ST[EMpower]

PALEONTLOGY 5: SPECIATION

VOLUME 9, ISSUE 5, January 2020

THIS MONTH

POWER WORDS

- **BYA**: billion years ago
- **eukaryote**: organism consisting of a cell or cells in which the genetic material is in **chromosomes** contained within a distinct nucleus
- **phylum**: (plural phyla) a major division of life after Kingdom and before Class (see pg. 2 for more information)
- **prokaryote**: a microscopic single-celled organism with no internal membrane bound organelles, DNA is in a circle

CAREER CONNECTION

DESCENT WITH MODIFICATION

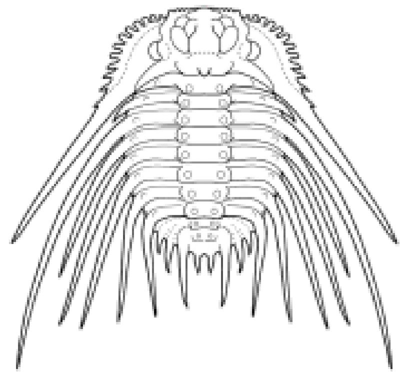
The Paleozoic Era lasted from 541 to 252 million years divided into six Periods:

- Cambrian
- Ordovician
- Silurian
- Devonian
- Carboniferous
- Permian

At the end of the Precambrian, there is evidence of soft-bodied, multicellular organisms (mostly frond-like and tubular forms) found in locations around the world. This is called the Ediacaran biota. These animals were composed of individual cells organized into colonies, like sponges.

The Cambrian Explosion refers to a burst of fossils. The reason is simple; animals developed hard parts, like shells. We find fossils representing almost all of the 35 animal **phyla**! The only modern animal phylum missing is Bryozoa, moss animals.

This issue focuses on trilobites, both their natural history but also as an example of how all organisms speciate. Trilobites are incredibly awesome!



The Ute Tribes are now located in SW Colorado and Utah. They roamed throughout the Western Rocky Mountains, venturing onto the Eastern Plains. They found Cambrian trilobites and carried them as protective charms, “Timpe-Konitza-Pachuee.” or “little water bug living in a house of stone.”

Samuel Turvey found new Chinese trilobites. He gave one of them the genus name of *Han* after the biggest ethnic group in China. The species name is *Han solo*!

A **mnemonic** is a trick to help remember something. Here is a **mnemonic** for planets:

My — Mercury
Very — Venus
Educated — Earth
Mother — Mars
Just — Jupiter
Served — Saturn
Us — Uranus
Nachos—Neptune

Before advanced technology in **molecular techniques,** Dr. Carl Woese and Dr. George Fox painstakingly analyzed a very stable section of DNA of hundreds of organisms. They found a hidden group of single-celled **prokaryote** organisms, distinct from bacteria, and called them archaebacteria (now called **Archaea**). Domain **Eukaryota** organisms can be single-celled or multicellular. They are distinct from both Domain Bacteria and Domain Archaea: DNA is formed into **chromosomes** residing in the cell's nucleus, and the cell contains **organelles**. Domain is the highest hierarchy, and all known life falls into one of these three Domains.

Within the Domain **Eukaryota** are 10 Kingdoms, seven of which are mostly single-celled organisms, and three contain multicellular organisms:

- Kingdom Plantae (plants)
- Kingdom Fungi (fungus)
- Kingdom Animalia (animals)
    - Within Kingdom Animalia are 35 phyla, including Phylum Arthropoda.
    - Within Phylum Arthropoda is the Class Trilobita (also known as Trilobitomorpha)
    - Within Class Trilobita are 10 Orders of trilobites, like the Order Proetida.
    - Within Order Proetida are 13 Families, like Family Proetidae.
    - Within Family Proetidae, there are 288 Genera including Genus *Proetus*.
    - Within Genus *Proetus* are two species, *P. concinnus* and *P. latifrons*.

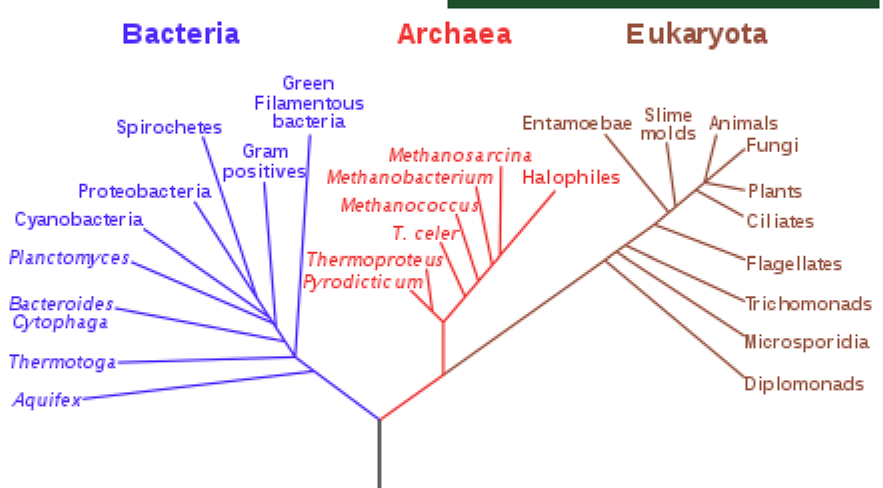
Directions:

- Develop a **mnemonic** to help you remember the hierarchy of life:

Domain—
Kingdom—
Phylum—
Class—
Order—
Family—
Genus—
Species—

POWER WORDS

- **Archaea**: microorganisms similar to bacteria in size and simplicity but different in molecular organization
- **chromosome**: threadlike structure of DNA found in the nucleus of **eukaryote** cells carrying genetic information in the form of genes
- **hierarchy**: taxonomic classification of successive levels of complexity of life
- **mnemonic**: a device such as a pattern of letters, ideas, or associations that assists in remembering something
- **molecular techniques**: manipulation and analysis of DNA, RNA, and/or proteins
- **organelle**: organized or specialized structures bound by a membrane within a living cell



MATERIALS

- Paper
- Pencil

The Cambrian Explosion occurred 541 **MYA** and lasted 20 million years. During this time, almost all major animal **phyla** appeared in the fossil record. Not only that, but there were some weird and wonderful experiments in life, like *Opabinia regalis.* with 5 eyes and a long **proboscis**, and *Marrella splendens*. (the lace crab—but not a crab), the most common animal in the Burgess Shale.

The Burgess Shale is a location in British Columbia that is a treasure trove of these amazing Cambrian fossils. It was found in August 1909 by Charles Doolittle Walcott, paleontologist from the Smithsonian. It was almost at the end of the season, so the following year, Walcott and his family returned and began extracting these incredibly well preserved fossils, both hard and soft bodied organisms, from this site dated 508 **MYA**.

Walcott and his family continued collecting at this site until 1924, and had collected over 65,000 specimens for the Smithsonian. They were considered only a curiosity, and were not studied again until 1962, when Alberto Simonetta recognized that many of these fossils did not fit in modern groups.

The quarry was reopened by the Geological Survey of Canada under a trilobite expert Harry Blackmore Whittington. Dr. Whittington had two graduate students, Derek Briggs (now with Yale University) and Simon Conway Morris (now with University of Cambridge), who began a thorough assessment of the Burgess Shale **fauna** in the 1980s. These three men were instrumental in bringing to light the amazing and wonderful life that had lived in there half a billion years ago!

The Burgess Shale is not the only location from this time in Earth's history with well preserved fossils. There are three other places in the world that remarkable preservation of fossils from this time: Chengjiang and Doushantuo, both in China, and Sirius Passet in Greenland. There are fossil sites throughout the world, just not with the detail of the ecosystem preserved, like it is in these four site.

The earliest known trilobites are from 521 **MYA** found in Siberia, Morocco, Spain, and North America. At this time, the evidence indicates that trilobites originated in Siberia, and then migrated throughout the world. They survived 250 million years. During this time, they speciated into over 20,000 species!

Directions:

- Explore the links in the green box below, A Guide to the Orders of Trilobites and American Museum of Natural History Trilobite Website.

POWER WORDS

- **e.g.**: Latin for exempli gratia meaning for the sake of example, or for example
- **fauna**: animals from a particular region, habitat, or geological period
- **MYA**: million years ago
- **proboscis**: elongated appendage from the head of an animal (**e.g.** elephant trunk)
- **stratum** (plural **strata**): layer, or series of layers, of rock in the ground

Order Redlichiida, *Paradoxides sp.* may represent the ancestral trilobite.

MATERIALS

- Computer with internet
- https://www.trilobites.info/
- https://www.amnh.org/researcHpaleontology/collections/fossil-invertebrate-collection/trilobite-website
- Optional: Gould, Stephen Jay (1989) Wonderful Life: The Burgess Shale and the Natural History, W.W. Norton & Co. Your county library has a copy, or can find one for you. Wonderful story! A must read!

Prior to the Cambrian, there is no fossil record of organisms with eyes. Cambrian fossils, however, show many different forms of eyes. Eyes can be simple light sensing cells differentiating between shade and full sun or extremely complex, like human and bee eyes. Of the 10 Orders of Trilobites, nine Orders had **compound eyes**, similar to insect eyes. Trilobites came up with a unique solution for a lens—they used calcite.

Calcite is a mineral composed of calcium, oxygen, and carbon ($CaCO_3$). It is found throughout the world. Some forms of calcite have a unique property: they are clear and **birefringent** (cool science word!) See the image below how light splits.

- **bi** means two
- **refringent** means split

Order Agnostida trilobites lost their eyes. Only the very earliest agnostids had eyes. Agnostic means someone who believes that nothing can be known about the existence or nature of God; they neither have faith nor disbelief in God. In other words, the agnostid trilobites do not see the light, a reference to this Order having no eyes!

