Shape of Life
The Story of the Animal Kingdom

Terrestrial Arthropod Adaptations + Engineering Design

Successful Arthropod Structures, Behaviors, and Inspiration for Innovation

Overview

Students explore the extraordinary adaptations and diversity of terrestrial arthropods through short Shape of Life videos and student-centered activities in the 5E Instructional Model. Options to engage students include showing a short clip of an interesting arthropod phenomenon with the audio muted. Then students identify the structures of all arthropods with the support of one or more video segments. Students will record notes about physical and behavioral adaptations, then create a diagram of their favorite arthropod species, labeling its structures and adding annotations to describe their functions. Possible Enrich / Extend activities are listed at the end of the lesson, including a design thinking / biomimicry / engineering activity inspired by arthropod adaptations, a comparison activity, and field studies to investigate the arthropods in nearby natural areas.

Objectives

- Students will describe terrestrial arthropod adaptations orally and in writing.
- Students will create labeled diagrams of a terrestrial arthropod species of their choice.
- If the design process / engineering extension is completed, students will develop and construct a design for a useful invention inspired by one or more arthropod adaptations.
- If the comparison extension is completed, students will compare adaptations of an arthropod species to those of another animal.

Subjects

Science, Environmental Education, Writing, and Art

Grades 6–12

Time

45–90 minutes

Vocabulary

Adaptations, antennae appendage, Arachnida/arachnid, arthropod, chitin, Crustacea/crustacean, evolution, exoskeleton, genetic variation, gills, Insecta/insect, larva, marine, metamorphosis, molting, Myriapoda / myriapod, natural selection, niche, predator, segmented, terrestrial

Spiders are helpful arthropods in gardens for pest control.
Image from Scopio: scop.io/products/brown-and-yellow-spider

Standards		Middle School / High School
Next Generation Science Standards	Performance Expectations	MS-LS1-3: Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells. 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-LS1-5: Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms. MS-LS1-8: Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories. MS-LS3-2: Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation. 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. HS-LS1-2: Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
	Disciplinary Core Ideas	LS1: From Molecules to Organisms: Structures and Processes LS1.A: Structure and Function LS1.B: Growth and Development of Organisms LS4: Biological Evolution: Unity and Diversity LS4.C: Adaptation
	Crosscutting Concepts	• Cause and Effect • Structure and Function • Systems and System Models
	Science & Engineering Practices	• Developing and Using Models • Engaging in Argument from Evidence • Obtaining, Evaluating, and Communicating Information
Common Core ELA	Writing	7
	Speaking & Listening	4, 6
	Language Standards	1, 2, 3, 6

Teacher Background

Phylum **Arthropoda**, which contains both marine and terrestrial species, has by far the largest number of species on Earth. There are over seven million terrestrial arthropods and the vast majority are insects.

For hundreds of millions of years, arthropods and their ancient ancestors lived only in the oceans. Then, about 400 million years ago, fossil tracks suggest that an arthropod left the water to walk on land. Fossil evidence shows that different groups including insects, millipedes and centipedes, spiders, and scorpions all came ashore on their own at different times.

Leafcutter ants move leaves back to their nest. They will use them to "farm" fungi for food.

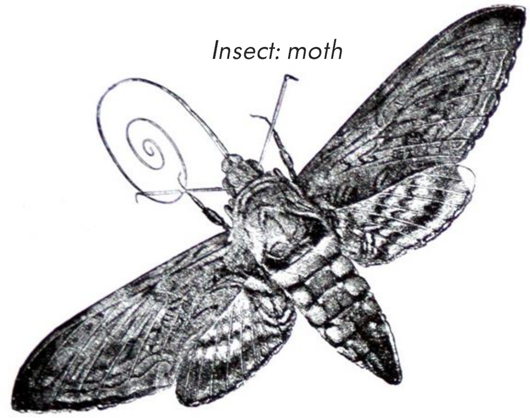
Creative commons image by Geoff Gallice

:en.m.wikipedia.org/wiki/File:Leaf_cutter_ants_arp.jpg

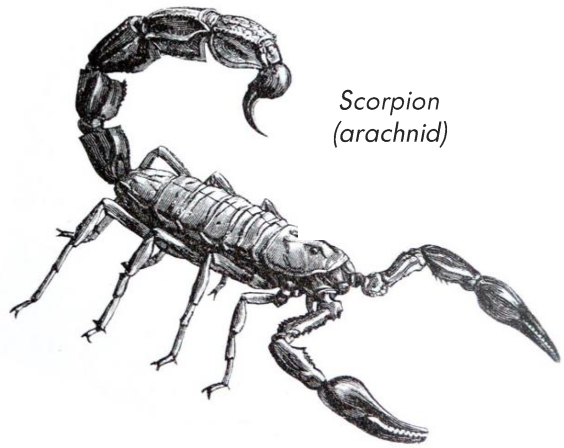
Where They Live

Arthropods first evolved about 500 million years ago in the ocean, and they live in more habitats on Earth than any other phylum of animals. They took over the earth through extraordinary feats of evolution that allowed them to thrive in nearly every terrestrial and marine ecosystem.

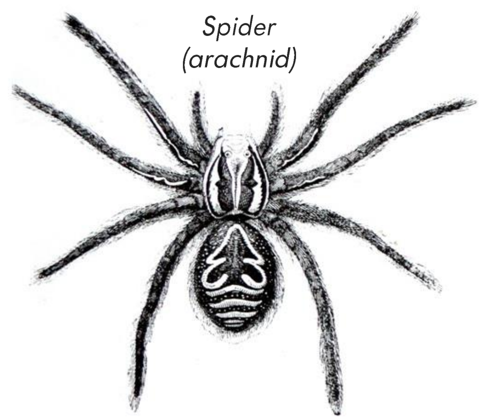
Once arthropods were air breathers, their dependence on damp coastal environments ended, and they began to move inland. They fed on the rich detritus of organic plant debris, much in the same way that burrowing worms thrived on the debris sediments in the sea. Living plants provided limited potential for nourishment because their cells have hard walls that were difficult for the first waves of arthropods to penetrate. But the invading arthropods found plenty of debris broken down by fungi and bacteria that was much easier to digest. Many of the first land-dwellers ate each other, dead or alive, and the same arms race that produced dramatic evolution in the ocean began on land.



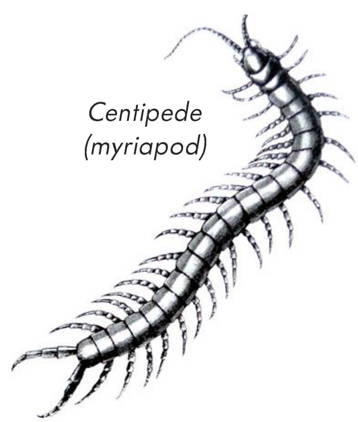
A damselfly at rest: A beneficial insect that preys on other insects



Insects began to fly soon after their ancestors first came ashore, and when they did, their dominance on land began in earnest. Flight gave them a speed advantage over other ground-bound insects and animals of all kinds that was simply insurmountable. The ground speed of a running insect, for instance, is about 0.2 miles per hour; for a flying insect, about 35 miles per hour.



