, damaged when you opened your mussel. But probe UNDER the body, and you'll see it's still intact, snug against the shell. Though soft and flimsy, the mantle has a very important protective function: It creates the **shell**. First, tiny glands lay down a web of protein fibers. Next, these glands secrete a paste of calcium carbonate (CaCO3) onto the web, which hardens like plaster. ***What are the OLDEST layers of the shell? The NEWEST? Sketch a side-view of a valve and label the oldest and newest parts.***

Dinner Date Tip #1: Next time you're at a seafood restaurant with your sweetheart, and you see oysters on the menu, astonish your date with this little known fact: Oysters do NOT make pearls! At least not the lustrous, spherical ones that are prized for jewelry. Those are built by so-called "pearl oysters," which are really more closely related to MUSSELS! And here's another myth debunked: It normally isn't sand that stimulates pearl-production, but a bit of indigestible food or a small parasite. The mantle coats the irritant with glossy **nacre**, or "mother-of-pearl." In truth, many bivalves make pearls, just irregular and unpretty ones. Hey, order a plate of raw oysters or steamed mussels as an appetizer, and maybe you'll find a lopsided pearl to present your date!

Foundation

Find the **foot** in the anterior ventral region. Remember that the ancestral snail's foot was big and muscular for locomotion. But in the blue mussel, it's reduced to a little stump, useless for crawling. Yet it still serves an important function: It creates the beard-like **byssal threads** that anchor the animal to its rock. To do this, the mussel presses its little foot against the rock. The **byssal gland** then secretes a liquid protein that oozes down a groove in the foot (find this!). Finally, this stream of protein hardens into a tough byssal thread.

Thus the foot has now taken on the OPPOSITE of its original function: It was once used for moving around, but now keeps the animal motionless!

So how do you think the feeding method of the modern mussel has changed, versus the ancestral snail?

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Shape of Life

Dinner Date Tip #2: Class Bivalvia includes many of the so-called "shellfish" found on a seafood restaurant menu. Next time there, impress your sweetheart with the following trivia. Clams are burrowers with a thick meaty foot for digging, the perfect body part for chowders and fried nuggets. Scallops, on the other hand, don't dig, but they do swim. They do this by clapping their shells like Pac Man to squirt out jets of water. For this reason they have huge adductor muscles, and this is the disc of meat you see on your plate. But oysters and mussels have hardly any muscle at all, because they spend their entire lives cemented to a solid surface. Consequently, the brave among us just dab on a little cocktail sauce and eat the entire animal off the half shell: gut, gills, glands, gonads, and all!

Plumbing and Air Conditioning

For a better view of internal features, trim away the blanket of mantle lying atop the body. Lift it with fingers or forceps and remove it with scissors or scalpel.

Find the four flap-like **gills** in the **mantle cavity**, where seawater flows in and out. (Technically there are TWO PAIRS of gills …a trace of the mussel's bilateral ancestry.) These absorb oxygen into the bloodstream. Study them under a magnifying glass or binocular scope. ***Describe their texture. How do you think this helps increase the amount of oxygen absorbed?***

The **heart** is suspended in a room of its own, called the **pericardial cavity**, near the dorsal edge (see diagram above). This compartment is probably enveloped by a wrinkly membrane. Open it with scissors or scalpel. The heart is a small nugget of muscle. It has three chambers: two **atria** receive oxygenated blood from the gills, and a stronger **ventricle** pumps it to the rest of the body.

If your teacher has opened a live mussel to show you, you might see its heart slowly swell and relax! A gentle squeeze with forceps might cause it to contract in response.