In this activity, you will make an eye model of a single **facet** of a trilobite eye.

Directions:

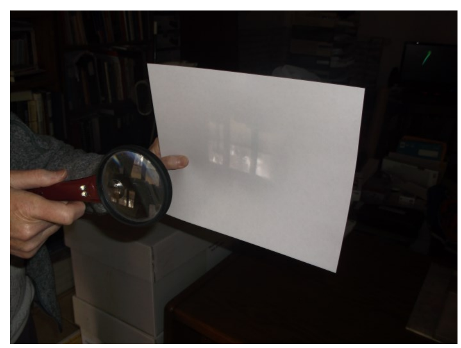
- Do this by a window during the day.
- Stand on one side. Hold your paper vertically in the hand farthest from the window.
- Hold the **biconvex** lens vertically in the other hand. Be sure that the light from the window through the lens to the paper is not blocked.

- Move the lens slowly back and forth until the image comes into sharp focus on the paper. Measure and record the distance between the paper and the lens. This is called the **focal length**. Different lenses have different **focal lengths**. If you have more than one lens, do the same with each lens. Record each measurement.
- TP tubes are 4” long, and paper towel tube is 11” long. If your focal length is longer than 7”, you need to also use the paper towel tube.

POWER WORDS

- **accommodate**: the ability of the eye to change focus from distant to near objects
- **analogous**: structures performing similar function but having a different origin; example insect wings and bat wings
- **biconvex**: surface curved like the exterior of a circle on both sides
- **birefringent**: light will travel in two different directions when passing through a material like calcite
- **circumference:** the distance around something
- **compound eye**: an eye consisting of an array of numerous small visual units, as found in crustaceans or insects

Definitions continue page 5



MATERIALS

- magnifying lens (hand lens or **biconvex** lens)
- 2 TP (toilet paper) tubes and 1 paper towel tube
- wax paper
- scissors
- 1 rubber band
- tape
- ruler and pencil
- optional: bag of lenses (search internet for a good deal—around $20)
- optional: clear calcite (ask at a rock shop—around $8)

- Your tubes will be like a telescope. One tube nests inside the other tube. Cut one TP tube down the length, and tape it together with a slightly smaller diameter so it will fit inside the other TP tube. If your lens with the longest focal length is over 8”, you need to use a paper towel tube.
- If you have different lens **focal lengths**, you can adjust your tubes to accommodate for each **focal length**. This is similar to our ability to keep close objects or far objects in focus.
  - Use the distance of the lens with the shortest **focal length**. If your focal distance is less than 4”, cut your inner, thinner tube’ **circumference** ½” shorter than your focal length. Cut your outer, fatter tube 1” shorter than the focal distance.
    - Example: The **focal length** is 3.5”. Cut the outer, wider tube 1½” around the **circumference** so the tube is 2½” long. Cut the longer, inner tube 1” so it is 3” long.
  - If your **focal length** is 4½ to 7”, only cut your outer, fatter tube ½” shorter.
    - Example: The **focal length** is 4½”. Cut only the outer, wider tube by ½” so that it is 3½” long. The thinner tube remains 4” long.
  - If your longest **focal length** is over 7”, you will need to use a paper towel tube in addition to the TP outer tube. Cut the paper towel tube down the length, and tape it together with a slightly smaller diameter so it will fit inside the wider TP tube. Cut the paper towel tube ½” shorter than the lens with the longest **focal length**.
    - Example: The **focal length** is 8”. Cut the paper towel tube lengthwise, and tape it back together with a smaller diameter to fit inside the TP tube. Also cut the paper towel tube shorter, so that it is 7½” long.
- Attach a small piece of wax paper to the shorter outer TP tube and fasten it with a rubber band. If the wax paper is wrinkled or ripped, it will be easy to replace.
- Insert the longer tube into the shorter tube. Telescope the tubes as long as possible.
- Stand in front of a window. Hold the magnifying lens in one hand. Hold the tubes in the other hand, with the wax paper towards you. Hold the lens and tubes arms-length away.
- Slowly push the lens against the furthest tube, decreasing the length of the tube. Look at the wax paper. The image will come into sharp focus.

POWER WORDS (cont.)

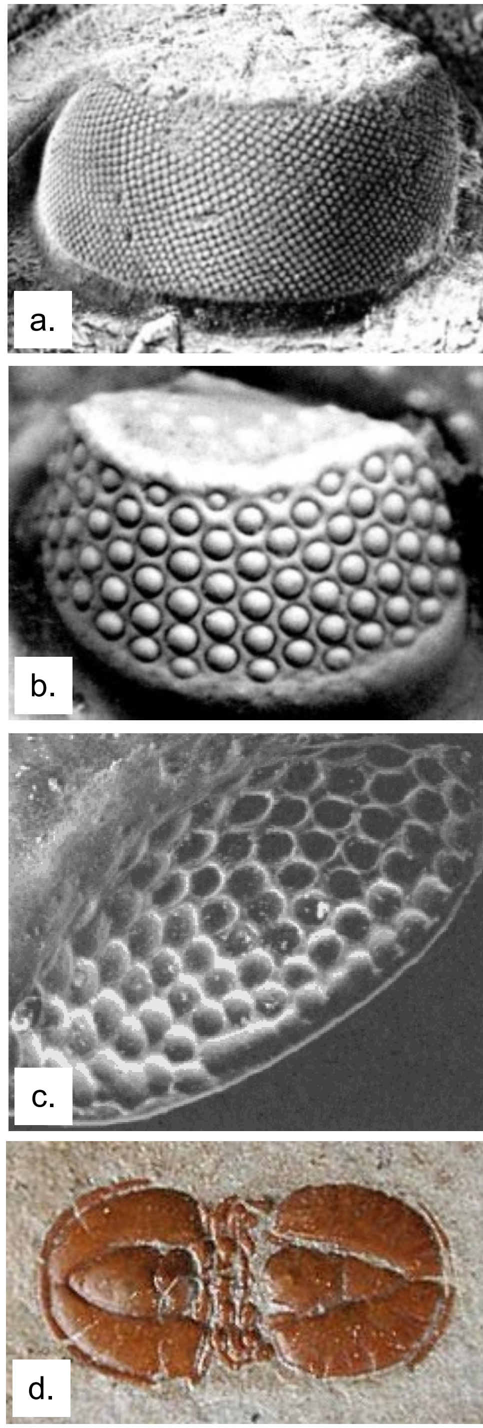
- **diameter**: a straight line passing from side to side through the center of a body or figure, especially a circle or sphere
- **facet**: any of the individual units (ommatidia) that make up the compound eye
- **focal length**: the distance from the lens to the image in focus
- **homologous**: similar in position, structure, and origin, but not in function; example bird and bat wings

Definitions start page 4

The longer thinner tube nests inside the shorter, wider tube with wax paper on one end.

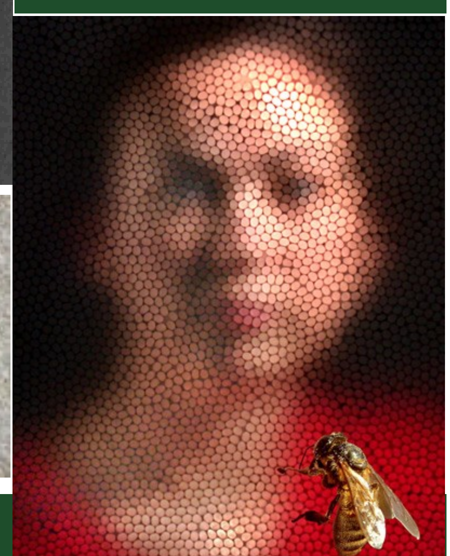
TRILOBITE EYES—

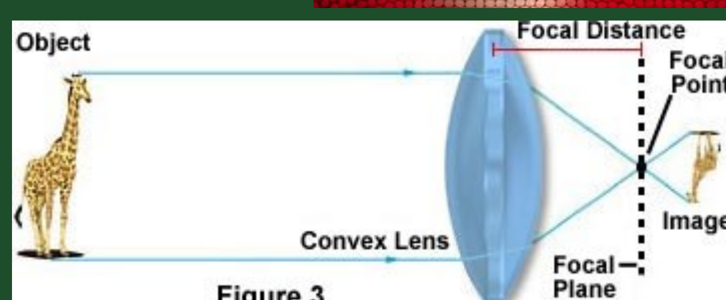
Reflect:
- Describe the image. What do you notice about it?
- Wax paper represents the light sensitive cells that send the image to the brain. The lens represents the calcite lens.
- Your "eye" represents only a single facet. Trilobite fossils had many facets, some had 15,000 facets per eye!
- What is the advantage of so many facets? They are extremely motion sensitive.
- A calcite lens is hard, and cannot **accommodate**. Instead, they relied on the **birefringent** properties of calcite to change focus.
- There are three "styles" of trilobite eye:
  a. Holochroal eye is the most common. It has a few to over 15,000 facets; no separation between facets.
  b. Schizochroal eye; fewer, larger facets separated by a sclera (like the whites of our eyes). Found in few species in Order Phacopida.
  c. Abathochroal eye: flat facets found only in a few primitive agnostids from the Early Cambrian.
  d. Trilobites that lacked eyes are thought to have **secondarily lost** them. Organisms living in caves or deep in the ocean **secondarily lost** eyes.
- How a basic eye works:
  - Light passes through an opening usually with a lens to focus the light.
  - The image is **inverted**.
  - Light **receptors** are located focal distance (or so) behind the lens.
  - **Receptors** send electrical signals to the brain for interpreting the light. If the eye does more than sense light and dark, the brain re-**inverts** the image.