Learning to fly was perhaps the single most important adaptation that allowed them to eventually dominate every habitable ecosystem on earth. The small size of insects, perhaps a drawback in the sea and certainly a problem for most other animals on land, gave them an advantage when trying to get into the air. Flight also was the greatest step in the weaving of an ecological tapestry upon which all animal life on earth now depends—the synergy between flowering plants and insects. Pollinators such as bees, butterflies, and moths also help drive plant evolution and feed countless other species that depend on the fruits and other products of plant reproduction, including humans.



Once the air was alive with animals, it became a new food niche for spiders and they evolved the miraculous ability to spin nets to catch flies, gnats, and their airborne cousins. A spider web is one of the most marvelous structures on earth, strong enough, if proportionate in size, to stop a flying 747 airplane.

Body Plan

The key to the incredible diversity and success of arthropods is their very adaptable **body plan**. The segmentation of both their body and appendages opened the door for the evolution of their body having many parts and many types of appendages. In primitive arthropods, each segment had an appendage. Today, terrestrial arthropods have many diverse appendages—antennae, walking legs, and mouthparts.

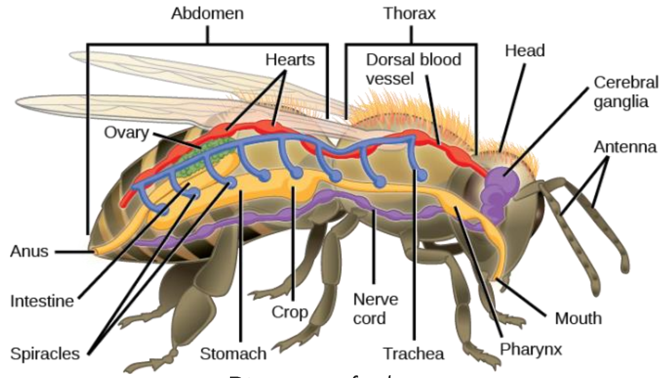


Diagram of a bee
commons.wikimedia.org/wiki/File:Figure_28_04_06.png

Body Structures

The name arthropod means "jointed foot" in Greek, and their **jointed appendages** have been a key part of their success. Despite their myriad shapes and behaviors, all arthropods have in common the important structures listed below.

Segmented body

- All arthropod bodies are divided into segments.
- Usually grouped into larger functional units (such as cephalothorax and abdomen), most of them are divided into three units: the **head**, **thorax**, and **abdomen**. The terrestrial crustaceans called **woodlice** (pill bugs) may look like they have similar segments, but really they have a head that is referred to as a cephalothorax, a pereon (in place of a thorax), and a pleon (abdomen).
- Many pairs of limbs: Usually each segment has a pair of appendages and the appendages have diversified uses. Many of the tasks of arthropod living, like eating or sensing the world are handled by appendages attached to each segment of the body or the head.
- The segmented body is a powerful arthropod evolutionary trait that is common elsewhere in the animal kingdom. People are segmented, too, though not as obviously as earthworms or lobsters, and you have to know how to look at our spine and muscles to see the segmentation. This kind of construction allows a body to build itself in identical segmented units that become specialized for particular functions.

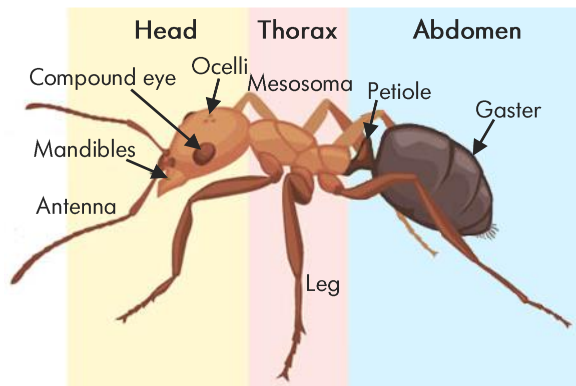
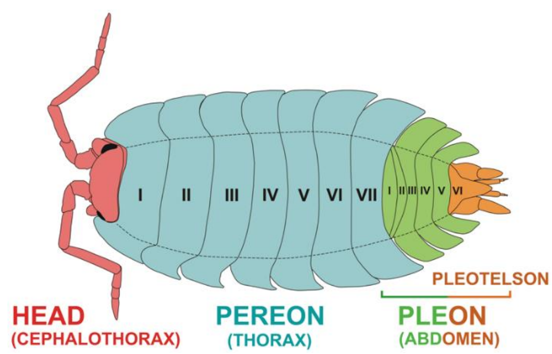


Diagram of a worker ant
commons.wikimedia.org/wiki/File:Worker_ant_anatomy_Formicinae_-_Myrmicinae_ASU_AAB.jpg



Woodlouse (pill bug) body plan
en.wikipedia.org/wiki/Woodlouse#/media/File:Oniscidea_woodlouse_morphology.png

Jointed Appendages

- Possess numerous **jointed appendages**, such as legs
- Jointed legs allow flexibility and range of motion; can work as shock absorbers
- Controlled by tendons and powerful muscles
- These appendages are segmented, which makes them both flexible and easily adapted to become antennae, claws, jaws, and other mouth parts, and especially legs—for walking, clinging, holding onto egg sacs, digging, etc. Through evolution they were modified for specialized functions, such as sensing, feeding, defense, and flight.

Jointed appendages like legs and antennae—not to mention their armor-like exoskeletons—helped arthropods conquer they world's ecosystems.
Image by Nghang Vu, Pixabay: pixabay.com/users/Nghangvu-13510079