We vertebrates have a **closed circulatory system**, meaning blood is pumped through our bodies in highly pressurized pipes. Bivalves, by contrast, have an **open circulatory system**. Although they do have a few blood vessels – indeed, the tube-like heart is just an enlarged, muscular vessel – blood mainly just soaks into spongy spaces in their tissues (called **sinuses**). Because the blood isn't pressurized, tissues don't get the direct oxygen delivery that our own capillaries provide. Also, the blood is watery and colorless; it lacks the iron-based hemoglobin that makes our own blood red and especially effective at transporting oxygen. ***We vertebrates could never survive with such an inefficient oxygen-delivery system. Why are mussels able to get away with it?***

Although bivalves and gastropods (snails and slugs) have open circulatory systems, there is one line of molluscs that evolved a closed circulatory system: the cephalopods (squid and octopi). They also have THREE hearts! Besides the main heart, each gill has its own heart. Also, their gills are very branched and bushy. What do these circulatory and respiratory adaptations probably tell you about cephalopods' lifestyle? Explain your reasoning.

In most underwater animals, gills are for respiration: taking oxygen from the water. But in bivalves, the gills have evolved another very important function: they harvest food! Bivalves are **filter feeders** that sift microscopic **plankton** from the water (algae and bacteria). They coat their gills with sticky **mucus**, which ensnares plankton. The gills are also carpeted with thousands of **cilia**, microscopic "hairs" that whisk back and forth like fluttering eyelashes. These sweep food up to the **palps**, which you can find at the anterior end of the gills. Between them is a pinhole **mouth** (hard to see). ***What do you think is the function of these leafy "lips"? (helpful hint: they're not for kissing)***

If your teacher opened a live mussel, your teacher might put a piece of gill in a well slide, to view under a compound microscope on low or medium power (not high). Look for "shimmering" on the edge and in the channels. Those are fluttering cilia. Your teacher may also add microscopic yeast cells near the gill. If so, these will look like tiny ping pong balls being swept in and through the gill's channels.

Next, food moves into the **stomach**, buried within the **digestive gland** above the foot. You can fillet into this region with your scalpel, but the stomach is hard to distinguish. Anything indigestible passes through the **intestine** and out the **anus**. Look for these on the posterior (left) side of the adductor muscle. **Bivalves feed ONLY on microscopic, single-celled organisms. How are their gills and other body parts built for size-selective feeding?**

> **Dinner Date Tip #3:** As you enjoy the giant plate of spaghetti that you and your date are sharing, use this as an opportunity to impress him/her with another fascinating bit of molluscan trivia: Bivalves possess the only rotating organ in the animal kingdom – called a **crystalline style**. It's a jelly-like rod sitting inside the animal's stomach, with one end pressed against a hard plate called the gastric shield. Model the style's action for your date by twirling your fork against a spoon to reel in a long strand of spaghetti. This how the style works too: Food entering the mouth is drenched in sticky, stringy mucus, and by spinning around, the crystalline style reels it in. The food eventually spirals down to the gastric shield, where it is ground up and attacked by digestive enzymes.

Another oddity of mussels is that they're HEADLESS! Remember, their snail-like ancestors DID have heads. That is, they were **cephalized**. Bivalves first appear in the fossil record over 500 million years ago, during the "Cambrian Explosion" when all major animal groups were evolutionarily diverging from one another. Among the diverse new species was a horde of predators able to crack open mollusc shells. In response, some molluscs began burrowing to safety. Still snail-like, their umbrella-shaped shell creased along its dorsal edge, probably so they could wriggle into the seafloor by flapping their shells. Their bodies gradually became wedge-shaped for easier digging. Eventually they took up permanent residence underground. They quit crawling around, stopped foraging for food, and began filter feeding. And in time, they "de-cephalized" (lost their heads), and some species – like oysters and scallops – even "un-bilateralized" (lost their perfect bilateral symmetry).

Why did natural selection allow the bivalve line to abandon the cephalized, bilateral body plan? (Hint: Recall that bilateral symmetry and cephalization were originally adaptations for… what?)