POWER WORDS
- **invert**: put upside down
- **receptor**: an organ or cell able to respond to light, heat, or other external stimulus and transmit a signal to a sensory nerve
- **secondarily lost**: organisms whose ancestors had a structure that is no longer present (**e.g.** mice and squirrels have secondarily lost their thumbs and only have four fingers; their ancestors had 5 fingers)

Image below is the best understanding bee scientists think bees see through their compound eyes.



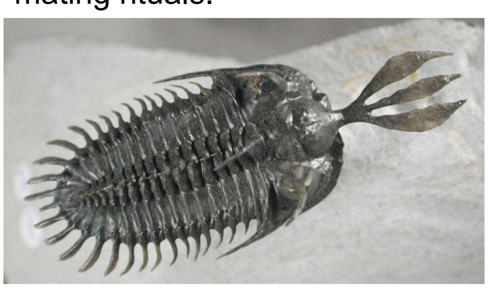


Trilobite size ranges from tiny to huge (well, huge for a trilobite),

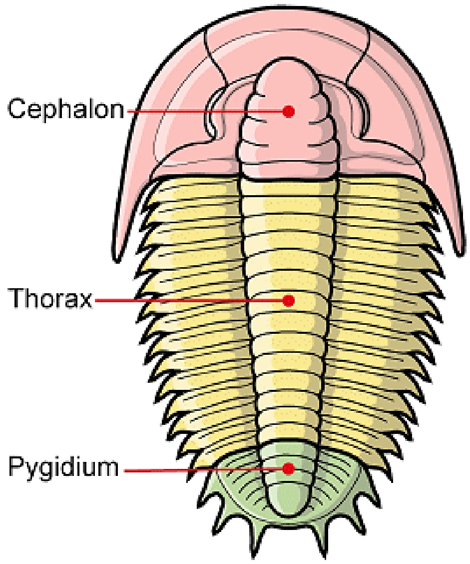
- The smallest trilobite found is *Acanthopleurella stipulae* in the Order Ptychopariida. It is only 1-2 mm (size of a fleck of pepper).
- The largest known trilobite is *Isotelus rex* in the Order Asaphida. It is 28" long and 18" wide. It lived during the Ordovician, and the fossil was found in Manitoba, Canada.

Trilobites had a broad spectrum of feeding habits, ranging from predatory to filter-feeders. That mean to their mouth parts were different. See https://www.trilobites.info/feeding.htm for a discussion on feeding and mouth parts. An example of a filter feeder *Cordania* is pictured below.

Some trilobites had amazing structures, like *Walliserops trifurcatus* pictured below. Scientists are not sure how the "trident" was used, but it could have been for protection or mating rituals.



Trilobites had three body parts, similar to insects. They had a **cephalon** (head), **thorax** (chest) and **pygidium** (tail).



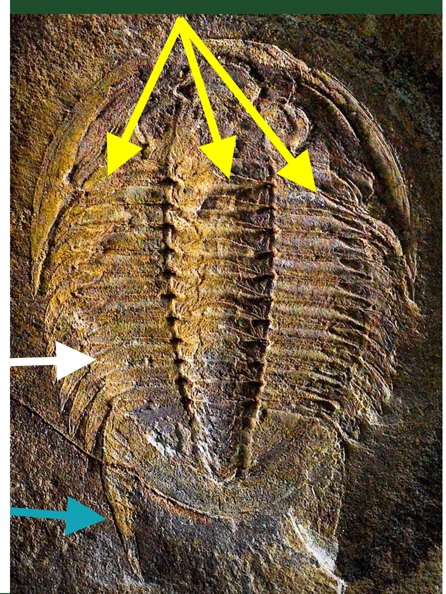
The name trilobites means three lobes. This does NOT refer to their three body parts, but to the left, center and right sections that ran down their bodies as shown by the yellow arrows on *Postikaolishania jingxiensis,* the trilobite imaged on the right.

Different species have a different number of repeating segments along their **thorax** and **pygidium**. The white arrow shows one of the 16 **segments** on *Postikaolishania jingxiensis*.

Many trilobites have spines. The blue arrow points to a plural spine.

POWER WORDS

- **cephalon**: in trilobites and some other arthropods, the region of the head, composed of fused segments
- **pygidium**: the hind segment of the body in certain invertebrates
- **segments**: (also called ribs) each of the series of similar anatomical units of which the body and appendages of some animals are composed, i.e. rings of an earthworm's body
- **thorax**: the middle section of the body of an insect or trilobite, between the head and the abdomen, bearing the legs

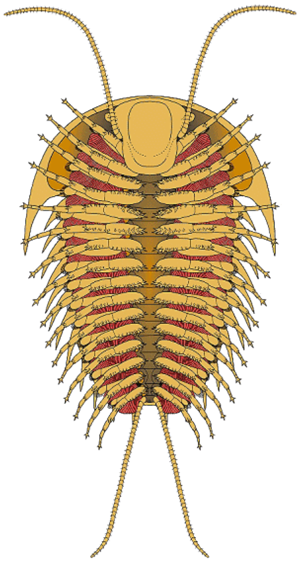


MATERIALS

- 3 cup flour
- 3 cup water
- 6 tsp cream of tarter
- 1 cup salt
- 3 TBS vegetable oil
- red food color
- green food color
- stove
- large pot
- wood spoon
- measuring spoons
- measuring cup
- adult supervision
- wax paper
- computer & internet

cont. on page 8

Finally, if you turned a trilobite over, beneath the **carapace** were legs. Nested between the legs and the **carapace** were the gills. The drawing below is the **ventral** (belly) side of a trilobite.



For this activity, you will make playdough and sculpt 3 trilobites of different sizes. The recipe includes directions to add a brown color to your playdough. You can skip adding the color for white trilobites. You could even add a rainbow of colors if you want to make them colorful!

Directions:

- Measure 3 cups water and pour into your pot. Add 10 drops of red and 10 drops of green food color. Mix. If it isn't dark enough, and another 10 drops of red and 10 drops of green food color.
- Add to your pot of water, 3 cups flour, 6 **tsp** cream of tarter, 1 cup salt, 3 **Tbl** vegetable oil and mix with the wooden spoon.
- Cook over low/medium heat. Continue stirring until the mixture thickens and forms a ball of dough.
- Remove from the heat and place the dough in a gallon baggie to cool 30 minutes.
- When cool, knead playdough in the baggie until smooth.
- Store any unused playdough in the zip lock baggie.

Sculpt your trilobites:

- On page 9 are three trilobite images and information about them. They represent the largest trilobite, a small (but not the smallest) trilobite, a trilobite that is a very common size.
- Using your homemade playdough, sculpt each trilobite on a sheet of wax paper. When you have completed that trilobite, place it, with the wax paper, on a cookie sheet.
- When you have sculpted all three of your trilobites, preheat the oven to 200°F.
- Place the cookie sheet in the oven for 15 minutes. At the end of 15 minutes, turn off the oven, but do not open the door. Allow the oven to return to room temperature with the sculptured trilobites inside overnight.
- Remove the cookie tray from the oven. You may need to let the trilobites cure longer if they are soft anywhere.
- When completely hard, you can optionally apply a thin coat of varnish to each trilobite. Be sure you do this outside. To apply, move the spray can in slow broad sweeps while spraying. Allow to thoroughly dry.
- Turn over the trilobite and repeat on the underside Allow to thoroughly dry.
- You can always make more trilobites. Just search the web for information and images of them.

POWER WORDS

- **carapace**: the hard upper shell of a turtle, crustacean, arachnid, armadillo, or trilobite
- **Tbl**: abbreviation for tablespoon
- **tsp**: abbreviation for teaspoon
- **ventral**: of, on, or relating to the underside of an animal or plant; abdominal

MATERIALS

- zip-lock bag(s) kneading and extra playdough
- sculpting tools (**e.g.** wood craft stick, toothpick, nail, etc.)
- cookie sheet
- ruler
- oven
- optional spray can of varnish

Domain Eukaryota
Kingdom Animalia
Phylum Arthropoda
Class Trilobita
Order Asaphida
Family Asaphidae
Genus *Isotelus*
Isotelus maximus (to the right)
Upper Ordovician
Found North America

- 15” long
- 8” wide
- Center lobe higher than the left or right lobes
- genal spines (deriving from the **cephalon**)
- 8 segments (ribs) in the **thorax**

Domain Eukaryota
Kingdom Animalia
Phylum Arthropoda
Class Trilobita
Order Odontopleurida
Family Odontopleuridae
Genus *Dicranurus*
Dicranurus monstrosus
Upper Devonian
Found in Morocco

- 2.25” long
- 1” wide, with genal spines, 2.5”
- Center lobe higher
- genal and plural spines
- 2 curling occipital spines (like ram horns)
- 10 segments (ribs) in the **thorax**

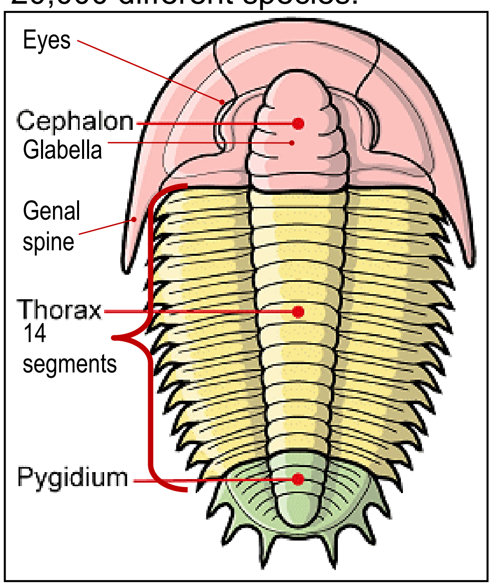
Domain Eukaryota
Kingdom Animalia
Phylum Arthropoda
Class Trilobita
Order Agnostida
Family Peronopsidae
Genus *Itagnostus*
Itagnostus interstrictus
Middle Cambrian
Found Asia, Australia, Europe, and North America

- 1/2” long
- 1/4” wide
- 2 segments (ribs) in the **thorax**
- no eyes
- cephalon and pygidium similar

The past two ST[EMpower] newsletters explored **cladograms**. Both **shared** and **derived characteristics** determine how the **cladogram** is made.