Exoskeleton

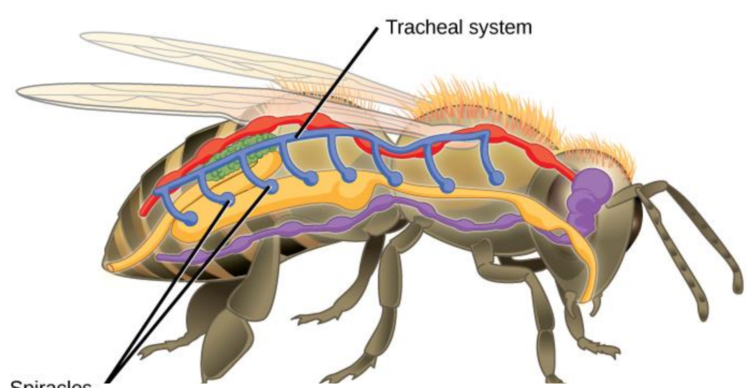
- A jointed protective armor, called an **exoskeleton**, covers the body; it's called a cuticle in insects
- Hard exoskeleton is made mostly of **chitin** and protein, sometimes made more impermeable to water with wax
- Supports body
- Provides protection like armor
- Their body parts and muscles attach to the inside of this armor. It provides a framed support that muscles attach to.
- Prevents water loss
- **Molting**: An arthropod must molt to grow, regularly shedding its exoskeleton. The growing body cracks it open and pulls out of it. Then the animal expands its body before the new exoskeleton hardens. This process is called **molting**. The new exoskeleton is soft immediately after molting, making the animal vulnerable to predation, but it hardens in a couple of days.
- **Wings**: The emergence of wings represents a profound moment in evolution, which made insects one of the most successful groups of animals. Wings develop as an outgrowth of the exoskeleton; they only become functional in the adult. Most insects have two pairs of wings. They probably developed from airfoil-like structures that evolved on insect thoraxes and continued to evolve as the advantages of flight were passed from generation to generation. "Since the invention of flight by insects probably allowed for their enormous diversification, I would say that it was one of the most important events in the history of the earth." Bill Shear, Paleontologist

Respiration

- With their highly adaptable body plans, arthropods evolved a way to breathe air. In the damp coastal zone spiders modified their book gills to become **book lungs**, very similar biological devices. See "Arthropod Animation: Scorpion Book Gills" (1:05): shapeoflife.org/video/arthropod-animation-scorpion-book-gills.
- Insects solved the problem of breathing air with a **tracheal system** that allowed them to mainline oxygen directly into their muscles without passing it through any gill-like or lung-like structures. They could draw air into their bodies through minute pores on their undersides, near the junction of their appendages and their shells, and distribute it through their bodies in a kind of open capillary system without fluid. See "Arthropod Animation: Millipede Breathing Tubes" (0:59): shapeoflife.org/video/arthropod-animation-millipede-breathing-tubes.

Monarch butterflies are beautiful pollinators imperiled by habitat loss, pesticides, and climate change. Schools are partnering with the National Wildlife Federation and the U.S. Fish & Wildlife Service to plant milkweed (shown here) that their young need. Learn more: nwf.org/Our-Work/Wildlife-Conservation/Monarch-Butterfly

Public domain image from Pixabay: pixabay.com/photos/butterfly-monarch-insect-wings-bug-18313



Tracheal breathing system
commons.wikimedia.org/wiki/File:Figure_39_01_05.jpg

- Arthropods' tracheal breathing systems proved very efficient at oxygenating the fast-moving muscles necessary for flight. For the muscles in a bird to do the same work as a mosquito in flight, its lungs would be too big and heavy to allow flight at all. A large animal simply cannot deliver oxygen to contract its muscles at the same rate as an insect, so it depends on increasing the mechanical efficiency of its wings.
- A concentrated supply of oxygen reaches every cell of the insect's body as a gas. This kind of internal plumbing makes insects and other arthropods intensely aerobic, feeding their muscles enormous doses of oxygen and allowing them to move very quickly.
- Eventually, some spiders and millipedes would evolve tracheal systems, too, an example of the dynamic parallel evolution of which arthropods are so capable.

Bilateral Symmetry

- Same anatomy on left and right sides of body
- Differs from radial symmetry of organisms like corals

Classification

Animals of the phylum **Arthropoda** possess an almost incomprehensible variety of body shapes and ways of living. **The 5 main groups are:**

- **Crustaceans** (subphylum **Crustacea**) includes some of the most prized (and expensive) human foods, such as lobsters, king crabs (12-foot leg span!), and shrimp.
- **Chelicerates** include **arachnids** (class **Arachnida**, such as spiders and disease-carrying parasites, such as ticks), as well as sea spiders, scorpions, and horseshoe crabs, which may be aquatic arachnids according to a 2019 molecular analysis published by Ballesteros and Sharma in *Systematic Biology*: doi.org/10.1093/sysbio/syz011.
- **Insects** (class **Insecta**) comprise over 75% of all known animal species. Their **biodiversity** around the world on every continent (including Antarctica) is astounding, from large flying dragonflies to microscopic animals found in soil.

  There are 24 insect orders, including:

  - Lepidoptera: butterflies and moths
  - Coleoptera: beetles
  - Hemiptera: true bugs
  - Orthoptera: grasshoppers and crickets
  - Odonata: dragonflies
  - Hymenoptera: bees, ants, and wasps
  - Diptera: flies

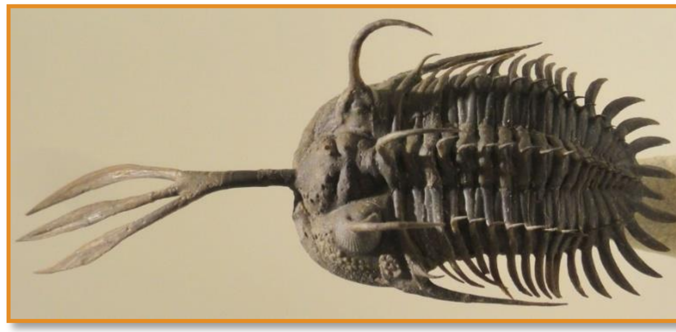
  The BugGuide website provides a good "Overview of Orders of Insects" with visuals and descriptions: bugguide.net/node/view/222292.

Woodlouse (pill bug): Terrestrial crustacean rolled up for defense. Wikimedia Commons: commons.wikimedia.org/wiki/File:Slater_rolled_up_for_wiki.jpg

A ladybug (ladybird) beetle prepares for flight. They are one of the many beneficial insect predators for pest control—without the need for harmful pesticides. Pixabay: pixabay.com/photos/ladybug-beetle-nature-macro-insect-2032355

- **Myriapods** include millipedes and centipedes. See "Arthropod Animation: Millipede Breathing Tubes" (0:59) for a fascinating glimpse into their bodies and how they became adapted to breathe air: shapeoflife.org/video/arthropod-animation-millipede-breathing-tubes.