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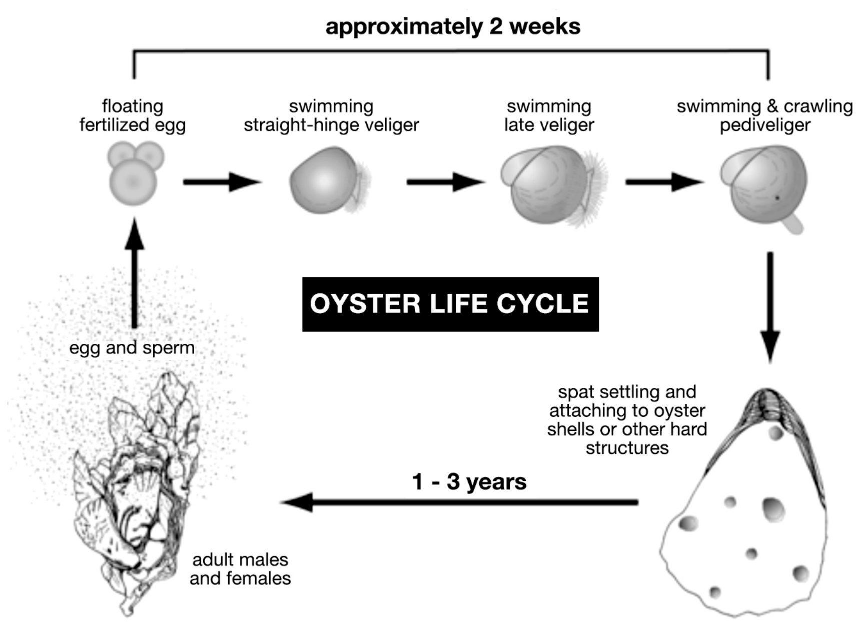
Electrical Wiring

Finally, examine the mantle's outer margin with a magnifying glass or binocular scope. It's fringed with **sensory receptors**. These include **chemoreceptors** that detect chemicals in the environment (akin to smell and taste) and **mechanoreceptors** that detect vibrations and physical touch. When touched by an intruder, or when it gets a "whiff" of a predatory starfish, the mussel slams shut. Some bivalves also have light-sensitive **photoreceptors** all along the mantle's margin, and some scallops have hundreds of bright blue eyes aiming in all directions, able to react to shadows and movements. Somewhere in the tattered remains of your mussel there are also **nerve cords** and **ganglia** (nerve centers), but nothing complex enough to call a "brain." So next time you and your dinner date share a plate of raw oysters on the half shell, take comfort that although it's still quite alive, it has no feelings or awareness and presumably feels no pain!

Expanding the Neighborhood

Also in the tattered remains of your oyster are **gonads**, the reproductive organs that produce **gametes**, or sex cells: **sperm** and **eggs**. These aren't well developed except during breeding season, and even then they're more a loose mass of gametes than a discrete organ. If an egg is lucky enough to bump into a sperm cell, it develops into a drifting larval form, too small to see. It soon grows a paper-thin shell and a weak ability to swim. Later it develops a tiny foot and starts to half-swim, half-crawl along the seafloor in search of something solid to cement itself to. If it finds a suitable spot, it metamorphoses into a filter-feeding juvenile no bigger than a fingernail. (A blue mussel's life cycle is very similar to that of an oyster, diagrammed to the right.)



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STUDENT EDITION

Intended Learning Outcomes

After these lessons, you will be able to:

- Distinguish between gastropods, bivalves, and cephalopods when given examples or distinctive traits of each.
- Match these anatomical traits to their descriptions or functions: bilateral symmetry, cephalization, anterior/posterior, dorsal/ventral, mantle, mantle cavity, foot, adductor, hydrostatic skeleton, funnel, chromatophore, gill, heart, "open" vs. "closed" circulatory system, radula, digestive gland (including liver and pancreas), intestine, kidney, gonad
- Explain the adaptive benefit of a cephalized body with bilateral symmetry (as opposed to radial symmetry).
- Describe 4 evolutionary changes that occurred in the bivalve body – versus the ancestral snail – to suit them for a sedentary, filter-feeding lifestyle.
- Describe a bivalve's "cilio-mucoidal" method of filter feeding.
- List and explain 4 external and 4 internal squid adaptations for its predatory, open water lifestyle.
- Interpret new examples of divergent evolution, convergent evolution, or coevolution. Be able to name, explain, and make predictions about each macroevolutionary pattern.