In this activity, you will identify specific **characteristics** on 24 species of trilobites from 4 Orders. For example, orders of trilobites have different number (or a range of numbers) of **thoracic** segments.

The "fossils" are paper representations of real trilobites. We are only looking at four Orders of Trilobites; scientists, however, have placed all trilobites into 10 different Orders. Trilobites were extraordinarily successful animals, and scientists have found over 20,000 different species!



Directions:

- Print the trilobite "fossils on page 14 and 15 single-sided. Each fossil is in its own separate box, and identified by genus name.
- Cut out each fossil along the box border so you keep the picture trilobite together with any information included (when in time it lived).
- It will be easier if you print 4 Order Characteristics pages 11—12, but it is not necessary. You can print that double sided or single sided.
- Print page 13, the table on the trilobite characteristics.
- The trilobite body has three major body parts. The **cephalon**, or head (colored in pink in the image below left), includes mouthparts and sensory organs such as antennae and eyes. The **thorax** (colored yellow) has multiple similar segments (that allowed some species to roll into a defensive ball. The **pygidium**, or tail section (colored green), is the third body part. Color the three body parts (pink cephalon, yellow thorax, and green pygidium) on each of your 24 trilobites with the color pencils.
- Use the table on page 13 to record the following answers on your trilobite:
    - Count and record the number of segments on the thorax.
    - Identify if that trilobite has eyes. Most trilobites did have eyes, but not all of them did. Record that with your fossil.
    - Identify if cephalon genal spines are present.
    - Identify if the pygidium is spiny or spineless.
    - Is your trilobite tiny?
    - Is the **glabella** large or small?
- Determine what Order each trilobite belongs based on characteristics, and record that.

POWER WORDS

- **characteristic**: a feature or quality belonging typically to a person, place, or thing and serving to identify it
- **cladogram**: branching diagram to show relationships
- **derived characteristic**: a **characteristic** that originates in a **lineage**
- **glabella**: smooth part of the forehead between and above the eyebrows; similar places on non-mammals
- **lineage**: **lineal** descent from an ancestor
- **lineal**: in a direct line of descent
- **originate**: having a specified beginning
- **shared characteristic**: a **characteristic** that is in common with two **lineages**
- **thoracic**: of the thorax

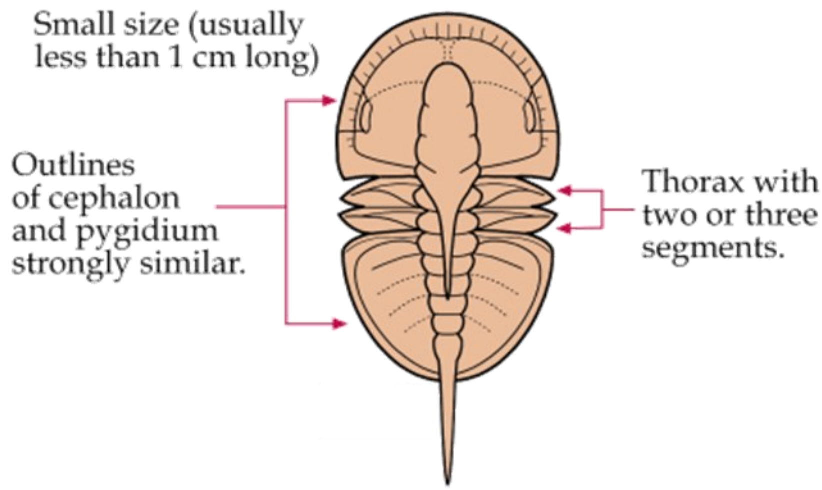
MATERIALS

- print pages 11—13 double sided (optional)
- print pages 14—15 single sided
- color pencils
- pencil or pen
-

Trilobite Orders
Characteristics

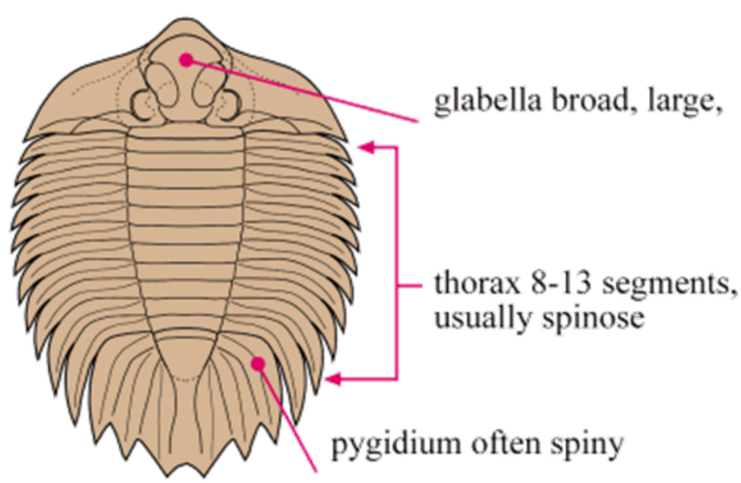
ORDER AGNOSTIDA

Introduction: Tiny trilobites (usually only a few mm long) with cephalon (head) and pygidium (tail) almost the same size and shape.
Cephalon: most species are eyeless
Thorax: 2-3 segments (ribs).
Pygidium: strongly matching the shape and size of the cephalon.
Occurrence: Lower Cambrian to Upper Ordovician.



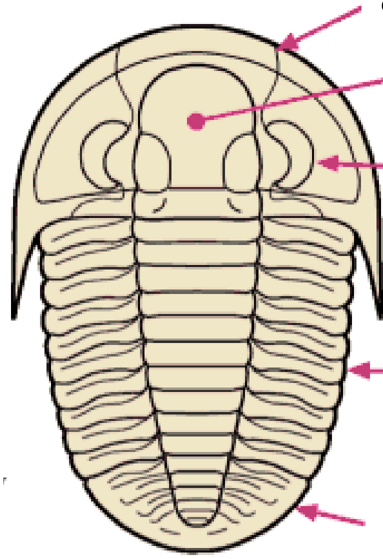
ORDER LICHIDA

Introduction: typically spiny with bumpy exoskeletons.
Cephalon: center part of head (called glabella) is broad and large; eyes usually present.
Thorax: between 8-13 segments (ribs), usually spine-tipped
Pygidium: often longer than wide, typically ending in spiny tips.
Occurrence: Middle Cambrian to Upper Devonian

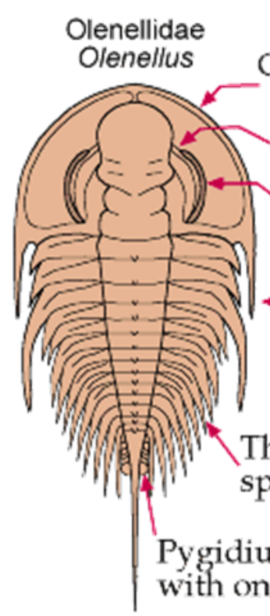


Trilobite Orders
Characteristics

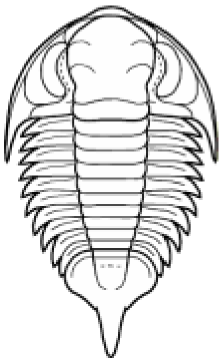
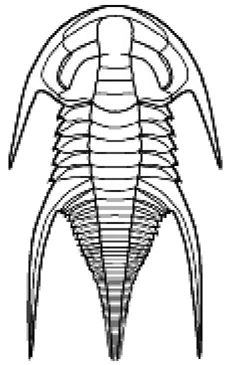
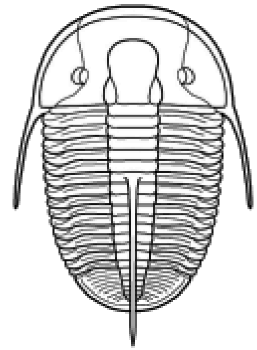
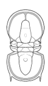
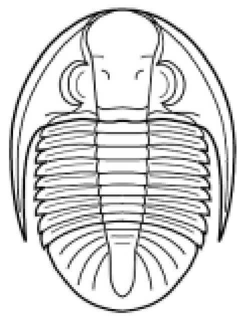
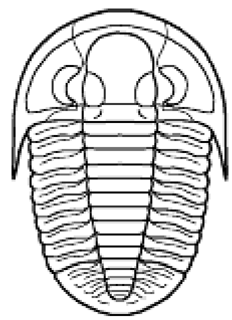
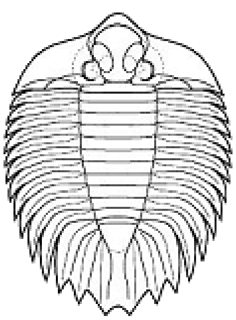
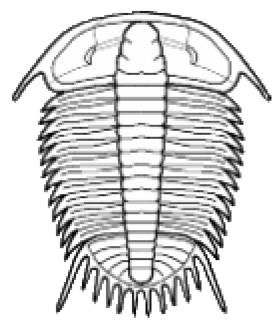
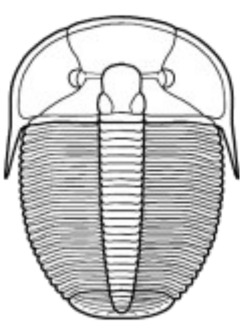
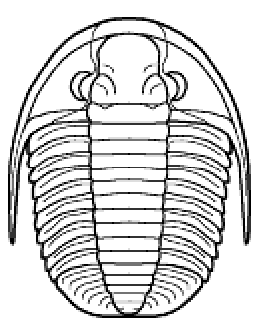
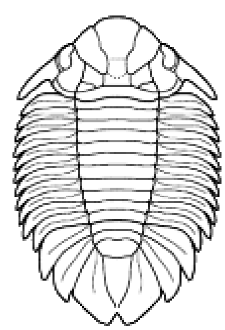
ORDER PROETIDA
Introduction: typically small trilobites, exoskeleton sometimes with pits or small bumps. One species of this order was the last group of trilobites to exist before the species went extinct.
Cephalon: each lobe distinct on the cephalon; glabella large; eyes usually present and large, typically with genal spines
Thorax: 8–22 (typically 10) segments (ribs), tips variable, blunt to long-spine.
Pygidium: often spineless, with 4-10 furrows
Occurrence: Lower Ordovician to Upper Permian