- **Trilobites**: An extinct group of arthropods that are found in the fossil record from about 521 million years ago until the mass extinction that occurred about 252 million years ago. They were a diverse group that included scavengers, predators, and filter feeders. Learn more on the Trilobita page from UC Berkeley: ucmp.berkeley.edu/arthropoda/trilobita/trilobitalh.html



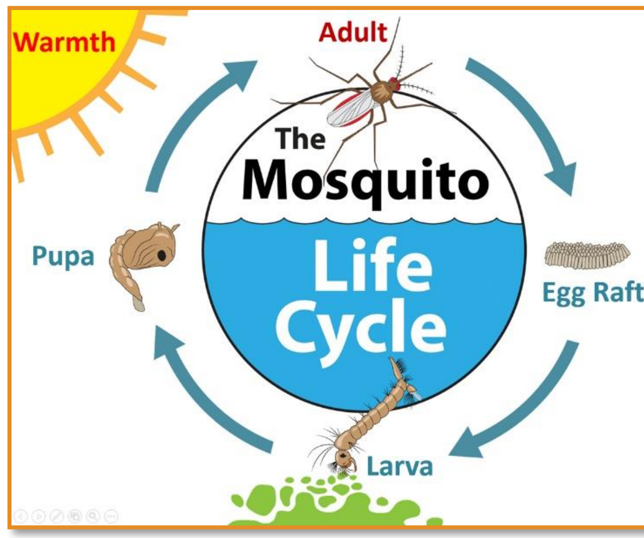
Walliserops were trilobites that had trident-like appendages
Creative Commons image by Daderot:
commons.wikimedia.org/wiki/File:Walliserops_trifurcatus,_Early_Devonian,_Timrhanrhart_Formation,_Jbel_Gara_el_Zguilma,_Draa_Valley,_Morocco_-_Houston_Museum_of_Natural_Science_-_DSC01584.JPG

Life Cycle

All arthropods begin life as eggs, with the majority of species then entering a juvenile **larval** stage, incapable of reproduction. The larvae often live in a different habitat to take advantage of a food source. Caterpillars, which are larval butterflies, feed on leaves; larval dragonflies and mosquitos live in water.

There are three types of insect life cycles:

1. The most primitive insects lay eggs from which tiny adults emerge, but most insects undergo partial or complete metamorphosis.
2. **Partial metamorphosis:** Some species, such as grasshoppers, emerge from eggs as simply smaller versions of their adult forms. They go through a number of molts before reaching their adult, sexually mature form, but they are otherwise indistinguishable from the immature forms.
3. **Complete metamorphosis**: Insects such as butterflies and mosquitoes go through complete metamorphosis, transforming their bodies in four life stages: egg, **larva**, **pupa**, and adult. For example, most mosquito species lay their eggs as an egg raft on the surface of standing water. **Larvae** emerge from eggs and go through a series of molts before turning into **pupae**, comparable to a butterfly **chrysalis**. During that stage they do not eat, and their bodies transform into adults with wings.



The larval stage of the mosquito life cycle requires standing water. Dump it out to reduce the number of biting adults!
Image by Eric Engh and Rick Reynolds; used by permission

Spiders: Most spiders have an egg sac with eggs. Spiderlings hatch out looking like tiny adults.

Scorpions have live births of 2–100 scorplings. The mother protects them until their exoskeletons have hardened.

Millipedes and centipedes lay eggs in soil. Hatchlings add additional segments with each molt until they are adult size.

Terrestrial crustaceans: Pill bug (woodlouse) females carry their eggs and hatchlings.

Materials + Preparation

- Shape of Life video "Terrestrial Arthropods: The Conquerors" (13:41): shapeoflife.org/video/terrestrial-arthropods-conquerors

  Decide if you will show the video to the whole class and/or have partners view the video while taking notes about arthropod adaptations and/or sketching them.
- Other short videos that can be incorporated into the lesson as Engage phenomena, to illustrate key concepts in the Explain section, or as part of Enrich / Extend activities are available at shapeoflife.org/arthropod:
  - "Arthropod Animation: Millipede Breathing Tubes" (0:59): shapeoflife.org/video/arthropod-animation-millipede-breathing-tubes
  - "Arthropod Animation: Scorpion Book Gills" (1:05): shapeoflife.org/video/arthropod-animation-scorpion-book-gills
  - "Arthropod Animation: Swiss Army Knife" (0:52): shapeoflife.org/video/arthropod-animation- swiss-army-knife
  - "Arthropods: Dragonfly Larva Hunts Newt" (2:06): shapeoflife.org/video/arthropods-dragonfly-larva-hunts-newt
  - "Arthropods: Dragonfly Metamorphosis" (2:46): shapeoflife.org/video/arthropods-dragonfly-metamorphosis
  - "Arthropod Locomotion: Engineering" (7:15): shapeoflife.org/video/arthropod-locomotion-engineering
  - "Bill Shear, Biologist: How Arthropods Left the Sea" (6:38): shapeoflife.org/video/bill-shear-biologist-how-arthropods-left-sea
  - "Paleontology: New Evidence Revises Thinking, Anomalocaris" (4:09): shapeoflife.org/video/paleontology-new-evidence-revises-thinking-anomalocaris
- Computer with Internet connection and data projector if you plan to show all or part of the video to the whole class
- Science notebook and pencil or pen for each student
- Whiteboard or chart paper and markers
- *Optional:* Colored pencils and/or markers for students to share

Scene from "Terrestrial Arthropods: The Conquerors"

Scene from "Arthropod Animation: Swiss Army Knife"

Teaching Suggestions in the 5E Model

Engage

1. Options to "hook" students and introduce the lesson. (2–5 min.)

- Show students a short video clip of a fascinating arthropod phenomena with the sound muted, such as "Arthropods: Dragonfly Metamorphosis" (2:46) shapeoflife.org/video/arthropods-dragonfly-metamorphosis. Then ask students to:
    - Explain the phenomenon.
    - Think about what group of animals they think is the most successful on Earth and why.
- Give students a minute to brainstorm ideas with a partner, then ask the groups to share their ideas with the whole class and discuss.
- Tell students that today they will be learning about the fascinating organisms that comprise over 85% of known animal species—terrestrial **arthropods**.
- Ask students to complete the "Arthropod Trivia" activity at the end of the lesson to see what they already know about the phylum and prime them for the lesson.

Scene from "Arthropods: Dragonfly Metamorphosis"

Explore

2. Students watch "Terrestrial Arthropods: The Conquerors" and consider arthropod adaptations. (20 min.)

- Depending on how many computers and/or other devices your students have access to, consider asking them to watch "Terrestrial Arthropods: The Conquerors" (13:41) shapeoflife.org/video/terrestrial-arthropods-conquerors with a partner while thinking about the **adaptations** that help arthropods survive. They should record notes about the physical adaptations (body structures) and behavioral adaptations (things the organisms do) that help them survive, including simple sketches of the organisms and their important structures. They might also add arrows or other symbols to indicate movements and other processes. Consider giving them a choice between recording notes in science notebooks and a digital format.
- Encourage students to turn on closed captioning using the CC button so they can read along with the video. Students can also use headphones, if available, to better hear the narration and minimize distractions from other groups.
- Circulate through students, answering questions and providing feedback, as necessary.

