Shape of Life

The Cambrian Explosion

Video Title: Cambrian Explosion
Related Videos: *A Paleontologist Searches for Bilateral Ancestors; The Secrets of Fossils;*
Related Readings: *The Cambrian Explosion: A Big Bang in the Evolution of Animals; Burgess Shale; Burgess Shale (advanced reading); Cambrian Explosion Causes; Cambrian Explosion Causes* (advanced reading); *What Came Before?*

Activity Subject: The Cambrian Explosion

Grade Level: 7–12

Introduction
In this lesson, students will watch a short film about the Cambrian Explosion and the extraordinary fossils of the Burgess Shale. Students will address preconceptions and misconceptions about early Cambrian life, and complete a timeline activity that will enable them to better appreciate just how recently—relatively speaking—multicellular life evolved on Earth.

Assessments
- Worksheets
- Class discussion

Time: 100–120 minutes (2 class periods)

Group Size: Individuals or small groups; some class discussion

Learning Objectives:
Students will understand the significance of the Burgess Shale fauna in the history of life on Earth, and will explore misconceptions related to the Cambrian "explosion" of life that occurred more than 500 million years ago.

Materials and Preparation:
- Access to the Internet to watch The Cambrian Explosion video (as a class and later in small groups)
- Calculators (for the timeline activity, Part A of "An Explosion of Life")
- "Preconceptions about the Cambrian Explosion" worksheet
- "An Explosion of Life" worksheet

NEXT GENERATION SCIENCE STANDARDS

MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. *[Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.]*

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. [*Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]*

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. *[Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]*

Teacher's Background Material:

Introduction: Paleontology is a historical science. The goal of a paleontologist is to understand past life, whether that life lived 1,000 or 1 billion years ago. While other types of historians rely on dusty library archives, or even ancient human relics to help them unravel their work, paleontologists rely on fossils. Fossils are preserved evidence of past life. Some fossils are dramatic—a five-foot Tyrannosaurus rex skull with twelve-inch teeth is not exactly subtle. But, in fact, most organisms never become fossils. To become a fossil, an organism must die in just the right way and in just the right spot. The body must be covered before it is too badly decomposed, scavenged, or otherwise broken apart. Once buried, the organism must remain undisturbed for thousands, or more likely millions of years. Then, the now fossilized organism has to somehow make its way back to Earth's surface. This could happen in several ways. The fossil can be uplifted and have overlying rock worn away. It can be when a river undercuts its bank. Or it can be exposed when rock is blasted to build a road and be found before it erodes and is lost forever. Road-cuts are a favorite place for fossil hunters to search for fossils. It's a millennia-long obstacle course that few organisms ever complete. In fact, only fifteen fairly complete T. rex skulls have ever been found. Just fifteen!

In this context, it is stunning that we know as much as we do about past life on Earth. As with any historical study, the further back in time you go, the more difficult it is to find clues. In general, the overall incomplete fossil record gets even more incomplete as you go back in time. But some exceptionally preserved fossils have provided priceless insights into the origin of animals. The most famous of these, the Burgess Shale fossils, are the subject of this lesson but it's important for your students to understand how these fossilized organisms fit into the history of life on Earth.

Teacher's Introduction to Misconceptions

Described below are a few of the many persistent misconceptions about the Burgess Shale organisms and what they represent. Exploring and debunking these misconceptions will be the focus of the lesson.

Misconception 1: The Burgess Shale organisms represent the origin of life.
Not only do they not represent the origin of life, they don't even represent the origin of animals! Earth is about 4.54 billion years old. Based on chemical analyses, scientists think that the first life appeared around 3.8 billion years ago, though the oldest true fossils we have (of cyanobacteria mats called stromatolites) are 3.45 billion years old. So it took just over 1 billion years for life to get going. You might think, then, that it wouldn't have been long before organisms we recognize showed up on the scene, but there you'd be wrong. You have to fast forward almost 3 billion years to get the first multicellular life.