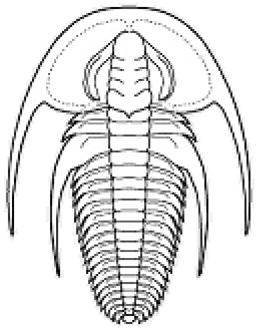
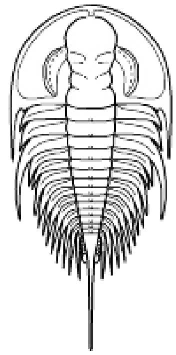
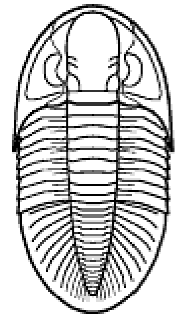
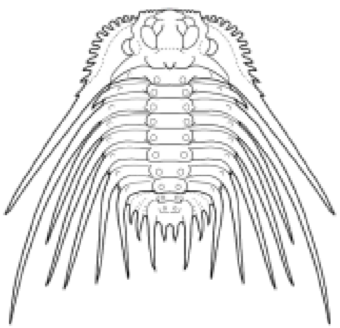
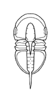
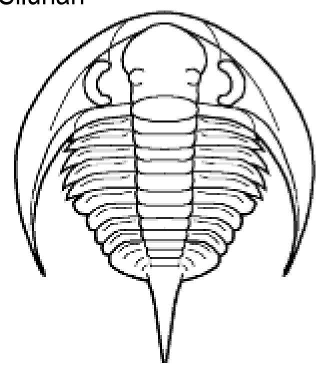
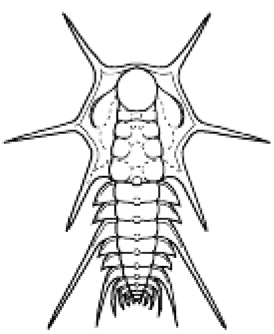
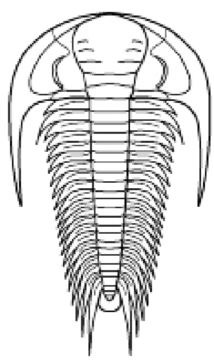
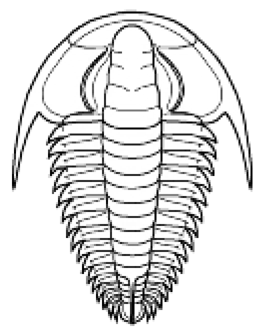
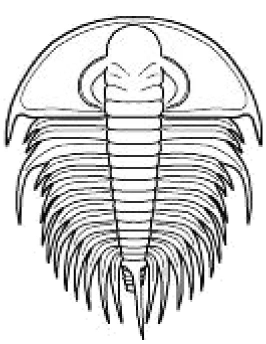
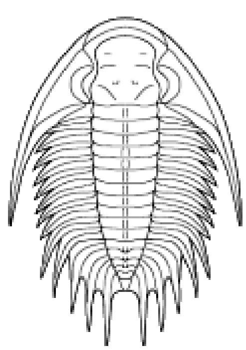
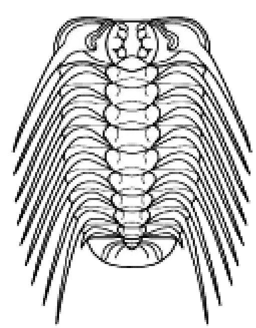


ORDER REDLICHIIDA
Introduction: Numerous thoracic segments (ribs) with spinose tips. One of the earliest species of trilobites.
Cephalon: large and semicircular; genal spines strong; eyes typically large, crescentic with ridge
Thorax: with numerous segments (up to 60+ ribs), and spiny tips
Pygidium: typically tiny with one or very few segments.
Occurrence: Cambrian

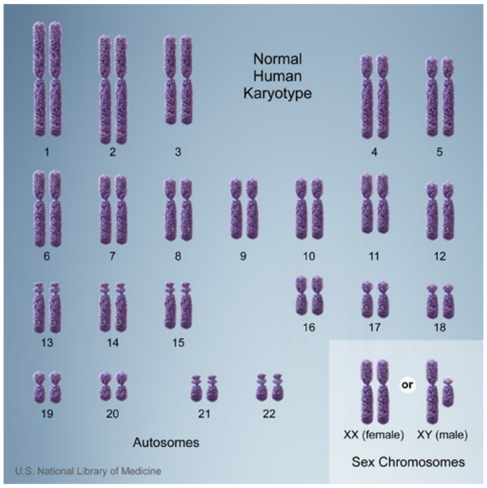


Genus of Trilobite	Number of Segments	Eyes Present?	Genal Spines	Pygidium Spines	Size Tiny	Glabella Large	Order
Acidiphorus							
Agnostus							
Arctinurus							
Aulacopleura							
Balcoracania							
Bathyurus							
Condylopyge							
Cornuproetus							
Cyphaspis							
Cyphoproetus							
Damesella							
Dicranopeltis							
Fallotaspis							
Kettneraspis							
Olenelloides							
Olenellus							
Paedeumias							
Pagetia							
Paradoxides							
Phaetonellus							
Phillipsia							
Platyantyx							
Redlichia							
Selenopeltis							

Acidiphorus Mid Ordovician 	*Balcoracania* Mid Cambrian 	*Cyphaspis* Lower Silurian 
Agnostus Mid Ordovician 	*Bathyurus* Lower Ordovician 	*Cyphoproetus* Permian 
Arctinurus Mid Ordovician 	*Condylopyge* Lower Ordovician 	*Damesella* Lower Silurian 
Aulacopleura Upper Silurian 	*Cornuproetus* Mid Devonian 	*Dicranopeltis* Upper Cambrian 

Fallotaspis Lower Cambrian 	*Paedeumias* Mid Cambrian 	*Phillipsia* Upper Carboniferous 
Kettneraspis Upper Silurian 	*Pagetia* Upper Cambrian 	*Platyantyx* Lower Silurian 
Olenelloides Mid Cambrian 	*Paradoxides* Mid Cambrian 	*Redlichia* Lower Cambrian 
Olenellus Mid Cambrian 	*Phaetonellus* Upper Ordovician 	*Selenopeltis* Upper Silurian 

Species have the ability to adapt to changes in their environment over generations. That is because populations carry a hidden reserve in its DNA in the recessive **gene** pool.



DNA in **eukaryote** cells (our cells are **eukaryote**) come in pairs of **chromosomes**. One is from our mother, and the other is from our father. Different species have different number of **chromosomes**. For example, humans have 23 pairs of **chromosomes**, and the two-toed tree sloth *Choloepus didactylus* (means lame-foot two-toes) has a varying number of 26-32 pairs of **chromosomes**, plus a couple of unmatched! Weird mammals for sure!

Gregor Mendel, the Father of Genetics, lived in the 1800s in what is now the Czech Republic. He was a monk, a member of the Catholic Church devoted to study, solitude, and prayer. He experimented with peas to figure out how **genes** work.

Genes are instructions how to make an organism. You inherit **genes** from your mother and **genes** from your father. That means you have two versions of all your **genes**. The different versions of the same gene are called **alleles**. The gene function remains the same. For example, we have three alleles for our red blood cells: A, B, and O. These three alleles give us our blood type of A, B, AB, or O. The only way to inherit O blood is if both parents have O blood.

Genes Mom/Dad	Blood Type
A/A A is dominant	A
A/O A is dominant O is recessive	A (O is hidden)
A/B A & B are codominant	AB
B/O B is dominant O is recessive	B (O is hidden)
B/B B is dominant	B
O/O O is recessive	O

Regardless of our blood type, the red blood cells still carry oxygen from our lungs to our body, and carbon dioxide from our body to be expelled by our lungs. The function is the same.

POWER WORDS

- **allele**: one of two or more alternative forms of a gene, for example curly or straight hair in Caucasians
- **chromosomes**: thread-like structures of nucleic acids adenine (A), thymine (T), guanine (G), and cytosine (C) see https://tra.extension.colostate.edu/stem-k12/stem-resources/ Paleontology 3, page 18 for more information
- **expression**: the allele that is translated into a function
- **gene**: a unit of heredity which is transferred from a parent to offspring and is held to determine some characteristic of the offspring

MATERIALS

- coin
- large marshmallows
- 2 flavors of frosting (i.e. chocolate and lemon)
- red, yellow, green, blue decorating sparkle gels
- pretzel sticks
- mini-marshmallows in 4 colors
- plate
- butter or plastic knife
- print page 18—three copies (opt. double-sided)

Genes followed certain patterns:

- dominant or recessive (dominant **allele** is **expressed** and recessive **allele** is hidden, like AO blood type, only A is **expressed**, and O is hidden)
- codominant (both **alleles** are **expressed**, like people with blood type AB inherited A from one parent and B from the other parent)
- incomplete dominance (**alleles** blend together, like curly hair and straight hair parents will have a child with wavy hair)
- multiple **genes** influence the trait (like the 378 genes that modify skin color in humans!)