Explain

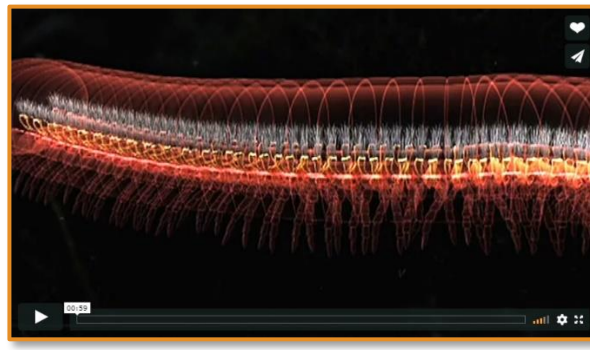
3. Discuss important concepts and terms with students. (5–15 min.)

- Gather students together and briefly discuss their ideas about arthropod adaptations—structures, as well as behaviors.
- Discuss important concepts explained in the Teacher Background section, writing them on the board and asking students to take notes on them in science notebooks. Use the short videos on the Shape of Life website as visual aids.
- Explain that the name Arthropoda means "jointed foot" in Greek. Do students think that name was a good choice for this phylum of animals? Why or why not?
- Discuss how despite their myriad shapes and behaviors, all animals in the phylum **Arthropoda** have certain important structures in common:

Segmented body

Discuss with support of clips such as part of "Arthropod Animation: Millipede Breathing Tubes" (from 0:09–0:25): shapeoflife.org/video/arthropod-animation-millipede-breathing-tubes (it shows clear segmentation in a millipede)

- Body divided into segments
- Usually grouped into larger functional units (such as cephalothorax and abdomen)



Scene from "Arthropod Animation: Millipede Breathing Tubes"

Jointed legs

Explain that all arthropods have many pairs of jointed limbs. Ask students to explain why that adaptation has been so helpful for their incredible success. Show "Arthropod Animation: Swiss Army Knife" (0:52) as a visual aid: shapeoflife.org/video/arthropod-animation-swiss-army-knife. You can also show and discuss all or part of "Arthropod Locomotion: Engineering" (7:15): shapeoflife.org/video/arthropod-locomotion-engineering.

- Increased flexibility, range of motion, and shock absorption
- Animal lower to ground to improve stability; lower center of gravity
- Steps in the **evolution** of arthropods to better fill specific **niches** in the environment—via **natural selection** and **genetic variation**—allowed new uses for their jointed appendages: **antennae**, claws, mouth parts, etc. For example, insect mouthparts have evolved for feeding in many different ways: piercing, biting and sucking.

Scene from "Arthropod Locomotion: Engineering"

Exoskeleton

Discuss student ideas about the benefits and drawbacks of an exoskeleton with a visual aid, such as "Arthropods: Dragonfly Metamorphosis" (2:46): shapeoflife.org/video/arthropods-dragonfly-metamorphosis.

- Hard exoskeleton, called a cuticle in insects, supports body and provides protection like armor; made mostly of **chitin** and protein, sometimes made harder by calcium carbonate
- Prevents water loss
- Gives a surface for muscle attachment
- Discuss the importance of wings and how insects are the only invertebrates that fly. Explain that the emergence of wings represents a profound time in evolution, making insects one of the most successful groups. The wings are not an appendage but rather they developed as an outgrowth of the exoskeleton; they only become functional in the adult. Most insects have two pairs of wings.
- **Molting:**
  - Growing body cracks open exoskeleton to shed it and grow larger; new exoskeleton is soft immediately after molting, making them vulnerable to predation
  - Softer, new skeleton inflates quickly to larger size and hardens in a couple days
  - Must molt to grow
  - Many terrestrial arthropods change their bodies when they molt, adding new segments (millipedes and centipedes) or developing wings.

Respiration

Show and discuss the following short videos to help students understand arthropod adaptations for breathing air:

- The rest of "Arthropod Animation: Millipede Breathing Tubes" (from 0:25–0:59): shapeoflife.org/video/arthropod-animation-millipede-breathing-tubes
- "Arthropod Animation: Scorpion Book Gills" (1:05): shapeoflife.org/video/arthropod-animation-scorpion-book-gills

Scene from "Arthropod Animation: Scorpion Book Gills"

- **Discuss the arthropod life cycle** and how terrestrial arthropods have many different types of life cycles. The majority of species emerge from eggs in a juvenile larval stage, which is usually quite different from the adult stage and incapable of reproduction. You might show part of "Dragonfly Larva Hunts Newt" (2:06) as a visual aid to help students understand how insects can be very different in their larval stage: shapeoflife.org/video/arthropods-dragonfly-larva-hunts-newt. Discuss how larvae often live in a different habitat to take advantage of a food source. Caterpillars, which are larval butterflies, feed on leaves; larval dragonflies and mosquitos live in water.

Scene from "Dragonfly Larva Hunts Newt"

- **Discuss the three types of insect life cycles:**
  - The most primitive insects lay eggs from which tiny adults emerge, but most insects undergo partial or complete metamorphosis.
  - **Partial metamorphosis:** Some species, such as grasshoppers, emerge from eggs as simply smaller versions of their adult forms. They go through a number of molts before reaching their adult, sexually mature form, but they are otherwise indistinguishable from the immature forms.
  - **Complete metamorphosis**: Insects such as butterflies and mosquitoes go through complete metamorphosis, transforming their bodies in four life stages: egg, **larva**, **pupa**, and adult. For example, most mosquito species lay their eggs as an egg raft on the surface of standing water. **Larvae** emerge from eggs and go through a series of molts before turning into **pupae**, comparable to a butterfly **chrysalis**. During that stage they do not eat, and their bodies transform into adults with wings.
- Discuss how **spiders** have an egg sac with eggs. Spiderlings hatch out looking like tiny adults. You might show an image such as the one shown to the right from Pixabay: pixabay.com/photos/spider-nest-baby-spiders-web-5215053.
- Discuss how **scorpions** have live births of 2–100 scorplings. The mother protects them until their exoskeletons have hardened.
- Discuss **terrestrial crustaceans:** Pill bug (woodlouse) females carry their eggs and hatchlings. You might find some outside and bring them in for students to observe, or take the class out for a field study (see Enrich / Extend). They are common under rotting logs.

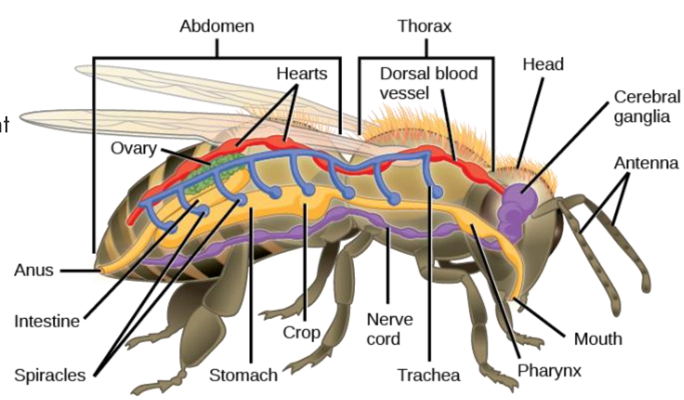
Newly hatched spiderlings

Pixabay: pixabay.com/photos/spider-nest-baby-spiders-web-5215053/

- Discuss how **millipedes and centipedes** lay eggs in soil. Hatchlings add additional segments with each molt until they are adult size.
- Discuss how arthropods left the sea, and the evidence for that transition, with the support of "Bill Shear, Biologist: How Arthropods Left the Sea": shapeoflife.org/video/bill-shear-biologist-how-arthropods-left-sea.