It is at that time, about 600–560 million years ago, that the Cambrian Explosion video begins. The "simple, sedentary, and peaceful" organisms featured at the start of the video belong to the Ediacaran fauna. The Ediacaran organisms are the first undisputed animals in the fossil record. They had, as the video describes, fairly simple anatomies and lifestyles. There is scant evidence of any known predators among them, nor are there any hints of complex structures such as eyes. The organisms that evolved during the Cambrian explosion do not appear in the fossil record until about 60 or so million years after the Ediacaran organisms.

Misconception 2: The Cambrian explosion was quick.
Not unless 40 million years meets your definition of quick. Although described in the film as happening "in a flash," "all at once" and in a "burst," it's important for your students to understand the geologic context. There is some variation in the exact dates that scientists use to bracket the event, but the Cambrian "explosion" is generally thought to encompass about 40 million years of Earth's history—from 570 to 530 million years ago. The Burgess shale is about 508 million years old, which actually puts it post-explosion. However, its stunning preservation of soft parts gives us one of the best looks of the animals that evolved during the "explosion" window. Forty million years is an incomprehensibly long time for most of us, but in the grand scheme of 3.8 billion years of history, it is pretty short. So while geologically a "blink of an eye," we have to be careful to make sure students do not think the evolution of Cambrian life took place in a literal blink of an eye.

Teacher's Introduction to Misconceptions cont.

Misconception 3: The direct ancestors of all life are found among the Burgess Shale organisms. In the film, we are shown a modern-day velvet worm, which is described as "almost a double" for Aysheaia, a creature found among the Burgess organisms. The takeaway message is that the velvet worm is related to Aysheaia, but again, context is important. It is nearly impossible to trace direct, linear ancestry through the fossil record. We cannot know whether a Burgess Shale organism is a direct ancestor of a modern-day organism. What we are confident about is that among the Burgess organisms are representatives of most of today's animal phyla. Pikaia is far more likely to be a close relative of the ancestor of all chordates than it is to be the actual direct ancestor of all chordates. It may seem like a very fine line to draw, but it's an important one.

Procedure:

1. Pass out the worksheet “Preconceptions about the Cambrian Explosion.”
2. Ask students to complete the Preconceptions worksheet. Reassure them that they are not supposed to know all the answers—the point is to get a sense of what they think they know about the Cambrian explosion. They will have a chance to revise their answers after watching the film.
3. Watch the video The Cambrian Explosion. Instruct students to take notes on their Preconceptions Worksheet as they watch.
4. After watching, have a class discussion to go over the Preconceptions worksheet. Ask volunteers to share how their answers changed after watching the video.
5. Pass out the Explosion of Life worksheet. Then explain that the worksheet has two parts.
6. Depending on the strength of your students’ math skills, you may want to walk them through not only the sample calculations in Part A, but the first few questions as well.
7. As individuals, in pairs, or in small groups, have students complete the “An Explosion of Life” worksheet. To complete the worksheet, students will need to have access to calculators (for Part A) and have the ability to re-watch the film (for Part B).

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Preconceptions about the Cambrian Explosion

Student Name_____

Instructions: What do you know, or think you know about the Cambrian Explosion? Today, you will be watching a short film about it and one of the scientists that studies it. Before you watch the film, read each of the statements below and decide whether it is a true statement or a false statement. Circle the appropriate letter (T or F) and jot down your reasoning. It is completely fine if you are only guessing—you are not expected to know these answers yet.

As you watch the video*,* note any of your answers that change. Do not erase or cross out your original answers. Instead, take notes in the appropriate space after each question. Be prepared to discuss your answers with the class.

1. Paleontologists study fossils. T/F
reasoning:

Did your answer change?

2. The first organisms that evolved on Earth were animals. T/F
reasoning:

Did your answer change?

3. The animals that evolved during the Cambrian explosion are the first animals that ever lived on Earth. T/F
reasoning:

Did your answer change?

4. The first animals lived in the oceans. T/F
reasoning:

Did your answer change?