In this activity, you will make three monster offspring based on the rules of genetics.

Directions:

- We inherit traits from our parents randomly. To simulate the randomness, flip a coin for each parent. <u>Heads (**H**) represents the dominant **allele**. Tails (**t**) represents the recessive **allele**.</u> If the gene is codominant or incomplete dominance, the directions will state what to do.
- Make three monster offspring. Complete the data sheets (one for each monster). After you have determined the genotype of your monsters, interpret the phenotype. Build your three monsters based on the phenotype. If you have 2 or 3 body parts, push a pretzel stick halfway into one marshmallow, then push the second marshmallow on the open end of the pretzel. If you have three body parts, attach the third marshmallow with another pretzel stick.
- Our monsters have 6 limbs (legs, arms, antennae, etc.). Add your monster 6 limbs.
- The color of the body is controlled by a gene with 2 alleles: dominant is chocolate and recessive is lemon frosting. Flip your coin and record (**H** or **t**).
- The color of the appendages (all 6 of them) are either blue (**H** dominant), yellow (**t** recessive) or a combination of the two (green) if both **H** and **t** (incomplete dominance).
- The number of the eyes: 5 small if **H** dominant or 3 large **t** recessive.
- Eye color is red (**H** dominant) or blue (**t** recessive).
- The mouth is either a **H** dominant green stinger (coat a pretzel stick with green gel and place in the mouth area) or **t** recessive blue open (place a blob of blue gel in the mouth area).
- Spots are **H** dominant yellow or **t** recessive blue (make at least 12 spots on the body).
- The nose is a mini-marshmallow. Add a pink mini if **H** dominant or orange mini if **t** recessive.
- The hands and feet are mini-marshmallows. Push them on the ends of the pretzel sticks—green if **H** dominant or **t** yellow if recessive.
- Circle the number of recessive (**t/t**) traits on your data sheet. How many are there? Circle the number of **H/H** or **H/t** traits? You should have about 1/4 recessive traits expressed.
- Compare / contrast your three monsters.

POWER WORDS

- **genotype**: the genetic make-up of an individual
- **phenotype**: observable characteristics of an individual based on genotype **expression**

Genetics Punnett Square

- <u>Mom</u>: tri-colored beagle, but carries the lemon allele (T/H)
- <u>Dad</u>: lemon beagle (H/H)
- What are the <u>chances</u> of a lemon puppy? (Two out of 4 puppies will be lemon.)

Mom (H / t)

Dad (t/t)	H	t
t	H / t tri-color	t / t lemon
t	H / t tri-color	t / t lemon

- Molly is a tricolor beagle (dominant—black in coat).
- Sam is a lemon beagle (recessive—no black).
- Molly and Sam are from a litter of seven puppies. Only two of the puppies are lemon beagles.
- Punnett Square (above) helps us to determine the chances of a lemon puppy.

Assume parents carry one dominant and one recessive **allele** for each trait.

DNA — Dominant and Recessive Alleles

Genotype (DNA Gene) Dominant/Recessive Codominance Incomplete	Mom Heads = Dominant (D) Tails = Recessive (R)	Dad Heads = Dominant (D) Tails = Recessive (R)	**Phenotype** (How It Looks)
Body Parts Heads/Heads—2 body parts Tails/Tails—1 body part Heads/Tails—3 body parts **CODOMINANT**	Heads or Tails?	Heads or Tails?	How many body parts? If 2 or more body parts, attach with pretzel sticks
Body Color Heads/Heads—chocolate Tails/Tails—lemon Heads/Tails—chocolate **DOMINANT/RECESSIVE**	Heads or Tails?	Heads or Tails?	What color is the body? Use your knife to add frosting to your marshmallows
Appendages Color Heads/Heads—blue gel Tails/Tails—yellow gel Heads/Tails—green gel **INCOMPLETE DOMINANCE**	Heads or Tails?	Heads or Tails?	What color are you appendages? Use your knife to add gel to the pretzel sticks
Number of Eyes Heads/Heads—5 small eyes Tails/Tails—3 big eyes Heads/Tails—5 small eyes **DOMINANT/RECESSIVE**	Heads or Tails?	Heads or Tails?	How many eyes does your monster have? Before adding your eyes, flip your coin to determine color
Color of Eyes Heads/Heads—red gel Tails/Tails—blue gel Heads/Tails—red gel **DOMINANT/RECESSIVE**	Heads or Tails?	Heads or Tails?	What color are your monster's eyes? Add eyes with your sparkling decorating gel
Mouth Heads/Heads—green stinger Tails/Tails—blue open Heads/Tails—green stinger **DOMINANT/RECESSIVE**	Heads or Tails?	Heads or Tails?	What kind of mouth does your monster have? Pretzel coated green gel or blob with blue gel
Body Spots Heads/Heads—yellow gel Tails/Tails—blue gel Heads/Tails—yellow gel **DOMINANT/RECESSIVE**	Heads or Tails?	Heads or Tails?	What color spots (at least 12) does your monster have? Dot your monster body with the sparkling decorating gel
Nose Heads/Heads—pink mini Tails/Tails—orange mini Heads/Tails—pink mini **DOMINANT/RECESSIVE**	Heads or Tails?	Heads or Tails?	What color nose does your monster have? Add mini-marshmallow to your monster's head
Feet/Hands Heads/Heads— green mini Tails/Tails—yellow mini Heads/Tails—green mini **DOMINANT/RECESSIVE**	Heads or Tails?	Heads or Tails?	What color hands/feet does your monster have? Push the mini-marshmallow on the end of the pretzel sticks

Different alleles may give an organism an advantage over others that don't inherit the allele. There is a great example of this with the peppered moth (*Biston betularia*) in England.

This common moth has two very different color **morphs**: white-bodied and black-bodied. Before the Industrial Revolution, the black-bodied **morph** was unknown. In Manchester, England during the Industrial Revolution, coal soot filled the air, covering everything with a dark film, including tree bark. By the end of that century, 98% of all peppered moths were dark-bodied. When soot pollution was reduced, the white-bodied **morphs** once again were favored.

This is the most cited example of natural selection. Moths with white-bodies were nicely camouflaged on the tree bark. When the bark was soot colored, these white-bodied moths were easily seen, and picked off by the birds. The black-bodied peppered moths were camouflaged. The advantage favored the black-boded forms. Once pollution was reduced and the tree bark was no longer soot-stained, the white-bodied moths were camouflaged, and black-bodied peppered moths were seen and eaten by the birds.

Through this example, we can see change happen over a very short period of time. Over millions of years, this one species of moth with two distinct **morphs** could eventually become two different species.

What is a **species**? In the strictest biological sense, it is a group of animals that can breed and produce **fertile offspring**. Of course it isn't that simple, but it is a good place to start thinking about what a species is.

Speciation happens to a group, not to an individual. It generally takes millions, even tens or hundreds of million years. **Allopatric** speciation can occur when a single species is divided by a barrier, like a new river channel cuts through a territory. Each side of the river could have different microclimates (see 47.Here Comes the Sun for activities on these concepts—https://tra.extension.colostate.edu/stem-k12/stem-resources/). The Columbia River Gorge divides Washington from Oregon. The Washington south-facing side of the river is slightly drier and warmer than the north-facing side in Oregon, which is cooler and moister.

What happened to a species of mice when suddenly the Columbia River formed through their **habitat**? Each side of the river has different microclimate conditions. The Washington mice with alleles favorable to dry have an advantage. They can be stronger and have more babies. The Oregon mice, on the other hand, would do better with alleles that favor wetter conditions. Eventually the population begins to shift towards those favorable alleles.

- Add millions of years…
- A few mutations…

Note: next month's issue will cover mutations.