Scene from "Bill Shear, Biologist: How Arthropods Left the Sea"

4. Discuss how understanding arthropod structures and their functions helps us understand the evolution of animal adaptations. (2–10 min.)
    - Ask students to reflect on how adaptations, such as jointed appendages, help to explain the evolution of arthropods. (For example, jointed appendages evolved into different structures, such as antennae, and mouth parts, to help them adapt to particular environmental niches.) This can first be done as a think-pair-share activity before discussing it as a class.
    - Relate the important concept of cause and effect to your discussion. For example, how available food sources—such as nectar in different shapes of flowers—led to different types of proboscis in butterflies and moths, so they could suck up the nectar. You might also share the example of the special proboscis of mosquitoes that uses six needles to suck blood. "How Mosquitoes Use Six Needles to Suck Your Blood" (2:55) from PBS could help inspire your students to stay safe from mosquitoes and their many vector-borne diseases: pbs.org/video/deep-look-mosquitoes.
    - *Optional:* You might also discuss how **natural selection** of species through competitive pressures can result in the long-term effects of evolutionary changes over time. What might have caused the further evolution of arthropods to create those structures found in modern animals, such as the wings of flying insects?
5. Students create a detailed model of an arthropod. (20 min. or more)
    - Ask students to make a detailed scientific sketch, 3-D model, or computer-generated diagram of their favorite arthropod species, labeling the individual structures and their functions. You might also provide options to create a robot based on an arthropod.
    - The models could show only external structures, or you might encourage advanced students to include some internal anatomy, too. Consider sharing one or more exemplars that you and/or a student created, or share a model online, such as the diagram of a bee shown to the right and found on Wikimedia Commons: commons.wikimedia.org/wiki/File:Figure_28_04_06.png



- Discuss with students how they should add labels and annotations (more detailed explanations of the features of the diagrams). They can also color their diagrams and explain them in writing, including the adaptations that help the organisms survive (for example, structures and behaviors that help them catch food, escape predators, and reproduce).
- Students can complete diagrams with the support of reference materials such as books and reputable sources on the Internet.

6. Discuss connections between terrestrial arthropods and humans. (2–5 min.)
    - Ask students to think about human connections to arthropods, including ways they help us. Discuss how bees and other pollinators like butterflies are essential for pollinating our crops and other plants to provide us with food. Can students think of other human uses? (grasshoppers, crickets, and other terrestrial insects for food in some places; crickets and tarantulas as pets; marine arthropods like lobsters, crabs, and shrimp as delicacies around the world)
    - Ask students to think about ways we might be hurting them and discuss. (loss of habitat, pesticides, climate change, monocultures, etc.)
    - Discuss ways we might help beneficial terrestrial arthropods. (restoring habitat, such as planting diverse flowering plants for pollinators, including milkweed for threatened monarch butterflies, reducing or eliminating pesticides, reducing our greenhouse gas emissions to slow climate change and extreme weather events, removing carbon from air by planting trees, restoring wetlands, and marine ecosystems such as kelp forests and eelgrass)

A beekeeper checks a beehive
Creative Commons license by Ivan Radic: flickr.com/photos/26344495@N05/48414250731

Evaluate

7. Students can present their diagrams and/or other projects to the class.
    - Provide a rubric such as the one at the end of the lesson so students know how they will be assessed.
    - Help guide students to "use argument supported by evidence" that explains how their organisms "are a system of interacting subsystems composed of groups of cells" (NGSS). You might provide the example of an ant that has 3 main body sections—the head, thorax, and abdomen—that each contain subsystems of cells that interact. Within the head, for instance, are groups of cells that form the compound eyes, and other groups of cells that form the ocelli (also used for vision in some species). These visual sensory organs relay information to the brain, which can control the legs, mandibles, and other structures in response to the visual information, such as an attacking predator.
    - You could also ask students to create a larger version of their diagram on poster board with more detail, color, etc. These can include clear annotations which could also serve as notes if you would like students to present their diagrams to the class.

- Completed projects can also be displayed on classroom and/or school walls.

8. Review completed student diagrams and science notebooks.

    - Review student diagrams, labels, and annotations.
    - Check that they have explained arthropod structural and behavioral adaptations, including ways they are able to catch food, reproduce, and escape predators.

9. Closing discussion / reflection (5 – 15 min.)

    - Ask students to reflect on what they learned in the lesson, including about arthropod adaptations, orally and/or in writing. Ask them to reflect on what you, as the teacher, might do to improve the lesson next time.
    - Ask how adaptations, such as jointed appendages and segmented bodies, help explain the evolution of arthropods.

Extend / Enrich

- Conduct a field study into the arthropods found in your area so students can observe and compare living arthropods. (Will vary)

    - Take students outside to investigate the insects, spiders, woodlice, and other arthropods—as well as the ecosystems they are part of—in your schoolyard and/or other local areas. Bees and other pollinators, such as butterflies, are particularly good for investigations because of how important they are for plant reproduction and human food production. This is a particularly effective phenomenon-based approach in alignment with NGSS best practices.
    - Research available through the Children and Nature Network and other sources shows that connecting students with your nearby natural areas—even small green spaces—is a particularly effective way to engage students, improve their mental and physical health, and inspire them to learn more. Review the latest research at childrenandnature.org/research-library.
    - Be sure students are prepared with appropriate clothing, safety rules, ways to avoid damaging the ecosystem, etc.