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The Cambrian Explosion

Preconceptions about the Cambrian Explosion

Student Name_____

5. Sponges, like this one, are animals. T/F
reasoning:

Did your answer change?

6. Dinosaurs are among the first animals that lived on Earth. T/F
reasoning:

Did your answer change?

7. The Cambrian explosion happened quickly. T/F
reasoning:

Did your answer change?

8. The evolution of predation (when animals kill and eat other animals) sped up the pace of animal evolution. T/F
reasoning:

Did your answer change?

9. Scientists can trace the direct ancestry of every living thing back to the Burgess shale. T/F
reasoning:

Did your answer change?

10. Humans share a basic body plan with all mammals, reptiles, birds, and amphibians. T/F
reasoning:

Did your answer change?

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The Cambrian Explosion

Preconceptions about the Cambrian Explosion

Teacher Edition Worksheet

1. Paleontologists study fossils. T/F

This is true. In your discussion, you might talk a bit about fossils so that students understand that most organisms do not fossilize. If there is time, it could also be worth discussing different types of fossil preservation (body fossils v. trace fossils, for example). The Burgess Shale fossils are extraordinary fossils because they include preserved "soft parts" of the organisms, which gives us a tremendous amount of detail about their physical biology.

For more information about different fossil preservations in general see:
https://ncse.com/blog/2014/11/misconception-monday-fossils-everywhere-part-2-0016012
For more information on the Burgess shale fossils in particular see:
http://www.burgess-shale.rom.on.ca/en/science/burgess-shale/03-fossils.php

2. The first organisms that evolved on Earth were animals.

This is false. The first organisms were bacteria. The oldest chemical signatures of life are 3.8 billion years old, and the first true fossils are 3.45 billion years old. The fossils are of stromatolites, which are layers of mud and mats of bluegreen algae built up into a layered rock structure. You can still find stromatolites in the oceans today. Animals do not appear in the fossil record until much later.

To see a short video of modern-day stromatolites, see: http://www.pbslearningmedia.org/resource/nvmn-sci-stromatolites/wgbh-nova-making-north-america-stromatolites-worlds-oldest-living-fossil/

3. The animals that evolved during the Cambrian explosion are the first animals that ever lived on Earth. T/F

This is false. The earliest known animals belong to the Ediacaran biota, which are at least 560 million years old. These animals predate the organisms that evolved during the Cambrian explosion (which occurred over about 40 or so million years) and are represented in the 508- million years old Burgess
Shale.

4. The first animals lived in the oceans. T/F

This is true.

5. Sponges, like this one, are animals. T/F

This is true. In your discussion, it may help to remind students of the characteristics of animals. All animals rely on other organisms for a source of energy and nutrients (they are heterotrophs), are multicellular, and have cells with nuclei (are eukaryotic). Sponges may not look like animals, but they meet all of these criteria.

6. Dinosaurs are among the first animals that lived on Earth. T/F This is false. The first dinosaurs evolved more then 220 million years ago in the Triassic—but the first animals evolved at least 560 million years ago in the Pre-Cambrian.
For more information on these first animals, see: *http://www.ucmp.berkeley.edu/vendian/ediacaran.php*

7. The Cambrian explosion happened quickly. T/F
This is false. Although there is some difference among scientists and institutions about exactly-which dates to use to bracket the event, it's generally understood to have taken place over about tens of millions of years. The introduction uses the dates 570–540 million years ago, while others will count from the beginning of the Cambrian (542 million years ago) to the time of the Burgess shale, 508 million years ago. In discussions, be sure to emphasize this point to your students: there is a big difference between a geologic "blink of an eye" and an actual one! The film emphasizes the suddenness of the Cambrian explosion, but remind students that fossils represent snapshots in time, not a complete record of events.

8. The evolution of predation (when animals kill and eat other animals) sped up the pace of animal evolution. T/F
This is true. Rudy Raff describes the concept of an "evolutionary arms race" near the end of the film. He says: "[Eventually] some animals learned to become predators, they began to eat other animals. And as soon as that happened, of course, now the arms race begins because there is an advantage to avoid being eaten and there is an advantage to eating. So an arms race begins, an arms race that hasn't ended yet in the animal kingdom, and this is still driving evolution, even now."
For more on evolutionary arms races, see: *http://evolution.berkeley.edu/evolibrary/article/arms-race_01*

9. Scientists can trace the direct ancestry of every living thing to the Burgess Shale. T/F
This is false for two reasons. Most, if not all modern-day animal phyla are thought to have a representative among the animals in the Burgess Shale—but animals are only one type of living thing! And even among animals, it is nearly impossible to trace direct, linear ancestry through the fossil record. We cannot know whether an organism from the Burgess Shale is a direct ancestor of a modern-day
organism.

Moreover, students should also be sure not to come away with the misunderstanding that all groups of organisms are represented in a 1:1 fashion. Pikaia is thought to be representative of an ancestor to all chordates, so in that manner, elephants and humans and frogs are represented—but it's not like there is an ancestor of frogs in the Burgess shale and an ancestor of humans, and an ancestor of elephants—it's all the same representative.

10. Humans share a basic body plan with all mammals, reptiles, birds, and amphibians. T/F
This is true. Mammals, reptiles, birds, and amphibians are all vertebrates. Vertebrates, along with a few oddball organisms such as tunicates and hagfish, make up the phylum Chordata. Chordates all share basic features at some point in their development such as a dorsal hollow nerve chord, notochord, pharyngeal pouches, and a post-anal tail. These features define one of the 35 basic body plans described in the film.

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An Explosion of Part A: Analogy Timeline

Student Name_____

Introduction: When you think about the past life on Earth, what do you picture? Dinosaurs, maybe? Or human ancestors covered in hair? Perhaps you have seen reconstructions of early whales with legs, or early amphibians with fins? But from watching the short film The Cambrian Explosion, you know that all of those creatures appeared on the scene relatively recently in Earth's history.

Instructions: In the first part of this activity, you'll build a timeline to model events in the history of life, and come to appreciate just how new we humans are to the scene. Then, in the second part, you'll zoom in on the Cambrian to answer questions based on the film and demonstrate your understanding of common misconceptions. You may watch and re-watch The Cambrian Explosion as many times as you need to answer these questions.

Part A: Timeline Analogy

It can be very hard to comprehend numbers in the millions and billions. Earth is about 4.54 billion years old. Based on chemical analyses, scientists think that the first life appeared around 3.8 billion years ago, though the oldest true fossils we have (of cyanobacteria mats called stromatolites) are 3.45 billion years old, so it took about 100–350 million years for life to get going. But what does that really mean? Is that a long time? Or a relatively short time?

To help put events in the history of life in context, we can use an analogy. What if Earth's 4.54 billion year history was compressed into one 24-hour day? So Earth forms at 12:00 midnight and the present is 12:00 midnight the next day. In this model, each hour represents about 190 million years (190,000,000).

So, let's do some math!

The oldest fossilized organisms we have (3.45 billion years old) showed up about 1.1 billion years after Earth formed. So if Earth formed at midnight, then these organisms evolved a little bit before 2:00 A.M.

1 hour = 190,000,000

x hours = 1,100,000,000

x = 5.8 = 1 hour, 48 minutes = 5:48 AM [0.8 hours*60 min/hour = 48 minutes]

For later events, it's easier to calculate the time since present, instead of the time since Earth formed.

For example:

Multicellular life evolved about 600 million years ago.

1 hour = 190,000,000

x hours = 600,000,000

x = 3.2 = 3 hours, 12 minutes

This is the time since present, which would be midnight, so 3 hours earlier is 9:00 PM and 12 minutes before that is 8:48 PM.

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The Cambrian Explosion

An Explosion of life Part A: Analogy Timeline

Student Name_____

Follow the examples to determine the approximate time the following events occurred in the 24-hour clock model. Show your work.