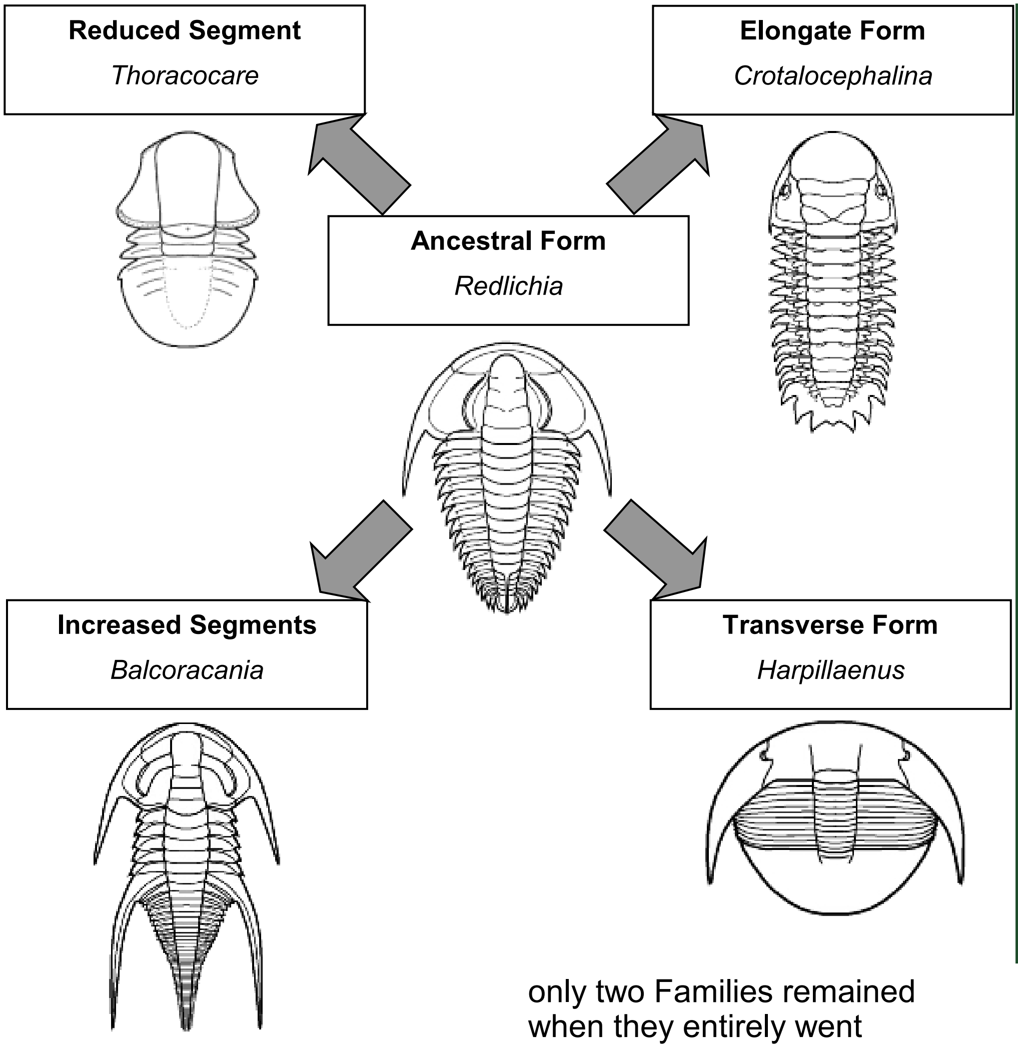
POWER WORDS

- **allopatric**: separate non-overlapping geographical areas
- **fertile**: able to have young or produce seed
- **habitat**: environment of an organism
- **microclimate**: climate of a very small area, especially when this differs from the climate of the surrounding area
- **morph:** an individual of one particular form in a species that has two or more forms
- **offspring**: children
- **speciation**: formation of new and distinct species in time
- **species**: a group of organisms capable of exchanging genes or interbreeding

Peppered Moth

White-bodied **morph** ←

Black-bodied **morph** →



POWER WORDS

- **Permo-Triassic Boundary**: another name for the mass extinction event at the end of the Permian, also known as The Great Dying
- **Phanerozoic**: relating to or denoting the eon covering the whole of time since the beginning of the Cambrian period, and comprising the Paleozoic, Mesozoic, and Cenozoic eras

Trilobites are in the Phylum Arthropoda (together with insects, spiders, centipedes, millipedes, crustaceans, and some lesser-known animals), Class Trilobita. They are the only extinct Class of Arthropods.

Trilobites are first found in 542 million year old rocks of the lower Cambrian. They are well preserved because they had calcified exoskeletons. They increased in numbers of species through the Ordovician (488-444 **MYA**) to 46 Families. The number of Families suddenly dropped at the end of the Ordovician, and in the Silurian, only 13 Families remained. By the Permian (299-251 **MYA**) only two Families remained when they entirely went extinct at the **Permo-Triassic Boundary** (The Great Dying).

These remarkable animals diversified into 5000 genera, and over 20,000 described species. Trilobites survived for about 300 million years. Even through they are extinct, they were extremely successful throughout the entire Paleozoic Era.

In this activity, you will look at how trilobites changed through time using the 24 images of trilobites that you organized into four Orders (pages 10-15). You will also add when in time they were found. Each image includes

MATERIALS

- Your timeline (see https://tra.extension.colostate.edu/stem-k12/stem-resources/ 53.Paleontology 1; pg. 16)
- 24 trilobite “fossils” (pages 14-15)
- glue stick
- 4 sharpies (**e.g.** black, blue, green, and red)
- ruler
- print page 22
- pencil

the Period (example, "Upper Silurian" for the trilobite *Kettneraspis*), and with that information you can place each trilobite in time on your timeline.

Directions:

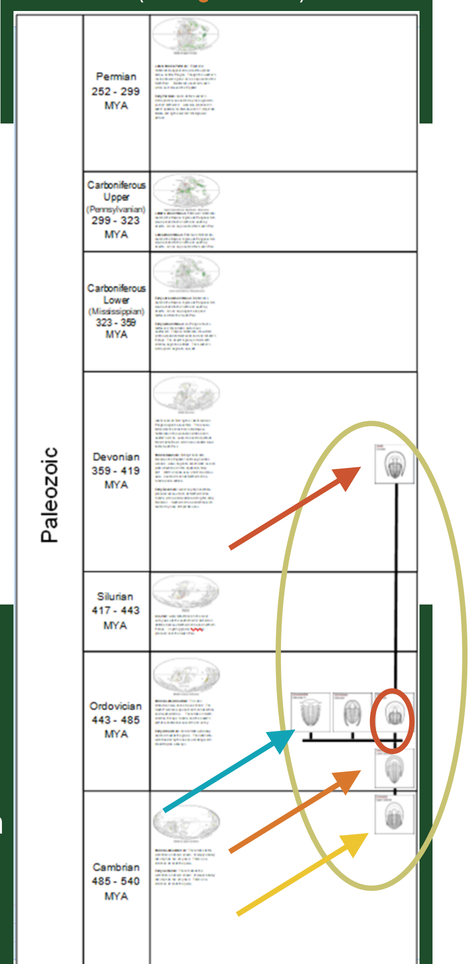
- Go through your 24 "fossils" (paper trilobites) and sort them into the four Orders: Agnostida, Lichida, Proetida**,** and Redlichiida.
    1. Start with the Agnostida trilobite fossils, and place them on your timeline in a **vertical** line. Place the trilobites in the correct period on your time chart. Do not glue your fossil to the time chart yet. You will want to move them around.
    2. Each Period can be divided by an Upper, Mid, and Lower **designation**. You place your paper "fossil" at the top for Upper, the middle for Mid the bottom for Lower of the **designated** Period.
    3. If you have two or more trilobites in the same Order from the same time Period (e.g. two from the Mid Ordovician), place them side by side.
- Repeat steps 1, 2, and 3 for the "fossils" from the Order Lichida. They should be in a new **vertical** line.
- Repeat steps 1, 2, and 3 for the "fossils" from the Order Proetida. They should be in a new **vertical** line.
- Repeat steps 1, 2, and 3 for the "fossils" from the Order Redlichiida. They should be in a new **vertical** line.
- For the next steps, if you have two or more trilobite fossils side by side in the same Order, draw a **horizontal** line under the group (see the example to the right with the blue arrow). Examine the characteristics of the fossil above (if there is one), and determine which individual in the group most closely resembles the one above. Your line will connect those two trilobites. The example indicates the third trilobite (circled in red) is most similar to the trilobite above it.
- Only connect fossils in the same Order.
    - Start with the Agnostida fossils. Use the ruler, and draw a straight line to the Agnostida trilobite above it. From that trilobite, draw a straight line to the last Agnostida trilobite about it. (There were only 3 Agnosida trilobites.)
    - Repeat for Order Lichida but with a different color sharpie. Connect the Lichida trilobites.
    - Repeat with a different color sharpie for Order Proetida. Connect the Proetida trilobites.
    - Repeat with a different color sharpie for Order Redlichiida. Connect the Redlichiida trilobites.
- Glue down your trilobites!

POWER WORDS

- **designate**: appoint to a specified position.
- **horizontal**: parallel to the plane of the horizon; at right angles to the vertical
- **vertical**: in a direction, or having an alignment, such that the top is directly above the bottom

EXAMPLE: Below is your timeline with "fossils" of the Order Harpetida (another Order of trilobites).

- Upper Cambrian "fossil" is at the top of the Cambrian Period (goldenrod arrow).
- Lower Ordovician "fossil" is at the bottom of Ordovician Period (orange arrow).



- Three "fossils" listed as Ordovician placed in the center of Ordovician (blue arrow).
- No Silurian "fossils"
- "Fossil" from the Devonian in middle of Devonian (orange arrow).
- Black line connects "fossils."

POWER WORDS

- **articulation**: a point connected between two bones at a joint that allows motion

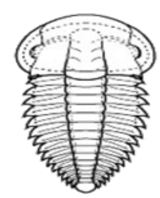
Natural History Museums are incredible places. The specimens they preserve are kept in safety for all of us. They house collections of extant and extinct species for scientists to study, as well as cultural and geological specimens. For example, I spent time at the American Museum of Natural History is in New York City collecting data on ground sloths, glyptodonts, and their kin. The images to the right are from this museum. It shows how fossils are preserved for scientists. The fossil in the middle image is a glyptodont jaw. The bottom image is a species of glyptodont.

The preparators remove rock matrix from fossils brought in from the field, preserving even scarring on the bones where tendons attached.

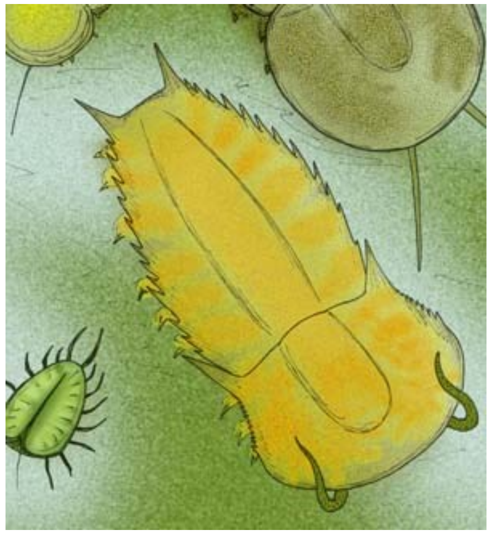
After the fossils have been prepared, they are either stored in "cans" (the cabinets), or they can be **articulated** and displayed for the public. The third image is an **articulated** glyptodont *Panochthus frenzelianus*. Colorado has some amazing natural history museums. Examples: the Denver Museum of Nature and Science, or the Dinosaur Journey Museum, Museums of the West in Fruita.

Directions:

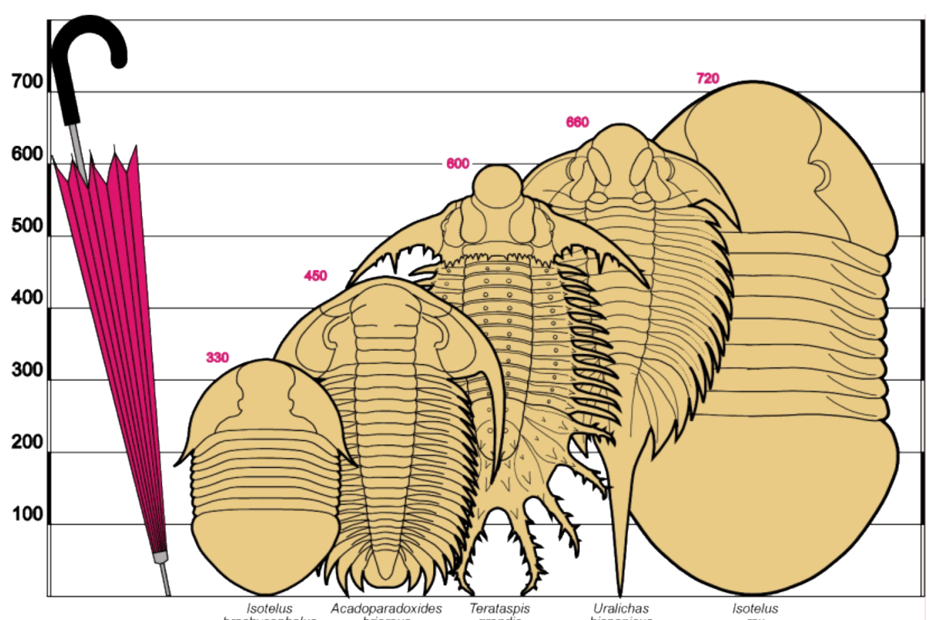
- Examine page 19 Trilobite Trends. Do you see any trends in the 4 Orders you examined? For example, did any of the Orders increase segments? Did any become broader? Note that on your timeline.
- Was there a time when the fossils differentiated into two or more species (the horizontal line to group trilobites)? Note that on your timeline.
- While working in a museum, you find the two unidentified trilobites (below). Develop a list of their characteristics. Can you determine the Orders?
- Trilobite 1 Characteristics:
    - Order:
- Trilobite 2 Characteristics:
    - Order:
- Where would you place them on your timeline? Why?

Trilobite 1	Trilobite 2
	

- *Fun Facts*:
- Order Nektaspida is almost a trilobite, but it is not included here. It shares many characteristics with trilobites, but also lacks one important feature: it does not have a hard shell. Image on the right.



- Trilobites thrived during the Paleozoic Era. Scientists have found over 20,000 different species!
- Trilobites are arthropods. They are the only arthropod class that is extinct. Other arthropods include insects, arachnids (spiders and scorpions), crustaceans (shrimp and crabs), millipedes and centipedes.
- The name trilobite refers to the three **longitudinal** lines along its body, not the three body parts. Trilobite means:
    - tri – three
    - lob – lobes
    - ite – rock
- A lobe is the roundish and flattish part of something
- The suffix “ite” means formed from rock or stone
- Trilobites were one of the first species to have eyes!
- The largest trilobite ever found is *Isotelus rex*, over 28 inches long! The image to the right shows some of the largest trilobites found so far.



- The smallest trilobite, Agnostida, is a bit smaller than 1 millimeter. It is about the size of a grain of rice! It did not have eyes.
- The age and **morphology** (shapes and forms) of fossils can be used to place them in sequences. This reveals the patterns of changes that have occurred over time. This relationship can be depicted in either a **cladogram** or an **phylogenetic** tree.
- **Scientific nomenclature** is like your first and last name, but the last name always goes first. The genus and species names are in italics when typed, or underlined if handwritten. Genus is capitalized, but species name is not. Example: *Tyrannosaurus rex*
    - If the genus name is understood, you can use the initial instead. Example: *T. rex*.
    - If the species name is unknown but you know the genus name, you can use “sp.” as in *Tyrannosaurus sp.*

POWER WORDS

- **longitudinal**: running lengthwise rather than across
- **phylogenetic**: relating to the development and diversification of a species or group of organisms through time, or of a particular feature of an organism
- **scientific nomenclature**: the system of naming organisms; species to which the organism belongs is indicated by two words, the genus and species names, which are commonly Latinized

When most people think of a paleontologist, they think of someone digging up dinosaur fossils. While some paleontologists do just that, most other paleontologists study different times, places, or species.

Dr. Smith studies **Cenozoic** Era fresh water fish. There are more kinds of fishes in the world than all other vertebrate animals combined. About half of the 25,000 species live in freshwater, even though this habitat is less than 1% of the total water on the planet. The nature of species restriction to river and lake drainages has contributed to their reproductive isolation and species origins.

Cenozoic fish paleontology reveals **ecological** causes of **morphological** change through time, past drainage isolation and connections, causes of extinction, and a surprising amount of hybridization that reunites lineages and changes the rates of organism's change through time and **speciation**.

Dr. Smith is a member of the "Ask a Paleontologist" Team for the Society of Vertebrate Paleontology http://vertpaleo.org/. If you have a question about a fossil, he is one of the people who will respond to your question.

Paleontology is a wonderful career, and has many different research options. It is an amazingly interesting career, but it is hard to find a job in paleontology.

- museum curator (like Dr. Smith)
- university professor
- fossil preparator
- community college professor
- educator (university, nature center, museum, etc.

All positions require at least an undergraduate degree in biology and geology, and for museums and universities, you would need a Ph.D.

Job satisfaction is extremely high for paleontologists. We just love the "work." Pay is decent to support a family, but you probably won't become a millionaire.

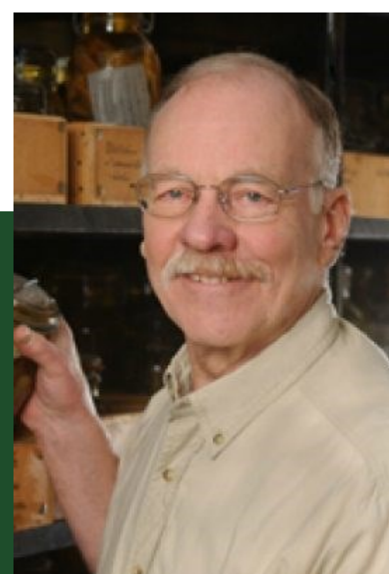
What is job satisfaction? It is a feeling of fulfillment and enjoyment that a person derives from their job. You could make a million dollars, hate what you do, and what do you have? You only have a million dollars. You could make a descent living and love what you do and what do you have? A great life!

In each ST[EMpower] issue, there is a Career Connection. It is to help you find jobs that you will love to do. For Dr. Smith, paleontology is the job that gives him satisfaction and meaning.

While you continue working on your career journal, keep asking yourself, "Will this work be meaningful to me?" That depends on your interests, talents, and life-style choices. The goal of these Career Connections is to help you find a career that gives you meaning.

POWER WORDS

- **Cenozoic**: current Era, starting with the end of dinosaurs and continuing to today
- **ecological**: relating to or concerned with the relation of living organisms to one another and to their physical surroundings
- **morphological**: relating to the form or structure of things



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CITATIONS

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- Trilobite Speciation Lesson developed by: Shaw, Barbara J. and Lindsay, Thomas L. (2006) Trilobite Speciation: 400-500 Course Life of the Past at Portland State University, modified for ST[EMpower] Paleontology kits 2019. Sources used in developing this lesson:
  - Amazing site on Trilobites by Dr. Sam Gon III; Retrieved from the internet 7 April 2006: http://www.trilobites.info/index.html
- Information, images and drawings are all used from Dr. Gon's amazing site, unless otherwise denoted: https://www.trilobites.info/trilobite.htm
- Cambrian: https://ucmp.berkeley.edu/cambrian/cambrian.php
- Phyla: https://simple.wikipedia.org/wiki/List_of_animal_phyla
- Play dough recipe: https://www.iheartnaptime.net/play-dough-recipe/

Images:

- Images and drawings from Dr. Gon's amazing site used with permission, unless otherwise denoted: https://www.trilobites.info/trilobite.htm
- Three Domains: https://upload.wikimedia.org/wikipedia/commons/thumb/7/70/Phylogenetic_tree.svg/440px-Phylogenetic_tree.svg.png
- birefringent calcite: https://socratic.org/questions/what-is-the-easiest-way-to-identify-the-mineral-calcite
- Compound eye: https://www.humboldt-foundation.de/web/kosmos-humboldtians-in-focus-91-1.html; https://en.wikipedia.org/wiki/Lens: Dr. Shaw's demo of focal length with virtual image upside down
- Trilobite images: https://assets3.fossilera.com/sp2/37619/oklahoma/620x400/cordania-falcata.jpg; https://en.wikipedia.org/wiki/Walliserops; https://en.wikipedia.org/wiki/Trilobite
- *Choloepus didactylus*, American Society of Mammalogists Image Library: http://www.mammalsociety.org/searcHasm_custom_searcHCholoepus%20didactylus
- Molly and Sam: my beloved beagles, always in my heart
- Peppered Moth: https://en.wikipedia.org/wiki/Peppered_moth_evolution
- Nektaspida: https://upload.wikimedia.org/wikipedia/commons/7/7b/Naraoia_spinosa.jpg
- Karyotype: https://www.news-medical.net/life-sciences/DNA-Biological-Functions.aspx