Multiple choice.

A. Class Gastropoda

B. Class Bivalvia

C. Class Cephalopoda

______ Clams, oysters, scallops, and mussels.

______ Squid, octopus, and chambered nautilus.

______ Conchs, whelks, cone snails, and sea slugs.

______ Jet propulsion.

______ Filter-feeders.

______ Closed circulatory system.

______ Complex, advanced brains and sense organs.

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STUDENT EDITION

Match these anatomical traits to the correct descriptions or functions

______ Toothy tongue of gastropods and cephalopods.

______ Nozzle for jet propulsion.

______ Secretes a mollusc's shell.

______ Ancestral mollusc's main organ of locomotion.

______ Evolution or development of a distinct "head" containing mouth and sense organs.

______ Filters nitrogen wastes from the bloodstream.

______ Muscles create movement by squeezing on fluid-filled spaces within the body.

______ In bilateral animals, the head end versus the tail end.

______ In bilateral animals, the back versus the belly.

______ Space between the mantle and soft body, where water flows across the gills.

______ Gas exchange.

______ Produces gametes (sperm or egg).

______ Secretes digestive enzymes for the chemical breakdown of food.

______ Blood is piped directly to all tissues in pressurized blood vessels.

______ Blood bathes tissues by soaking into open spaces ("sinuses").

______ Transports undigested food away.

______ Body plan in which a single plane of bisection creates mirror image halves.

______ Circular muscle that tightly shuts a bivalve's two shells.

______ Muscular blood pump.

______ Miniature organ that enables a squid or octopus to change colors.

a) bilateral symmetry
b) cephalization
c) anterior / posterior
d) dorsal / ventral
e) mantle
f) mantle cavity
g) foot
h) adductor
i) hydrostatic skeleton
j) funnel
k) chromatophore
l) gill
m) heart
n) open circulation
o) closed circulation
p) radula
q) digestive gland
r) intestine
s) kidney
t) gonad

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STUDENT EDITION

Short Answer

1. The earliest animals on Earth had either asymmetrical bodies or radial symmetry, but many animal lines eventually adopted a cephalized body with bilateral symmetry. What were the advantages of this new body plan? Explain.

2. Bivalves evolved from ancestral snails. Describe at least four major changes that occurred to suit them for their sedentary, filter-feeding lifestyle.

3. Describe a bivalve's "cilio-mucoidal" method of filter-feeding.

4. In contrast to their grazing, scavenging, and filter-feeding cousins, squid are molluscs that have evolved for a life of active hunting in the open ocean. Describe 4 external and 4 internal adaptations that cephalopods have (but gastropods and bivalves lack) that are specifically for this predatory, open water lifestyle.

5. Garden snails, snapping turtles, lobsters, armadillos, and the extinct dinosaur Stegosaurus are all animals that evolved a hard, protective covering on their backs, even though they come from very distant phylogenetic lines. What macroevolutionary pattern does this represent? Explain.

6. Banana slugs graze on leaves using a rasping radula to rake up plant tissue. Cone snails prey on small fish by harpooning them with a venomous, dart-like radula. The radula of predatory moon snails works like a drill to bore holes through the shells of their victims. The radula of squid is hooked for rasping meat off their prey. What macroevolutionary pattern does this represent? Explain.

7. In the Paleozoic era, molluscs protected their soft, vulnerable bodies with a hard shell. Then in the mid-to-late Cenozoic era, many groups of crustaceans (crabs, lobsters, etc.), gastropods, and fish developed the ability to eat molluscs by crushing their shells with powerful claws or jaws, or else by drilling holes in them. In response, molluscs developed thicker shells, often with narrow apertures or high spires, for better defense against predators. Predators in turn became better at breaking shells. And so on. This relentless "arms race" is an example of what macroevolutionary pattern? Explain.

8. For molluscs, mucus is truly a wonderful substance. (If you must know, it's a glycoprotein that creates a colloid in water …think Jello, only slimier.) Molluscs have modified mucus for dozens of different tasks. Creeping snails lubricate their way with trails of slime. Pteropods or "sea butterflies" are tiny snails that drift on ocean currents, where they capture food with webs of sticky mucus. Sea slugs secrete a noxious slime that is distasteful to predators. Oysters and mussels have sticky gills for harvesting microscopic algae. Limpet snails find their way back home by leaving a mucus trail, rather like Hansel and Gretel and their trail of bread crumbs. Some sea slugs can safely feed on stinging jellyfish and anemone by coating the stingers with mucus. Which macroevolutionary pattern is this? Explain.

9. A typical hardwood forest is home to many different species of trees, but they all share this trait in common: They are very tall, with their sun-soaking leaves propped up by tall trunks and sprawling branches. Wood is expensive to build and doesn't produce any food, so it seems a bit of a waste. But each species is forced to invest calories in wooden trunks and branches, because otherwise they'd be shaded out by other species – and vice versa. Over evolutionary time, competition for sunlight caused forest plants to grow ever taller simply to keep pace with other plants. What macroevolutionary pattern drove different tree species to such ridiculous heights?

10. Squid and octopi bite their food with a sharp beak. They also stun their prey with venomous saliva. What are some convergences with these two traits elsewhere in the animal kingdom?

11. Imagine a population of average snails that splits in two and migrates to two different habitats. One habitat is rich in food but also abundant with toothy predators. The other habitat is patchy, with food sources few and far between, yet relatively free of predators. Over many generations, how might these two populations diverge?

12. Bats are flying, bug-eating mammals that use echolocation ("sonar") to navigate at night and home in on prey. If a certain species of bat were to take to an aquatic lifestyle, swimming in the open ocean alongside tuna, sharks, squid, dolphins, and penguins, you might expect it to gradually evolve certain similarities to its swimming brethren. What sorts of convergent evolution might occur?

The Blue Mussel: A Not-So-Typical Mollusc

Lab Investigation: Class Bivalvia *High School Version*

Lesson by Kevin Goff

TEACHER EDITION

Intended Learning Outcomes (ILO's; for summative assessments aligned with these ILO's, scroll to the end of this instructor's guide).

After these lessons, each student will be able to:

- Distinguish between gastropods, bivalves, and cephalopods when given examples or distinctive traits of each.
- Match these anatomical traits to their descriptions or functions: bilateral symmetry, cephalization, anterior/posterior, dorsal/ventral, mantle, mantle cavity, foot, adductor, hydrostatic skeleton, funnel, chromatophore, gill, heart, "open" vs. "closed" circulatory system, radula, digestive gland (including liver and pancreas), intestine, kidney, gonad
- Explain the adaptive benefit of a cephalized body with bilateral symmetry (as opposed to radial symmetry).
- Describe 4 evolutionary changes that occurred in the bivalve body – versus the ancestral snail – to suit them for a sedentary, filter-feeding lifestyle.
- Describe a bivalve's "cilio-mucoidal" method of filter feeding.
- List and explain 4 external and 4 internal squid adaptations for its predatory, open water lifestyle.
- Interpret new examples of divergent evolution, convergent evolution, or coevolution. Be able to name, explain, and make predictions about each macroevolutionary pattern.

Summative Assessment Items (aligned with the unit ILO's; see above)

Multiple choice.

A. Class Gastropoda

B. Class Bivalvia

C. Class Cephalopoda

______ Clams, oysters, scallops, and mussels. [B]

______ Squid, octopus, and chambered nautilus. [C]

______ Conchs, whelks, cone snails, and sea slugs. [A]

______ Jet propulsion. [C]

______ Filter-feeders. [B]

______ Closed circulatory system. [C]

______ Complex, advanced brains and sense organs. [C]

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Match these anatomical traits to the correct descriptions or functions

______ Toothy tongue of gastropods and cephalopods. [p]

______ Nozzle for jet propulsion. [j]

______ Secretes a mollusc's shell. [e]

______ Ancestral mollusc's main organ of locomotion. [g]

______ Evolution or development of a distinct "head" containing mouth and sense organs. [b]

______ Filters nitrogen wastes from the bloodstream. [s]

______ Muscles create movement by squeezing on fluid-filled spaces within the body. [i]

______ In bilateral animals, the head end versus the tail end. [c]

______ In bilateral animals, the back versus the belly. [d]

______ Space between the mantle and soft body, where water flows across the gills. [f]

______ Gas exchange. [l]

______ Produces gametes (sperm or egg). [t]

______ Secretes digestive enzymes for the chemical breakdown of food. [q]

______ Blood is piped directly to all tissues in pressurized blood vessels. [o]

______ Blood bathes tissues by soaking into open spaces ("sinuses"). [n]

______ Transports undigested food away. [r]

______ Body plan in which a single plane of bisection creates mirror image halves. [a]

______ Circular muscle that tightly shuts a bivalve's two shells. [h]

______ Muscular blood pump. [m]

______ Miniature organ that enables a squid or octopus to change colors. [k]

a) bilateral symmetry
b) cephalization
c) anterior / posterior
d) dorsal / ventral
e) mantle
f) mantle cavity
g) foot
h) adductor
i) hydrostatic skeleton
j) funnel
k) chromatophore
l) gill
m) heart
n) open circulation
o) closed circulation
p) radula
q) digestive gland
r) intestine
s) kidney
t) gonad

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Short Answer

1. The earliest animals on Earth had either asymmetrical bodies or radial symmetry, but many animal lines eventually adopted a cephalized body with bilateral symmetry. What were the advantages of this new body plan? Explain.

Bilateral symmetry, cephalization, and sense organs clustered in the head foster directional movement in an active search of food (or mates, or habitat). (By contrast, radial symmetry is an adaptation for sessile or slow-moving niches in which the animal waits for food to come to it, such as filter-feeding, or the predation-by-ambush of jellyfish and anemone.)

2. Bivalves evolved from ancestral snails. Describe at least four major changes that occurred to suit them for their sedentary, filter-feeding lifestyle.

They "decephalized," losing the head and radula of their foraging forebears. The gill evolved for cilio-mucoidal feeding. The mantle developed siphons, and the mantle cavity evolved for filter-feeding. The shell became a hinged box, able to open for feeding but shut for protection. Clams evolved wedge-shaped shells and a backhoe-like foot for burrowing. The mussel's foot became a device for putting out anchor lines (byssal threads). Oysters and scallops abandoned bilateral symmetry in favor of a body form able to lie on one flank. Etc.

3. Describe a bivalve's "cilio-mucoidal" method of filter-feeding.

Sticky mucus on gills traps food particles. Waving cilia then pass food particles through channels to the palps and ultimately into the mouth.

4. In contrast to their grazing, scavenging, and filter-feeding cousins, squid are molluscs that have evolved for a life of active hunting in the open ocean. Describe 4 external and 4 internal adaptations that cephalopods have (but gastropods and bivalves lack) that are specifically for this predatory, open water lifestyle.

[See the complete list above under Lesson #4: "Life in the Fast Lane"]

5. Garden snails, snapping turtles, lobsters, armadillos, and the extinct dinosaur Stegosaurus are all animals that evolved a hard, protective covering on their backs, even though they come from very distant phylogenetic lines. What macroevolutionary pattern does this represent? Explain.

Convergent evolution. These species are only distantly related yet independently evolved a similar trait for a similar function.

6. Banana slugs graze on leaves using a rasping radula to rake up plant tissue. Cone snails prey on small fish by harpooning them with a venomous, dart-like radula. The radula of predatory moon snails works like a drill to bore holes through the shells of their victims. The radula of squid is hooked for rasping meat off their prey. What macroevolutionary pattern does this represent? Explain.

Divergent evolution. All four species are molluscs sharing a common ancestor, but that ancestor's radula has been modified for new functions and new niches.

7. In the Paleozoic era, molluscs protected their soft, vulnerable bodies with a hard shell. Then in the mid-to-late Cenozoic era, many groups of crustaceans (crabs, lobsters, etc.), gastropods, and fish developed the ability to eat molluscs by crushing their shells with powerful claws or jaws, or else by drilling holes in them. In response, molluscs developed thicker shells, often with narrow apertures or high spires, for better defense against predators. Predators in turn became better at breaking shells. And so on. This relentless "arms race" is an example of what macroevolutionary pattern? Explain.

Coevolution. Predators and prey are reciprocally adapting to each other.

8. For molluscs, mucus is truly a wonderful substance. (If you must know, it's a glycoprotein that creates a colloid in water …think Jello, only slimier.) Molluscs have modified mucus for dozens of different tasks. Creeping snails lubricate their way with trails of slime. Pteropods or "sea butterflies" are tiny snails that drift on ocean currents, where they capture food with webs of sticky mucus. Sea slugs secrete a noxious slime that is distasteful to predators. Oysters and mussels have sticky gills for harvesting microscopic algae. Limpet snails find their way back home by leaving a mucus trail, rather like Hansel and Gretel and their trail of bread crumbs. Some sea slugs can safely feed on stinging jellyfish and anemone by coating the stingers with mucus. Which macroevolutionary pattern is this? Explain.

Divergent evolution. These are all closely related molluscs that have evolved mucus for diverse new functions.

9. A typical hardwood forest is home to many different species of trees, but they all share this trait in common: They are very tall, with their sun-soaking leaves propped up by tall trunks and sprawling branches. Wood is expensive to build and doesn't produce any food, so it seems a bit of a waste. But each species is forced to invest calories in wooden trunks and branches, because otherwise they'd be shaded out by other species – and vice versa. Over evolutionary time, competition for sunlight caused forest plants to grow ever taller simply to keep pace with other plants. What macroevolutionary pattern drove different tree species to such ridiculous heights?

Coevolution. The different species adapted to one another reciprocally – an arms race that prevents them from saving calories by building shorter bodies. (This is not convergence, because all the trees descended from a common woody ancestor.)

10. Squid and octopi bite their food with a sharp beak. They also stun their prey with venomous saliva. What are some convergences with these two traits elsewhere in the animal kingdom?

(A) Bird bills, mammal jaws and teeth, turtle beaks, parrotfish teeth, grasshopper mandibles, sea urchin teeth, etc.

(B) The venomous bite of spiders, snakes, and centipedes; the venomous sting of scorpions, wasps, cone snails, and the Portuguese man-of-war.

11. Imagine a population of average snails that splits in two and migrates to two different habitats. One habitat is rich in food but also abundant with toothy predators. The other habitat is patchy, with food sources few and far between, yet relatively free of predators. Over many generations, how might these two populations diverge?

The first population might evolve heavier, more sculptured shells and slower locomotion, while the second population might evolve thinner shells or even lose their shells altogether, while becoming more mobile. The first might evolve for burrowing while the second might evolve for swimming. Etc.

12. Bats are flying, bug-eating mammals that use echolocation ("sonar") to navigate at night and home in on prey. If a certain species of bat were to take to an aquatic lifestyle, swimming in the open ocean alongside tuna, sharks, squid, dolphins, and penguins, you might expect it to gradually evolve certain similarities to its swimming brethren. What sorts of convergent evolution might occur?

The bat body might become even more streamlined. Wings might shorten and become robust enough to serve as fins/flippers. The stubby tail might broaden into a tailfin for propulsion. Fur might fall out, making the skin smooth and sleek. Echolocation might become more like that of dolphins and whales, with pitches appropriate for a liquid medium. Etc.