1. Middle of the Cambrian explosion: 550 million years ago

- TIME:

2. Time of the Burgess Shale: 508 million years ago

- TIME:

3. Tiktaalik (the "fishapod"): 360 million years ago

- TIME:

4. Early dinosaurs: 250 million years ago

- TIME:

5. Early mammals: 210 million years ago

- TIME:

6. Archaeopteryx (first bird): 140 million years ago

- TIME:

7. Early flowering plants: 120 million years ago

- TIME:

8. Non-avian dinosaur extinction: 66 million years ago

- TIME:

9. "Lucy" (Australopithecus afarensis, an early human relative): *3,200,000 years ago **For this calculation, use the fact that each minute in our 24-hour clock represents about 3.2 million years (3,200,000)***

- TIME:

10. Homo sapiens: 200,000 years ago *****For this calculation, use the fact that each minute in our 24-hour clock represents about 3.2 million years (3,200,000)*****

- TIME:

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An Explosion of life Part B: Film Guide

Student Name_____

1. Des Collins is a paleontologist. What is a paleontologist?

2. In what country is the Burgess Shale located?

3. True or False: The Burgess Shale contained just a few hundred fossils.

4. What type of animal were the first animals that evolved?

5. Sketch Aysheaia.

6. What is special about Anamalocaris?

7. What do scientists infer to be the function of the bristles along Canadia's body?

8. What type of animal is this?

9. Complete the sentence: The first animals to have a head and primitive sensory organs were_____

10. According to paleontologist Rudy Raff, what ecological change might have enabled organisms to get bigger during the Cambrian?

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An Explosion of life Part B: Film Guide

Student Name_____

11. What does Rudy Raff mean when he says that an “arms race” might help to explain the Cambrian Explosion?

12. What is special about the organism seen here?

13. If the history of life on Earth took place over 24 hours (part A), the first life for which we have direct fossil evidence evolved after 5.8 hours, or around 5:48 A.M. What percent of Earth’s history was therefore lifeless? Show your work.

14. Based on your calculations from Part A, for how many “hours” was there life on Earth before the Cambrian Explosion? Show your work.

15. There are many misconceptions about the organisms of the Burgess Shale. Based on what you’ve learned, what would you say to someone who tells you that the origin of life is captured in the fossils of the Burgess Shale?

16. How can the clock analogy from Part A help to correct misconceptions that people might have about the history of life on Earth?

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An Explosion of life Part A: Analogy Timeline

Teacher Edition Worksheet

1. Middle of the Cambrian explosion: 550 million years ago

- TIME: 9:06 P.M.

1 hour = 190,000,000
x hours = 550,000,000
x = 2.9 = 2 hours, 54 minutes

2. Time of the Burgess Shale: 508 million years ago

- TIME: 9:18 P.M.

1 hour = 190,000,000
x hours = 508,000,000
x = 2.7 = 2 hours, 42 minutes

3. Tiktaalik (the "fishapod"): 360 million years ago

- TIME: 10:04 P.M.

1 hour = 190,000,000
x hours = 360,000,000
x = 1.9 = 1 hour, 54 minutes

4. Early dinosaurs: 250 million years ago

- TIME: 10:42 P.M.

1 hour = 190,000,000
x hours = 250,000,000
x = 1.3 = 1 hour, 18 minutes

5. Early mammals: 210 million years ago

- TIME: 10:54 P.M.

1 hour = 190,000,000
x hours = 210,000,000
x = 1.1 = 1 hour, 6 minutes

6. Archaeopteryx (first bird): 140 million years ago

- TIME: 11:18 P.M.

1 hour = 190,000,000
x hours = 140,000,000
x = 0.7 = 42 minutes

7. Early flowering plants: 120 million years ago

- TIME: 11:24 P.M.

1 hour = 190,000,000
x hours = 120,000,000
x = 0.6 = 36 minutes

8. Non-avian dinosaur extinction: 66 million years ago

- TIME: 11:42 P.M.

1 hour = 190,000,000
x hours = 66,000,000
x = 0.3 = 18 minutes

9. "Lucy" (Australopithecus afarensis, an early human relative): *3,200,000 years ago **For this calculation, use the fact that each minute in our 24-hour clock represents about 3.2 million years (3,200,000)***

- TIME: 11:59 P.M.

1 minute = 3,200,000
x minutes = 3,200,000
x = 1.0 = 1 minutes

10. Homo sapiens: 200,000 years ago ***For this calculation, use the fact that each minute in our 24-hour clock represents about 3.2 million years (3,200,000)***

- TIME: 11:59:56 P.M.

1 minute = 3,200,000
x minutes = 200,000
x = 0.06 = 4 seconds

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The Cambrian Explosion

An Explosion of life Part B: Film Guide

Teacher Edition Worksheet

1. Des Collins is a paleontologist. What is a paleontologist?
A paleontologist is a scientist that studies the history of life on Earth. (timestamp 1:12)

2. In what country is the Burgess Shale located?
Canada (timestamp 2:12)

3. True or False: The Burgess Shale contained just a few hundred fossils.
False: the first person to collect fossils there got 65,000 specimens in five seasons (timestamp 2:23)

4. What type of animal were the first animals that evolved?
Sponges (timestamp 3:58)

5. Sketch Aysheaia.
(timestamp 4:15)

6. What is special about Anamalocaris?
It was a fearsome predator: “Nothing matched it for its sheer size and killing efficiency. Snaring its prey with its two powerful front claws, it was a swift and deadly hunter.” (timestamp 4:48)

7. What do scientists infer to be the function of the bristles along Canadia’s body?
Protection from predators, “Essential armor for a slow-moving beast” (timestamp 5:40)

8. What type of animal is this? (insert Cnidarian from Basecamp)
A cnidarian (timestamp 7:42)

9. Complete the sentence: The first animals to have a head and primitive sensory organs were _____.
Flatworms (timestamp 7:55)

10. According to paleontologist Rudy Raff, what ecological change might have enabled organisms to get bigger during the Cambrian?
An increase in available oxygen (timestamp 8:23)

11. What does Rudy Raff mean when he says that an "arms race" might help to explain the Cambrian Explosion?
That evolution was affected as predators experienced pressure to hunt, and prey experienced pressure to avoid being eaten: "That some animals learned to become predators, they began to eat other animals. And as soon as that happened, of course, now the arms race begins because there is an advantage to avoid being eaten and there is an advantage to eating." (timestamp 8:34)

12. What is special about the organism seen here?
It is thought to be similar to the common ancestor of all vertebrates. (timestamp 10:05)

13. If the history of life on Earth took place over 24 hours (part A), the first life for which we have direct fossil evidence evolved after 5.8 hours, or around 5:48 A.M. What percent of Earth's history was therefore lifeless? Show your work.
About 24% [5.8 = x%(24)]

14. Based on your calculations from Part A, for how many "hours" was there life on Earth before the Cambrian Explosion? Show your work.
15 hours, 8 minutes (from 5:48 A.M. to 9:06 P.M.)

15. There are many misconceptions about the organisms of the Burgess Shale. Based on what you've learned, what would you say to someone who tells you that the origin of life is captured in the fossils of the Burgess Shale?
Sample answer: I'd explain that there were other organisms that lived before those fossilized in the Burgess Shale. Before the "explosion" of life in the Cambrian, there were simpler multicellular organisms such as sponges and cnidarians, and that single-celled organisms evolved nearly more than three billion years before that!

16. How can the clock analogy from Part A help to correct misconceptions that people might have about the history of life on Earth?
Sample answer: It can help correct the misconception that most of the history of life involves the organisms we are familiar with, such as dinosaurs and other vertebrates. For the vast majority of Earth's history, (about 3 billion years) Earth was inhabited only by single-celled organisms.