- Have students design a useful new product inspired by the amazing adaptations of arthropods. (30 min. or more)

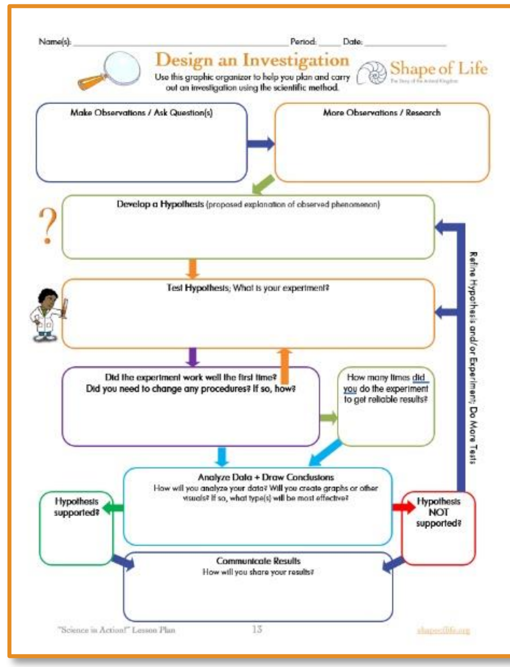
    - Watch the Shape of Life video "Arthropod Locomotion: Engineering" (7:15): shapeoflife.org/video/arthropod-locomotion-engineering.
    - Discuss the concept of biomimicry: using nature for inspiration to inspire human innovation. Drones and robots are already being developed based on their body plans, for instance. You might ask students to read an article, such as "Drones Become Even More Insect-like" in *Science* magazine, for additional information: science.sciencemag.org/content/368/6491/586.
    - Consider stepping students through the design process with resources such as those included to support Lesson 7 of the *Investigating Crayfish + Freshwater Ecosystems* curriculum from The River Mile Network/National Park Service: therivermile.org/network-projects/the-river-mile-crayfish-study/complete-crayfish-curriculum.

- Observe arthropods under magnification. (1 – 20 min.)

    - If you have access to live or preserved arthropods, students can view them and/or their body structures under magnification via a microscope, hand lens, and/or macro lens to better see their unique adaptations.
    - You can also use a microscope or macro lens connected to a computer and/or data projector to show them to the whole class.

- Dissect arthropods. (30 – 60 min.)
    - You can prepare to lead students in a dissection—or they can lead themselves—with the support of videos and/or other resources listed below and at the end of the lesson.
    - "Detailed Crayfish Dissection" (10:44) is one good option: youtu.be/AOZdmUKoViY.
- Students compare an arthropod species to another organism. (10–20 min.)
    - Ask students to compare an arthropod to another organism—either a modern one or an ancient ancestor. For example, a Venn diagram or another type of graphic organizer could be used. Then students could explain their graphic organizers in writing.
    - Students may give oral presentations to the class which explain their analytical comparisons.
- Discuss current events related to one or more arthropod species and human uses of them. (5 – 20 min.)
    - Find local news highlighting issues related to arthropods, such as bees impacted by pesticide use. This will make the activities and discussions more relevant and personal to students, as well as highlight important environmental issues.
    - Ask students to research news stories about humans benefitting from and/or helping arthropods. For example, they might find stories about how bees and other pollinators like butterflies are essential for pollinating our crops and other plants to provide us with food. They might find stories about other human uses, such as eating grasshoppers, crickets, and other terrestrial arthropods as an eco-friendly high-protein food source. Other topics include marine arthropods like lobsters, crabs, and shrimp—delicacies around the world—and how they are being hurt by human impacts like pollution and ocean acidification.
    - Important news related to the impacts of climate change on various arthropod species, as well as ways humans are trying to help, would also stimulate thinking and discussion.
- Students can conduct in-depth research projects about an unfamiliar arthropod species, its life cycle, and/or one or more of its adaptations. (40 min. or more)
    - Encourage students to use resources from Shape of Life and other authoritative sources, as well as connect with the school librarian(s).
    - Suggest public libraries and librarians as invaluable in the research process, too.
- Ask students to research the fascinating behaviors of social insects, such as bees, ants (including left-cutting ants), termites, and wasps. (40 min. or more)
- Students can write fictional stories or poems that involve arthropods. (15 min. or more)
    - Stories can include one or more arthropod species.
    - For example, it might be an imaginative piece about a day in the life of an arthropod.
- Set up learning/exploration centers and offer students a choice of activities. (40 min. or more)
    - Classroom centers can be set up with other activities related to arthropods and their adaptations, such as those listed above.
    - This would provide more opportunity for student choice and differentiated learning experiences to maximize intrinsic motivation, engagement, and learning.
- Students can plan (and possibly also conduct) their own investigations into arthropod species. (30 min. or more)
    - Challenge students to think about how they might design their own investigation to prove how and/or why an observed phenomenon occurs related to an arthropod. Use prompts like:

- "How might we design an investigation using an arthropod (living or already deceased)?"
    - "Are there animals in our schoolyard that we could investigate?"
    - "What question(s) would you ask scientists in the videos to help you design your study?"
    - "What materials might we need (and already have) to test interesting phenomena we observe?"
    - "How might we collect data?"
    - "How might we analyze the data and share it with others?"
- Pass out copies of the "Design an Investigation" organizer found at the end of the "Science in Action!" lesson plan from Shape of Life: shapeoflife.org/lesson-plan/sol/science-action.
- Have students form groups of 2 – 4 and use the organizer, their science notebooks, and/or a computer to help them develop an investigation plan. After groups start developing their ideas, ask the groups with especially interesting ones to share them with the class. This will help them refine their ideas and assist the other groups with developing their plans.
- Decide as a class which investigation(s) the students want to conduct. Each group might want to conduct their own unique experiment, or groups could break a larger investigation into smaller parts for each of the groups to investigate.
- **Ideas for student projects** if they need help generating them:
    - The proportions of different food groups they observe an insect species, such as ants, eating.
    - How and why populations of endangered butterflies are changing.
    - How species of aquatic insects are impacted by water quality (clarity of water, amount of dissolved oxygen and pollutants, etc.)
    - Groups could test the growth rate of arthropods under different conditions: varying amounts of food, water, light, salt, water pH, etc.
    - Investigate mosquito habitats and species in your area to help reduce the spread of mosquito-borne disease. The GLOBE Observer app from NASA with the "Mosquito Habitat Mapper?" can help support these studies and shares data with other groups around the world: observer.globe.gov/do-globe-observer/mosquitoes
    - Are there more crayfish in freshwater bodies in urban areas or rural areas?
- Students could also create presentations and/or videos about their investigations and results.



"Design an Investigation" graphic organizer found at end of "Science in Action!" lesson plan: shapeoflife.org/lesson-plan/sol/science-action

Expand Knowledge + Skills

Arthropod Background

- Shape of Life resources:
  - "The Land Arthropods: The Conquerors Coming Ashore.": shapeoflife.org/sites/default/files/global/TerrestrialArthropods.pdf
  - "Phylum Arthropoda.": shapeoflife.org/phylum-arthropoda
  - "The Marine Arthropods: A Successful Design.": shapeoflife.org/sites/default/files/global/MarineArthropods.pdf
- "Arthropods: A Success Story." Understanding Evolution: Univ. of California, Berkeley: evolution.berkeley.edu/evolibrary/article/0_0_0/arthropods_intro_05
- "Phylum Arthropoda." Exploring Our Fluid Earth: Teaching Science as Inquiry (TSI). Univ. of Hawai'i: manoa.hawaii.edu/exploringourfluidearth/biological/invertebrates/phylum-arthropoda
- "Introduction to the Arthropoda...the REAL rulers of the Earth." Univ. of California Museum of Paleontology: ucmp.berkeley.edu/arthropoda/arthropoda.html
- "Arthropods." projects.ncsu.edu/project/bio402_315/arthropods/a01.html
- "Arachnid." Wikipedia (also references many other excellent sources): en.wikipedia.org/wiki/Arachnid

Related Shape of Life Lesson Plans / Activities

- Shape of Life resources:
  - "Let's All Do the Wave!": shapeoflife.org/sites/default/files/global/arthropod-locomotion-lesson-plan.pdf
  - "Nature's Innovations: Animals as Engineers." shapeoflife.org/sites/default/files/SoL-Lesson-Natures-Innovations_0.pdf
  - "Phylum Arthropoda (Terrestrial) – Questions." shapeoflife.org/sites/default/files/global/phylum-arthropoda-terrestrial-questions.pdf
  - "World's Most Awesome Invertebrate.": shapeoflife.org/sites/default/files/SoL-Lesson-Awesome-Invertebrate_0.pdf
  - "Invertebrate Critter Cards.": shapeoflife.org/sites/default/files/lesson-plans/Invertebrate%20Critter%20Cards%20Activity___0.pdf
  - "Terrestrial Arthropods: The Conquerors Worksheet": shapeoflife.org/sites/default/files/global/terrestrial-arthropods-factsheet.pdf

Related Videos

- Explore the other Shape of Life arthropod videos: shapeoflife.org/arthropod
- "Learning about Arthropods." Fun student project: youtu.be/Zr4jiyhlCvw
- "Detailed Crayfish Dissection" (10:44). SDPB: youtu.be/AOZdmUKoViY

Standards

- Next Generation Science Standards, including a link to the *Framework for K-12 Science Education* to which this lesson was aligned: nextgenscience.org/framework-k%E2%80%9312-science-education
- Examples of what NGSS looks like for California students can be found in the 2016 Science Framework for California Public Schools: cde.ca.gov/ci/sc/cf/documents/scifwchapter4.pdf
- Common Core State Standards and links to the complete documents: corestandards.org

Shape of Life

The Story of the Animal Kingdom

Appreciation + Thanks

Thank you for using Shape of Life resources and helping to inspire the next generation of thinkers and scientists! We also greatly appreciate all of the scientists who have been collaborating with us to produce the videos and supporting resources. We welcome your questions or comments.

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Shape of Life

Arthropod Trivia

1. Put an "X" or checkmark in front of all the animals below that are classified as arthropods.

   ____ Corals ____ Millipedes
   ____ Crustaceans: crabs, crayfish, etc. ____ Arachnids (spiders, ticks, etc.)
   ____ Insects ____ Starfish

2. Arthropods are:

   ____ Carnivores ____ Omnivores
   ____ Herbivores ____ All of these

3. Mark all the things below that arthropods eat.

   ____ Algae ____ Insects
   ____ Fish ____ Plants
   ____ Zooplankton ____ Bacteria

4. All arthropods have straight **appendages** (like legs and antennae).

   ____ True
   ____ False

5. All arthropods have an **exoskeleton** that provides support and protects their soft internal organs.

   ____ True
   ____ False

6. Arthropods start life as eggs and usually go through different life stages, such as the **larval** stage, when they can have very different body structures and behaviors, before reaching the adult stage.

   ____ True
   ____ False

7. Molting is the process by which an arthropod sheds its exoskeleton to make room for a new, larger one.

   ____ True
   ____ False

Arthropod Glossary

appendage parts attached to the main body like claws and antennae

antenna one of two long sensory organs at front of arthropods such as insects and crustaceans (**antennae**: two or more)

arachnid arthropod in class **Arachnida**; predatory or parasitic animals that have 8 legs, such as spiders, scorpions, and ticks

arthropod animal in phylum **Arthropoda** that includes animals with exoskeletons and jointed appendages; includes over 85% of known animal species

biomimicry design and creation of products, materials, and/or systems inspired by biological organisms

chitin a substance that provides a tough, protective covering; similar to keratin, the substance that human hair and nails are made from

crustacean an arthropod in subphylum Crustacea that includes lobsters, crayfish, crabs, and shrimp

detritus dead material broken down by bacteria, fungi, and many arthropods

gills internal feathery organs in marine/aquatic arthropods (as well as fish) used to extract oxygen from the water

exoskeleton hard external covering of various animals, including arthropods, that provides attachment for muscles and protects the animal from drying out and injury

evolution process by which organisms change over time through **natural selection**

insect arthropod in class **Insecta**; insects comprise 75% of known animal species

metamorphosis dramatic change in structure and lifestyle a larva undergoes when it becomes an adult. When an arthropod passes through specific developmental stages during molting, it is said to be metamorphosing. For example, an arthropod like a dragonfly can start life in a pond as a swimming larva and then metamorphose into a completely different looking, winged adult.

larva free-living, immature stage in the life cycle of many animals (such as arthropods); often very different in appearance from adult stage and usually incapable of reproduction

marine found in or related to the sea

molting in arthropods, the periodic process by which the exoskeleton is discarded and replaced by a new, larger one that allows the animal to grow

myriapod arthropod in subphylum **Myriapoda** that includes centipedes and millipedes

natural selection process in which organisms better adapted to their environment survive to produce more offspring

pollination process by which pollen (grains that contain male reproductive cells) is transferred to the female structure in plants, thereby enabling fertilization and sexual reproduction

segmented the body is made up of a basic body compartment and the body gets longer by adding more compartments. Like a classic train with its engine and caboose, segmented animals have repeating segments between specialized front and back compartments

terrestrial found on or related to land

trilobite arthropod from extinct group found in fossil record from about 521 million years ago until about 252 million years ago; diverse species were scavengers, predators, and filter feeders

Presentation Rubric

Title: ____ Name: ______________________

Presentation Component	Maximum Points Possible	Self-Score (fill out before presentation)	Teacher Score
Part 1: Content			
Subject and purpose of presentation clearly introduced	10		
Key concepts identified and clearly explained in well-organized way	10		
Ideas supported by examples, data, graphs, etc.; All information accurate and obtained from reliable sources	10		
Conclusion summarizes key points in persuasive way; Questions answered thoroughly and accurately	10		
Part 2: Delivery / Audience Engagement			
Speech delivered clearly at appropriate volume and speed (not too fast, slow, loud, or soft)	10		
Speed, volume, and voice inflection are varied to engage audience and emphasize key points	10		
Speaker connects with audience through eye contact and does not spend too much time looking at notes or screen	10		
Speaker demonstrates enthusiasm for topic throughout presentation; audience is persuaded by speaker	10		
Part 3: Visuals			
Visuals help to clearly explain concepts	10		
Part 4: Writing Conventions			
Grammatical and spelling conventions followed	10		
TOTALS:	**100**		

Comments: