Educator's Guide *for*

MEGALODON

Largest Shark that Ever Lived


Illustration by Merald Clark

MEGALODON: Largest Shark that Ever Lived is a traveling exhibit by the Florida Museum of Natural History, funded in part by the National Science Foundation.

MEGALODON
Largest Shark that Ever Lived

Educator's Guide

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Introduction

Megalodon is the largest shark that ever lived! Estimated to be approximately 60 feet in length, this formidable top predator occupied the world's ancient oceans 17-2 million years ago. Megalodon consumed vast quantities of marine animals and likely contributed to the stability of ecosystems – as top predators do today. Understanding Megalodon's life history is critical to improving our knowledge of evolution and living shark conservation. Throughout the Megalodon Educator's Guide you will learn about Megalodon and gain ideas regarding how to integrate the Megalodon exhibit into your classroom activities.

A diverse array of activities is discussed in this guide, encompassing subjects within the Science, Technology, Engineering, and Mathematics (STEM) disciplines and in non-STEM fields. These STEM fields include: anatomy, chemistry, earth sciences, geology, life sciences, mathematics, marine biology, physics, and physiology. Non-STEM subjects covered include: anthropology, economics, English, geography, history, and the social sciences.

Students will actively inquire and evaluate hypotheses while answering the following questions about Megalodon:

- ***How big was Megalodon?***
- ***How long did Megalodon live?***
- ***What did Megalodon eat?***
- ***When did Megalodon live?***
- ***Where did Megalodon live?***
- ***Who was Megalodon related to?***
- ***Why is Megalodon important?***

Numerous extension ideas are mentioned throughout the Educator's Guide, providing opportunities for age appropriate adaptations and/or the further elaboration of key activities. All activities have been correlated to the National Science Education Standards at the K-4, 5-8, and 9-12 grade levels. A list of potentially helpful books and website references are included. Vocabulary covered in the Megalodon Educator's Guide is listed with scientific definitions that are generally appropriate for K-12 grade levels.

Lastly, but definitely not least, we have included a Teacher's Evaluation. If you download this document, please return the Teacher's Evaluation to the Florida Museum of Natural History. Your participation is greatly appreciated and will help us to improve educational materials as per your comments and suggestions. Thank you for your help! Enjoy your journey through the Megalodon Educator's Guide!

Educator information for Activity 1:
How big was Megalodon? *(page 1 of 2)*

Grade Level: 3-12
30-50 minutes

Lesson Summary:
This lesson will allow students the opportunity to estimate the body length of Megalodon based on modern shark models. Students are provided with actual data from which they will construct a graph demonstrating the relationship between living shark tooth width and body length. The resulting graph will then be used to estimate the body length of Megalodon, using the same methods as professional scientists. Younger students will instead construct Megalodon to scale.

STEM Subjects: anatomy, geology, life sciences, mathematics, physics

STEM Concepts & Skills: allometery, morphology, graphing, obtaining measurements

Vocabulary: allometery, cartilage, cartilaginous, centrum (centra), fossilization, morphology, ossification (ossified)

Background Information:
Megalodon is the largest shark to have ever lived! Based on the size of Megalodon teeth, we know that this shark was larger than all modern and extinct sharks. However, it is difficult to know the exact size of Megalodon as entire skeletons are not preserved. This is because all sharks have cartilaginous skeletons (i.e. composed of cartilage), which does not fossilize. Instead, scientists often only find fossilized shark teeth and/or ossified (i.e. boney) shark centra (i.e. vertebrae). Because of the lack of skeletal preservation of Megalodon, we must use modern sharks to estimate the size of Megalodon. In order to do this, scientists first determined that an allometric relationship (i.e. a relationship of anatomical variables that fits an equation) exists between the morphology of a preserved element (i.e. tooth width) and body length in living sharks. Because tooth width and body length are correlated in modern sharks, one can use this allometric relationship to estimate Megalodon's body length by instead measuring the width of Megalodon teeth.

Materials:
- ***copies of the activity sheet***
- ***pencils***

Educator information for Activity 1:
How big was Megalodon? *(page 2 of 2)*

Procedure:

This activity begins by getting students of all ages excited about their task of determining the body size of the largest shark that has ever lived. An opening inquiry-based discussion should include why complete shark skeletons, including Megalodon, are not found. This discussion can cover all vocabulary words and explain why modern sharks are needed to help us determine the body size of Megalodon. Next, students can either work in groups or individually to formulate their null hypothesis that "Modern shark tooth width does not correlate with body size." Subsequently, students will begin to graph their data (provided on the activity sheet) – graphing tooth width on the x-axis (independent variable) and body size on the y-axis (dependent variable). Once students have completed this task they should be able to conclude that an allometric relationship exists between shark tooth width and body size. Lastly, they are asked to extend their graph to meet the appropriate tooth width of Megalodon. This task will allow the students to estimate the body size of Megalodon. In conclusion, a Megalodon tooth that is 5.5 inches wide should yield a body length estimate of approximately 700 inches (~60 feet long)!

Discussion Questions:

- ***How big was Megalodon?***
- ***Why are complete Megalodon skeletons not preserved?***
- ***Can we use modern sharks to help us estimate Megalodon's body size? Why or why not?***

Extension Activities:

Once a size estimate for Megalodon has been determined, a roll of tape (or string) can be cut to represent Megalodon's body length and placed around the classroom. Younger students can instead forgo the graphing activity and construct Megalodon's body length to scale. Additionally, younger students can figure out how many of them (in height) equal one Megalodon (in body length). For more advanced classes, such as high school science or mathematics, a discussion can ensue that touches on the potential uncertainties regarding the Megalodon body length estimate (e.g., what if the graph is not linear with increasing body length and is instead exponential?).

Student Activity 1:
How big was Megalodon?

Megalodon is the largest shark to have ever lived! But just how big was Megalodon?
Today, you will determine Megalodon's size using the exact methods of professional scientists.

Background
Complete shark skeletons are not found in the fossil record. Do you know why that is (hint: wiggle your nose and ears for the answer)? Because we don't have complete fossilized skeletons of Megalodon, we must instead look at living sharks as a model.

Key Question
Is there a predictable relationship between tooth width and body length in modern sharks?

Directions
Develop a hypothesis to help answer the key question. Use the following data to test your hypothesis. This can be done by graphing tooth width (your independent variable) on the x-axis and body length (your dependant variable) on the y-axis. The first data point has been plotted on the graph.

After you have graphed all of the data in the data table, answer questions 1 & 2. Next, extend your graph to intersect with the Megalodon tooth width of 5.5 inches and determine Megalodon's body length.

Questions

1. What is your null hypothesis? Is it testable and falsifiable? Why or why not?

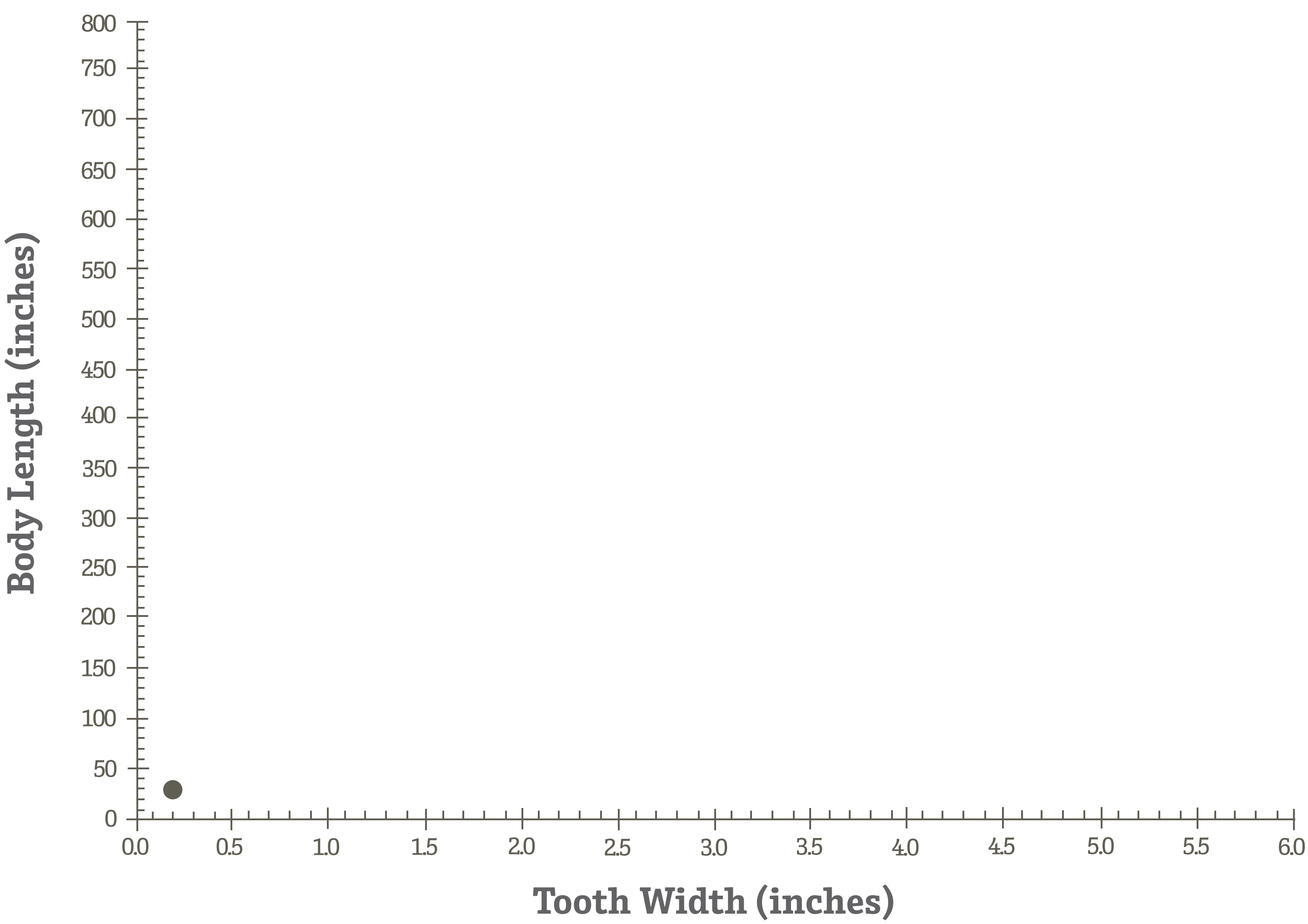
2. After graphing your data, is your null hypothesis supported or falsified? Explain.

3. After extending the graph to meet the tooth width of Megalodon, what is your estimate for Megalodon's body length?

Extra Credit:
Do you have any concerns about this estimate? Why or why not?

Student Activity 1:
How big was Megalodon?

Data Table	
Tooth Width (inches)	**Body Length** (inches)
0.2	26
0.5	64
0.8	100
1.0	127
1.2	150
1.4	180
1.5	190
2.0	250



Educator information for Activity 2:
How long did Megalodon live? *(page 1 of 2)*

Grade Level: 3-12
30-50 minutes

Lesson Summary:
This lesson compares shark centra to tree rings. By first determining that shark centra do record annual growth lines, students will age both modern and fossil sharks and make conclusions about rates of growth. This is an inquiry-based activity that engages students in the scientific process, either individually or in groups.

STEM Subjects: anatomy, life sciences, mathematics, physiology

STEM Concepts & Skills: morphology, ectothermy, growth rates, mathematical measurements

Vocabulary: centrum (centra), ectothermy, ichthyologist, ichthyology, ossification (ossified)

Background Information:
Shark centra (backbones analogous to our vertebrae) are the key to determining the age of living and fossil sharks. Because sharks are ectothermic (i.e. "cold-blooded," controlling one's temperature through external means), they record annual growth rings with the seasons, similar to tree rings. Dark bands indicate slower rates of growth during winter months while lighter bands correspond to faster growth rates during the summer, in both shark centra and tree rings. By counting these bands, we can determine the age of a shark at the time of its death. This method can be tested by counting the growth rings of captive sharks of known ages. For example, if you have 10 year old sharks (you know their age because they have been in captivity since birth) with 10 lines on their centra, these lines likely represent annual growth lines. The width of these bands can also provide information about a shark's rate of growth, with wider bands indicating greater growth than narrower bands.

Materials:

- ***copies of the activity sheet***
- ***pencils***
- ***rulers (optional - used to calculate relative growth rates)***

Educator information for Activity 2:
How long did Megalodon live? *(page 2 of 2)*

Procedure:
Begin this activity by passing around actual or photographic specimens (see the image sheet) of shark centra (actual fish centra can be supplemented) and tree cookies (cross sections of trees). Ask your students if they notice any similarities between the specimens. Subsequently, ask them if they know what the lines represent and how they were formed.

Next, provide the students with the activity sheet and have them formulate and test their null hypothesis that "The lines recorded on the shark centra are not annual growth lines." Students can test this hypothesis by counting the lines in the shark centra and comparing their counts to the known ages. Because the shark ages approximate the number of lines in the centra, they can falsify their null hypothesis and conclude that these lines represent annual growth lines. Once students have determined that these lines are laid down annually, they can now determine the age of Megalodon by counting its growth rings. Lastly, have them compare the growth lines of two similarly sized sharks. The students should be able to make inferences about rates of growth and advanced students can calculate how much faster one shark grew as compared to the other. Note, students should conclude that the shark with the wider spaces in between the growth rings grew more per year than the shark with growth rings that are closer together. They can calculate how much faster one shark grew relative to the other by measuring the width of the space between the growth rings and comparing them. For example, one shark grew ~2 mm per year (left centrum) while the other grew ~4 mm per year (right centrum). Therefore, the shark on the right grew twice as fast as the shark on the left (see activity sheet).

Discussion Questions:

- **How long did Megalodon live?**
- **How are trees and shark centra similar?**
- **Are the lines on shark centra laid down annually?**
- **Why are sharks good candidates for having annual growth rings as compared to humans and other mammals?**
- **How can we use annual growth rings to determine a shark's growth rate in comparison to other sharks?**

Extension Activities:
Advanced students or classes could extend this activity to actually determine the rate of growth of the two sharks on the activity sheet. Additional reading and discussions could delve into why sharks lay down these growth rings and what situations may contribute to exceptions to this rule.

Image Sheet for Student Activity 2 :
How long did Megalodon live?

Tree "Cookie" Cross Section

© Henri D. Grissino-Mayer, University of Tennessee

Shark Centrum (Megalodon)

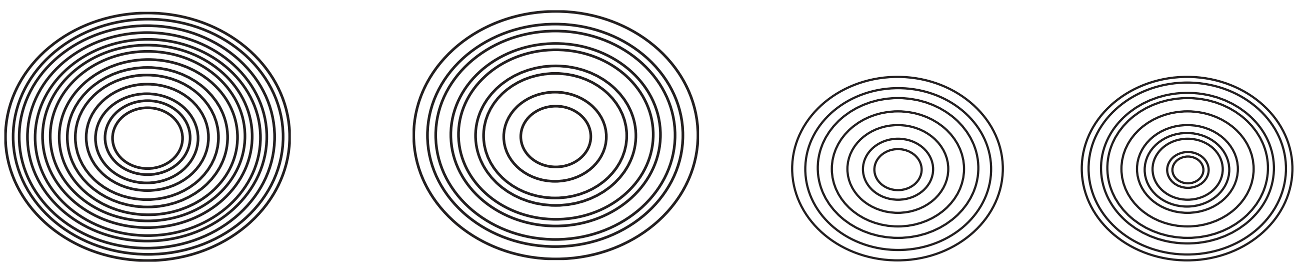
© Image courtesy of the Florida Museum

Student Activity 2:
How long did Megalodon live? *(page 1 of 2)*

Sharks have centra (i.e. backbones) that are analogous to our vertebrae. Similar to trees, these centra have lines that may indicate the age of the shark at the time of its death.

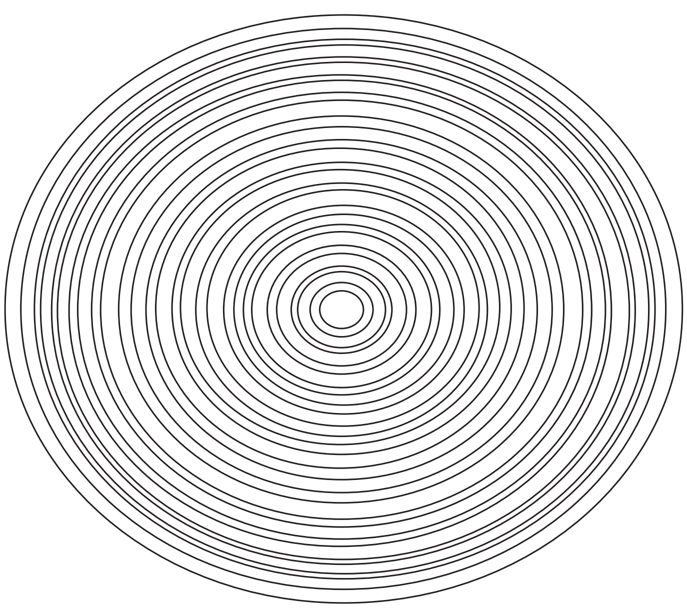
How would you test the hypothesis that shark centra growth lines can be used to age sharks (both modern and fossil)?

Using the following data on captive sharks, what conclusions can you draw about your hypothesis?



15 years old **9 years old** **7 years old** **10 years old**

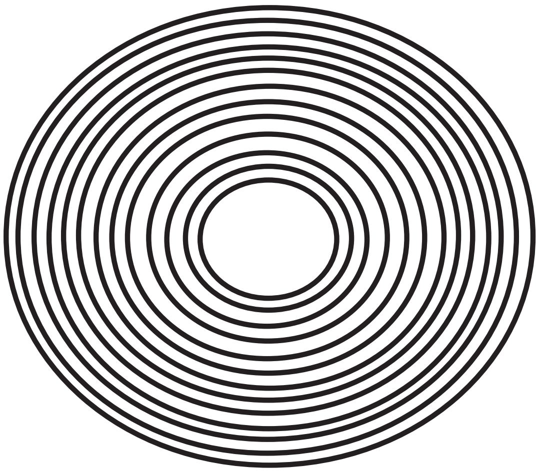
Can you determine the age of the Megalodon centra below? If so, how old was it when it died?

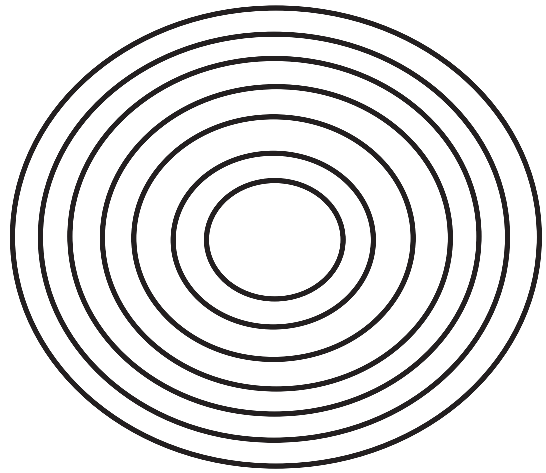


Student Activity 2:
How long did Megalodon live? *(page 2 of 2)*

This Megalodon = ____________ years old when it died

Compare these shark centra of similar sizes. Which shark grew faster?





How can you quantify this difference?

Extra Credit:

Calculate the relative growth rate for each and compare them. Explain how you did this.

- How much faster did one shark grow as compared to the other?

Educator information for Activity 3:
What did Megalodon eat? *(page 1 of 2)*

Grade Level: 4-12
20-90 minutes

Lesson Summary:
This lesson allows students of all levels to calculate and later visually represent how much food Megalodon consumed per day in terms of six-ounce tuna cans. Students will first figure out how many tuna cans Megalodon required per day, per week, and per year based on scientists' estimates of daily food requirements. Next, as a group or as an entire class (or multiple classes), students can actually make a graphical depiction of these cans via a poster, mural, or a pyramid of tuna cans. Discussions regarding the use of tooth morphology to understand diet are also integrated into this lesson.

STEM Subjects: anatomy, life sciences, mathematics, physiology

STEM Concepts & Skills: morphology, basic calculations & conversions

Vocabulary: cannibalism, carnivore, ecosystem, food web, herbivore, morphology, tooth serrations, trophic level

Background Information:
Megalodon was the largest shark that ever lived and likely ate just about whatever it wanted! More specifically, this top predator probably ate whales and large fish to meet its food requirements. By looking at the shape of its teeth, the tooth morphology, we know that this shark was carnivorous. Although Disney's "Finding Nemo" popularized the idea that sharks can be herbivorous (a.k.a. vegetarian), this is not supported scientifically.

Today, great white sharks with much smaller serrated teeth (at least compared to Megalodon) are well-adapted for hunting and consuming seals, porpoises, and large fish. Megalodon's large serrated teeth (the largest of any shark ever) were perfectly capable of slicing large fish, whales, and other sharks. They may have even eaten members of their own species (i.e. cannibalism).

Based on Megalodon's size (estimated from tooth width – see prior activity titled "How big was Megalodon?"), scientists estimate that Megalodon consumed an average of 2,500 pounds (~1,136 kilograms) of food per day.

Educator information for Activity 3:
What did Megalodon eat? *(page 2 of 2)*

Materials:

- **image sheet (and/or specimen casts)**
- **pencils**
- **materials for posters, murals, or a tuna can pyramid (e.g. crayons, poster paper, etc.)**

Procedure:

To start, students are provided with a series of tooth casts (or photos – see accompanying image sheet) of shark teeth, manatee teeth, and baleen. Students are asked to infer the diet of these animals, articulating their reasons for such dietary classifications. During this discussion, students are expected to conclude that Megalodon was a top predator capable of eating the largest fish, whales, and sharks (potentially including other Megalodon sharks – cannibalism) present in prehistoric oceans.

Next, students are told how many pounds of food Megalodon may have consumed per day. They can then calculate how many pounds of food they are estimated to have consumed per week and per year. Additionally, they can convert these estimates to numbers of six-ounce tuna cans. They should conclude that Megalodon would have consumed the equivalent of ~6667 tuna cans per day, ~46,667 tuna cans per week, and ~2,433,333 tuna cans per year, representing an average of 2,500 lbs of food per day, 17,500 lbs of food per week, and 912,500 lbs of food per year. Lastly, students can represent one or several of these estimates by making a small poster, larger poster or mural, and/or pyramid of paper tuna cans (i.e. trace the top of tuna cans and make hollow papers cans out of 2 identical circles and 1 narrow rectangular strip).

Note: Remember to tell students that 16 ounces = 1 pound.

Discussion Questions:

- **What did Megalodon eat?**
- **Could Megalodon have been an herbivore? Why or why not?**
- **On average, how many pounds of food did Megalodon consume per day, per week, and per year? In six-ounce tuna cans?**

Extension Activities:

Further conversions to the metric system can also be incorporated into this activity (e.g., pounds to kilograms). Depending on how elaborate the visual representation of Megalodon's diet via tuna cans, students can put the art work on display on school grounds. Younger students can forgo the calculations and instead focus on making a visual representation of Megalodon's diet via a mural, poster, or pyramid of tuna cans.

Image Sheet for Student Activity 3 :
What did Megalodon eat?

Megalodon Tooth
© Image by Jeff Gage, Florida Museum

Great White Shark Tooth
© Image by Jeff Gage, Florida Museum

Baleen (Minke Whale)
© Image courtesy of Larisa R.G. DeSantis

Manatee Teeth
© Image courtesy of Larisa R.G. DeSantis

Educator information for Activity 4:
When did Megalodon live? *(page 1 of 3)*

Grade Level: 3-12
30-50+ minutes

Lesson Summary:
Students will have the opportunity to both actively demonstrate and construct a football field timeline that includes major evolutionary events. This lesson consists of two parts, each of which can be done independently or combined, allowing students to relate uncommonly large concepts of time with a common football field. In Part I, students will construct their own timeline using a football field. They will place helmets or other icons on their football field that correspond to major evolutionary events. In the end, students will be able to understand when in geological time Megalodon's closer relatives including early fish and sharks first occurred, when Megalodon occurred, and how these events compare to other major evolutionary events including the first appearance of our human species, *Homo sapiens*. In Part II, students are assigned major evolutionary events (e.g., first appearance of land plants, extinction of non-avian (bird-like) dinosaurs, first appearance of Megalodon, etc.). These events include a date that can be converted to football field yardage. Students will soon realize the magnitude of the geological time scale and the relative timing of major evolutionary events.

STEM Subjects: earth science, geology, life sciences, mathematics

STEM Concepts & Skills: geological time scale, mathematic conversions and/or proportions, relative timing of major evolutionary events

Vocabulary: avian (and non-avian) dinosaurs, Cenozoic, evolution, extinction, fossilization, geological time scale, Homo sapiens, macroevolution, Mesozoic, Miocene, paleontologist, paleontology, Paleozoic, Pliocene

Background Information:
Megalodon occupied the world's ancient oceans approximately 17-2 million years ago. Megalodon's presence overlaps with the geological time periods known as the Miocene (24.5 to 5 million years ago) and the Pliocene (5-1.8 million years ago). Megalodon did not overlap with modern humans (*Homo sapiens*) whose first occurrence was around 100,000 years ago. Megalodon's relatives include ancient fish and sharks whose first occurrences are estimated at 510 million years ago and 435 million years ago, respectively. As you can see, Megalodon lived much later than some of its early relatives but is no longer found in today's oceans. Additionally, Megalodon did not live concurrently with non-avian dinosaurs (e.g., Tyrannosaurus rex). Therefore, it is important to discourage Megalodon reconstructions that include the presence of either humans or dinosaurs (although imaginative, it is not scientifically accurate)

Major evolutionary events include the age of the earth (4.6 billion years old), first plants - algae (3.6 billion years ago), first bacteria (3.2 billion years ago), first eukaryotes (2.1 billion years ago), first multi-cellular organisms (1.5 billion years ago), first jellyfish (670 million years ago), first fish (510 million years ago), first sharks (435 million years ago), first land plants (430 million years ago),

Educator information for Activity 4:
When did Megalodon live? *(page 2 of 3)*

first insects (385 million years ago), first amphibians (370 million years ago), first reptiles (330 million years ago), first mammals (240 million years ago), first non-avian dinosaurs (225 million years ago), first birds (220 million years ago), first flowering plants (115 million years ago), extinction of non-avian dinosaurs (65 million years ago), first evidence of Megalodon (17 million years ago), extinction of Megalodon (2 million years ago), first modern humans – *Homo sapiens* (100,000 years ago).

Materials:

- **Measuring tape (50-100 feet, more is better)**
- **Football field template (Part I)**
- **List of major evolutionary events (activity sheet; also, cut one sheet into strips of paper that can be handed out to the students – for Part II)**

Procedure:
This activity is divided into two parts that can be done sequentially or independently. For younger students, skip Part I and instead focus on Part II.

Part I: Provide each student with a list of major evolutionary events (see attached sheet). As a class, determine the following: if a football field equals 4.6 billion years then 1 yard = 46 million years. If your football field instead equals 570 million years (the Paleozoic through to the Recent), then 1 yard = 5.7 million years. You can also simplify this to 500 million years, with younger students, so that 1 yard = 5 million years. Have your advanced students convert the major evolutionary events to yardage. For younger students, provide them with the conversions or do them as a class. Next, have the students (individually or as groups) make football fields that include each of these major evolutionary events (or the ones of relevance if using the shorter time scale – 570 or 500 million years). Encourage creative icons to represent each event.

Part II: To begin, provide all students with a major evolutionary event. Feel free to add more events (or organisms) or pair up students. Travel to a local football field or large field that is 100 yards long. Have students bring along their individual football fields (or list of conversions) if they completed Part I of this activity. Have the class organize themselves, first by geological time periods (i.e. beginning of earth to the Paleozoic, Paleozoic, Mesozoic, and Cenozoic). Next, have them organize themselves within those classifications in a straight line. After all students are organized in a line (Note: they have NOT yet lined up on the football field, to scale), ask them to introduce themselves as their organism and tell when they first originated (or went extinct). After all students are aware of what everyone else is, have them organize themselves on the football field – to scale (according to their prior conversions, or your conversions if working with younger students).

Note: If the football field represents 4.6 billion years, 1 yard = 46 million years). When everyone is lined up to scale, have everyone re-introduce themselves (as loud as necessary). As you will see, most students will be clumped within a few yards. To conclude, you can ask students that are far away to

Educator information for Activity 4:
When did Megalodon live? *(page 3 of 3)*

walk up to the front. Now, ask students to explain to you the relative timing of various events (see discussion questions). Students should be able to acknowledge how long our earth has been around and the vast amount of time that has occurred since then. They should also conclude that Megalodon could not have eaten dinosaurs or modern humans. If time allows, you can repeat this activity having the football field represent the Paleozoic to the Recent (570 million years, 1 yard = 5.7 million years).

*Note, if doing this activity with younger students, have them construct images of their organisms prior to the football field trip so that they can visualize the organisms discussed (e.g. algae, mammals, *Homo sapiens).*

Discussion Questions:

- **When did Megalodon live?**
- **Did Megalodon live concurrently with non-avian dinosaurs or modern humans?**
- **When did other major evolutionary events occur in geological time?**
- **Could early Paleozoic sharks have eaten whales?**

Extension Activities:

The football field timelines can be posted around the classroom or school grounds. Additionally, students may want to further investigate particular time periods or organisms. For example, students can produce independent or group research reports on the first land plants, the first mammals, or non-avian dinosaur extinctions. These reports can be simple for younger grades, consisting of a drawing and a few sentences. Advanced students can produce research projects with either a scientific focus or reports that discuss the historical conditions surrounding particular discoveries (interesting ones include: Cope vs. Marsh Fossil Wars, Roy Chapman Andrews and his first expedition to Mongolia, and recent fossil discoveries – see current and recent science news).

Learning the geological time scale can also be a daunting task. If you intend to cover the geological time scale in detail, students can be encouraged to come up with and share their pneumonic devices.

Student Activity 4: Evolutionary Events
When did Megalodon live?

MAJOR EVOLUTIONARY EVENTS

Event	Yards from the End
Age of the earth (4.6 billion years old)	0
First plants - algae (3.6 billion years ago)	
First bacteria (3.2 billion years ago)	
First eukaryotes (2.1 billion years ago)	
First multi-cellular organisms (1.5 billion years ago)	
First jellyfish (670 million years ago)	
First fish (510 million years ago)	
First sharks (435 million years ago)	
First land plants (430 million years ago)	
First insects (385 million years ago)	
First amphibians (370 million years ago)	
First reptiles (330 million years ago)	
First mammals (240 million years ago)	
First non-avian dinosaurs (225 million years ago)	
First birds (220 million years ago)	
First flowering plants (115 million years ago)	
Extinction of non-avian dinosaurs (65 million years ago)	
First evidence of Megalodon (17 million years ago)	
Extinction of Megalodon (2 million years ago)	
First modern humans – *Homo sapiens* (100,000 years ago)	

Student Activity 4: Evolutionary Events

When did Megalodon live?

Football Field Timeline

50 Yard Line

Educator information for Activity 5: Where did Megalodon live? *(page 1 of 2)*

Grade Level: K-12
40-50+ minutes

Lesson Summary:
This lesson is primarily a geography and earth science lesson. Students are asked to create a map that includes a wide range of locations where Megalodon fossils have been found. By providing a list of the geographic locations, students construct a map that highlights these areas. They are also asked to reflect on why Megalodon teeth are found on current land masses.

STEM Subjects: earth sciences, geology

Non-STEM Subjects: anthropology, geography, history, social sciences

STEM Concepts & Skills: climate change, sea-level rise, geology

Vocabulary: climate change, elevation, fossilization, sea-level rise

Background Information:
Megalodon lived throughout the world's ancient oceans, approximately 2-17 million years ago. Today, Megalodon fossils can be found all over the world indicating that Megalodon was a cosmopolitan species (i.e. living worldwide). Additionally, these teeth are found on Florida's coastal shores to Peruvian deserts. Megalodon fossils in higher elevation areas indicate that these areas were underwater at the time Megalodon was alive (2-17 million years ago). Because these areas are no longer underwater, scientists conclude that climate change has occurred over the last several million years. Megalodon fossils are likely also present in today's deeper oceans, but difficult for us to find.

Materials:
- **variety of arts and crafts materials to construct a map (e.g., poster paper, paint, crayons, rulers, etc.)**
- **reference maps (Or, you may want to use a current map and add Megalodon teeth icons, representing fossil localities)**

Educator information for Activity 5:
Where did Megalodon live? *(page 2 of 2)*

Procedure:

This activity is very simple and appropriate for students of most ages. Begin by providing students with a list of Megalodon fossil localities (see the Megalodon locality list). Inform them that their job is to create a map that includes all of these Megalodon fossil localities. Students can be provided with either a blank sheet of paper, a map with continents outlined, a map with countries and continents outlined, or a detailed map (depending on grade and ability level). Students will then learn the locations of states and countries by mapping Megalodon localities on their map.

After students have completed their maps, as groups, ask them to think about and explain whey Megalodon teeth are found on land (especially at higher elevations or inland). Students should be able to articulate that sea-levels were higher at some point when Megalodon was alive (when these fossils were deposited), 17-2 million years ago. Additionally, you can discuss how fossils can subsequently inform scientists about climate change.

Discussion Questions:

- **Where did Megalodon live?**
- **Why do we find Megalodon fossils on land, today?**
- **What can Megalodon tell us about ancient climates?**

Extension Activities:

Completed maps can be posted around the classroom or school grounds. Additionally, students can make supplemental posters or labels that explain why Megalodon fossils are found on land and what they can tell us about past climates. Students can also complete accompanying reports that discuss fossil exploration in these areas. Advanced students may want to comment on how political situations can influence a scientist's ability to explore certain areas, globally. For example, is fossil exploration in Iraq a feasible goal – currently? How have political tensions influenced access to land and our current understanding of evolution? An interesting example is regarding fossil whale discoveries in Pakistan by Gingerich and others. These discoveries have changed the way we view mammalian evolution.

Where did Megalodon live?

Megalodon Locality List

Countries

- Argentina
- Belgium
- Chile
- Cuba
- France
- Italy
- Japan
- Malta
- New Caledonia
- Peru
- United States:
    - California (Bakersfield)
    - Florida (Jacksonville)
    - Georgia (St. Simons Island)
    - Maryland (Calvert Cliffs)
    - New Jersey (Big Brook in Monmouth County)
    - South Carolina (Westmoreland State Park)

Note: This is not a comprehensive list, just a few key Megalodon fossil localities.

Educator information for Activity 6:
Who was Megalodon related to? *(page 1 of 4)*

Grade Level: 4-12
50-100 minutes

Lesson Summary:
This lesson will allow students to collaboratively develop classification skills and gain an introduction to how organisms are related. Students will first learn cladistics (a method used to organize information) as a class through a hands-on activity. They will then work together, in groups, to classify their own organisms according to the methods they just learned.

STEM Subjects: anatomy, life sciences, mathematics

STEM Concepts & Skills: classification of organisms, evolution, morphology

Vocabulary: cladistics, cladogram, evolution, macroevolution, morphology

Background Information:
Megalodon's relationship to other organisms is difficult to determine, especially due to the lack of complete fossil specimens (see "How big is Megalodon?," for reasons why). Nevertheless, Megalodon fossils can be compared to living and extinct organisms using a method known as cladistics. Cladistics is a method used to organize information. A cladogram is a diagram that shows similarities of characters. Therefore, after organizing information using cladistic methods we can infer evolutionary relationships. Background information can be found at the American Museum of Natural History's Cladistics Website: (http://www.amnh.org/exhibitions/permanent/fossilhalls/cladistics/).

Cladistics can help inform us that Whale sharks are more closely related to Megalodon than to Baleen Whales with similar dietary habits. Additionally, we can learn that filter feeding arose multiple times – as is apparent from this disparate relationship. Although the debate over Megalodon's closest relative is still contentious, the front runners being the Mako Shark and the Great White Shark, there is a large amount we do know about Megalodon and its relatives by using cladistic methods.

Materials:
- **zip lock bags - each with one penny, one nickel, one dime, and one quarter (per group; Part I)**
- **activity sheet 6 (Part I)**
- **activity sheet 6 - data table (Part II)**
- **activity sheet 6 - cladogram (Part II)**
- **zip lock bags with cut out organism cards (per group; see image sheets – Part II)**
- **pencils**

Educator information for Activity 6:
Who was Megalodon related to? *(page 2 of 4)*

Procedure:

Part I: This activity begins by asking, "Who was Megalodon related to?" You can then list the following organisms on the board (Jellyfish, Jawless Fish – Lamprey, Great White Shark, Megalodon, Whale Shark, Manta Ray, Tuna, Crocodile, Penguin, Mallard Duck, Humpback Whale, Beluga Whale, and Dolphin), asking how these animals are related to Megalodon. This question is a teaser to get the students thinking about Megalodon and its relatives. You can then define cladistics and explain that it is a method of organizing information that can help us to determine how organisms are related. Next, you can lead them through a guided activity where they will use cladistics to classify coins and construct a cladogram demonstrating those relationships (see Activity Sheet – Part I).

Students should work in pairs when completing the guided cladistics activity. Instruct students to:

1. Check off all coins that share the feature "round."
2. List a feature (in the table, after the letter "B") that three coins have in common that the fourth does not, checking off that the three coins share this feature.
3. List a feature (in the table, after the letter "C") that two of the three checked coins have in common that the remaining third coin does not, checking off the two coins that share this feature. When students are completing this step, encourage them to find unique features that other groups have not mentioned (e.g. ponytails, the presence of plants, etc...)

Conduct a thorough wrap-up that summarizes all steps and discusses possible features and the remaining outcomes. As a class, now translate the table onto the cladogram. For example, if feature A is round, feature B is silver, and feature C is the presence of ridges on the outer edge of the coin, then you would place the penny in slot 1, nickel in space 2, and the quarter and dime next to 3 and 4 (the quarter and dime are interchangeable). This is because the penny is round but not silver. The nickel is silver and round but does not have ridges. The quarter and dime have all of the features; thus, they can be interchanged between positions 3 and 4. See the American Museum of Natural History's Cladistic Website:
www.amnh.org/exhibitions/permanent/fossilhalls/cladistics/ for further clarification.

Make sure to cover most combinations, so that students with different data-tables can confirm their proper translation of data to the cladogram. In conclusion of Part I, congratulate the class on their new mastery of a scientific method that professional scientists use everyday.

Part II: Pass out a set of organism cards to each group (2-5 people) and pass out a copy of each activity sheet to all students. As pairs/groups, ask students to fill out the following data table (see Activity Sheet - Part II data table) and then place the information from the table onto the cladogram (see Activity Sheet - Part II cladogram). The cladogram has some features filled in (in order to give some structure to the assignment and make sure that the basic relationships are revealed); however, feel free to fill

Educator Information for Activity 6:
Who was Megalodon related to? *(page 3 of 4)*

in more of the slots (reference the answer key) when working with younger children. Students can examine the organism cards to decide which organisms have the features described. Photos of each of the organisms are provided to each group. However, additional resources can also be used.

Once students have filled out their data table, they will translate their data onto the cladogram in the same manner as in Part I. For example, students can determine that all of their organisms except for one (Jellyfish) have a backbone – according to their data table. Therefore, feature A is vertebrae (backbones) and the Jellyfish can be filled in to the only organism spot available for non-vertebrates. Students should also determine the following:

- Feature B = flattened body, because the only organism with eyes on top of its head also has a flattened body; thus, the manta ray goes in the organism spot to the right of these features
- Feature C = wings, because the mallard duck and penguin are most similar to each other and are the only organisms to share this feature (thus, the penguin goes to the immediate left of the mallard duck);
- Feature D = production of milk, as mammals that give live birth also produce milk and all marine mammals listed share these features

Students can fill in the remainder of organisms by looking at what features these organism must have, as listed in the cladogram. For example, the organism to the right of the Beluga whale must produce milk and give live birth while the organism to the left of the Beluga whale has both of these features and also has baleen. Therefore, Dolphin belongs to the right of the Beluga Whale and Humpback Whale belongs to the left of the Beluga Whale. Similarly, Megalodon belongs to the immediate right of the Great White Shark as it has large triangular teeth and a cartilaginous skeleton, whereas the Whale shark can be placed in between the manta ray (see Feature B above) and other sharks. You will likely want to walk your students through one of these examples, as a class, so that they are better equipped to fill in their cladogram as pairs or groups.

When all students have completed the activity, make sure to include a wrap-up discussion that uses student participation to explain the organismal relationships and defining characters (see Activity Sheet - Part II cladogram Answer Key).

Discussion Questions:

- **Who was Megalodon related to?**
- **What is cladistics?**
- **How can you use cladistics to understand current and past relationships?**

Educator Information for Activity 6:
Who was Megalodon related to? (page 4 of 4)

Extension Activities:
Students can complete an excellent module on cladistic methodology and evolution titled, "What Did T-Rex Taste Like?" produced by the University of California Museum of Paleontology (UCMP).

The web site can be found at: www.ucmp.berkeley.edu/education/explotime.html, specifically the "What Did T-Rex Taste Like?" module can be found at: www.ucmp.berkeley.edu/education/explorations/tours/Trex/index.html.

This on-line module provides an excellent follow up to the cladistics activity. Students may also want to construct a poster that displays the final cladogram, adding additional characters and/or organisms.

Student Activity 6:
Who was Megalodon related to?

Part I

Examine all of the coins. Do all of them share a common feature? One feature they share in common is their round shape. Since all of the coins share the "round" feature, mark an "X" in each box in the "round" row.

As a team, you and your partner will do the following:

1) List a feature that three coins have in common that the fourth coin does not. List this feature next to the letter B" in the "Features" column.

2) Mark an "X" in the columns of the three coins that have feature "B."

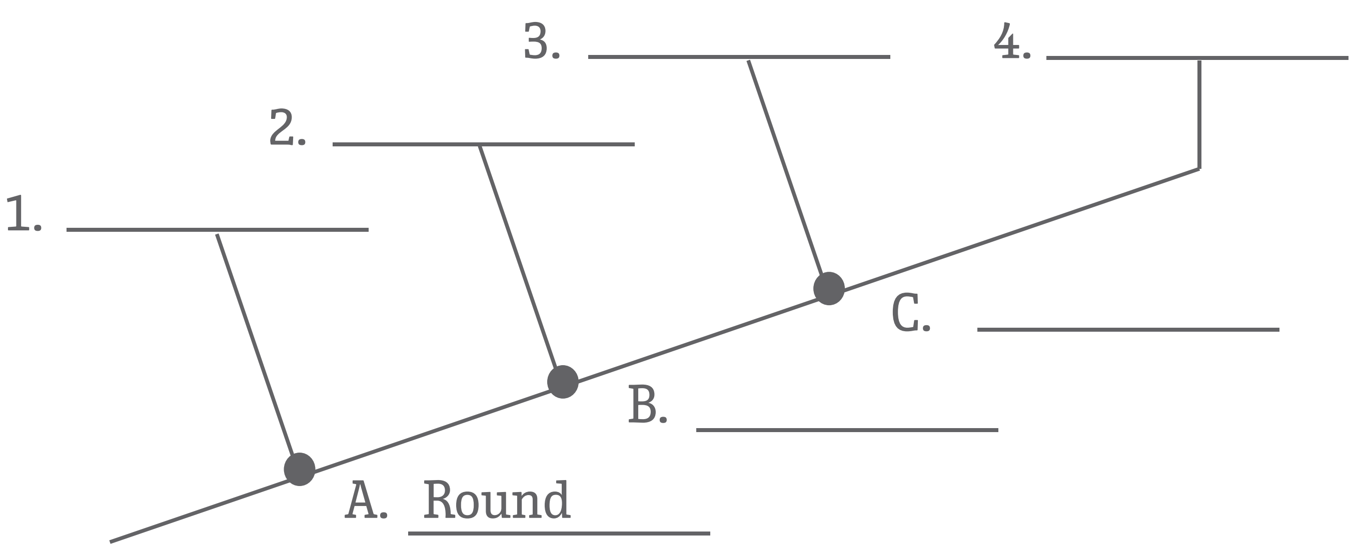
3) List a feature that two of the three coins checked have in common that the third checked coin does not. List this feature next to the letter "C" in the "Features" column. Be creative!

4) Mark an "X" in the columns of the two coins that have feature "C."

Features	Penny	Nickel	Dime	Quarter
A. Round				
B.				
C.				

As a class you will translate your data from the table onto the cladogram.

- What do you think goes next to letter "B"?
- What do you think goes next to letter "C"?
- What coin will go on line 2, according to your data (not the data of anyone else)?



Student Activity 6:
Who was Megalodon related to?

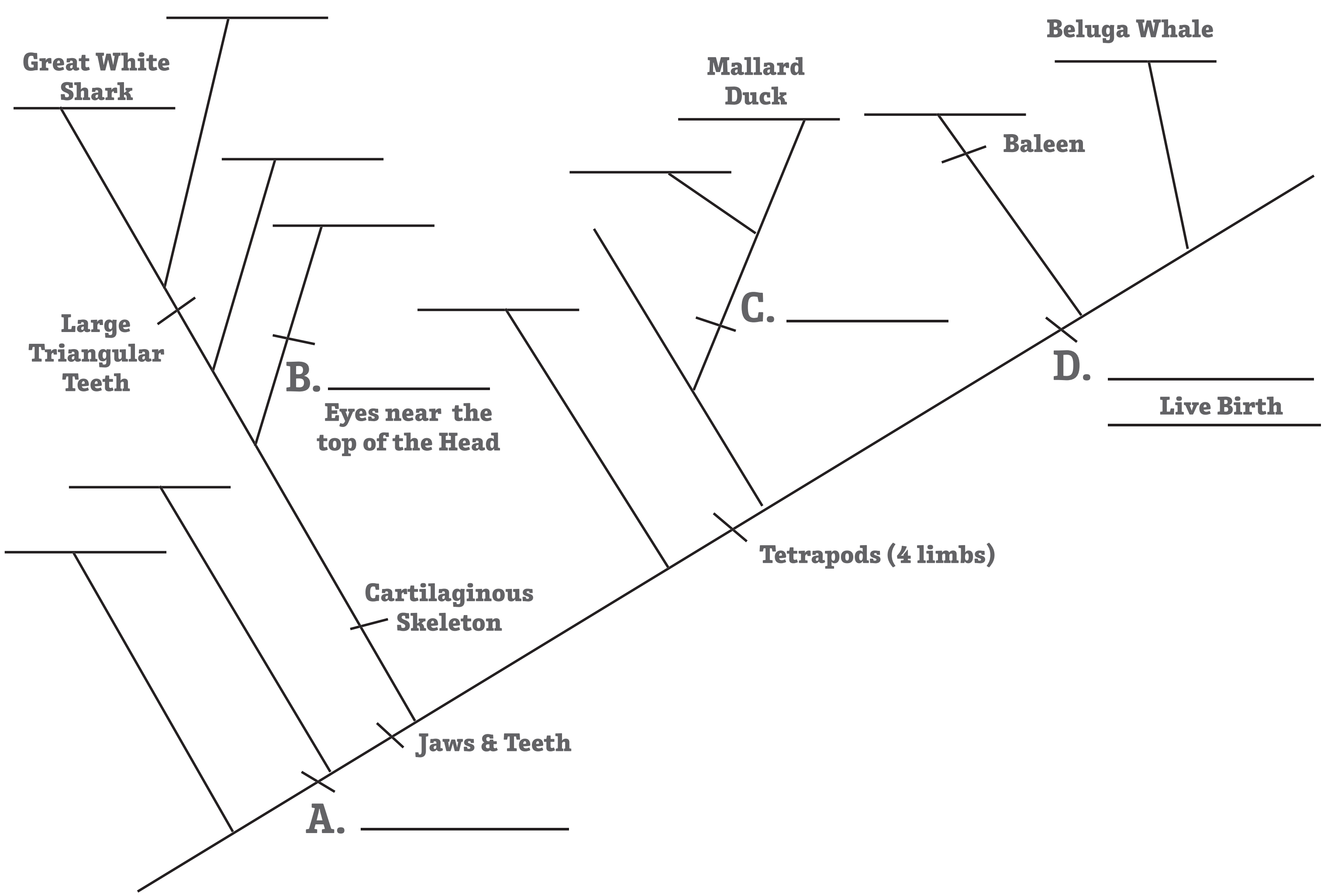
Part II - Data Table

Now that you have mastered cladistics, a method that university level scientists use everyday, you are now ready to use cladistics to determine how the following organisms are related. Put a plus (+) if the animal has the feature, a negative (-) if the animal does not have the feature, and a question mark (?) if you and others do not know if the animal has the feature. Examine the photos carefully! Now take this information and use it to fill in your cladogram.

Organism	Backbone	Jaws	Teeth	Large, triangular teeth	Baleen	Cartilaginous skeleton	Flattened body	Eyes near top of head	Four limbs	Females produce milk	Females have live birth
Jellyfish											
Lamprey (Jawless Fish)											
Tuna											
Manta Ray											
Whale Shark											
Great White Shark											
Megalodon											
Crocodile											
Penguin											
Mallard Duck											
Humpback Whale											
Beluga Whale											
Dolphin											

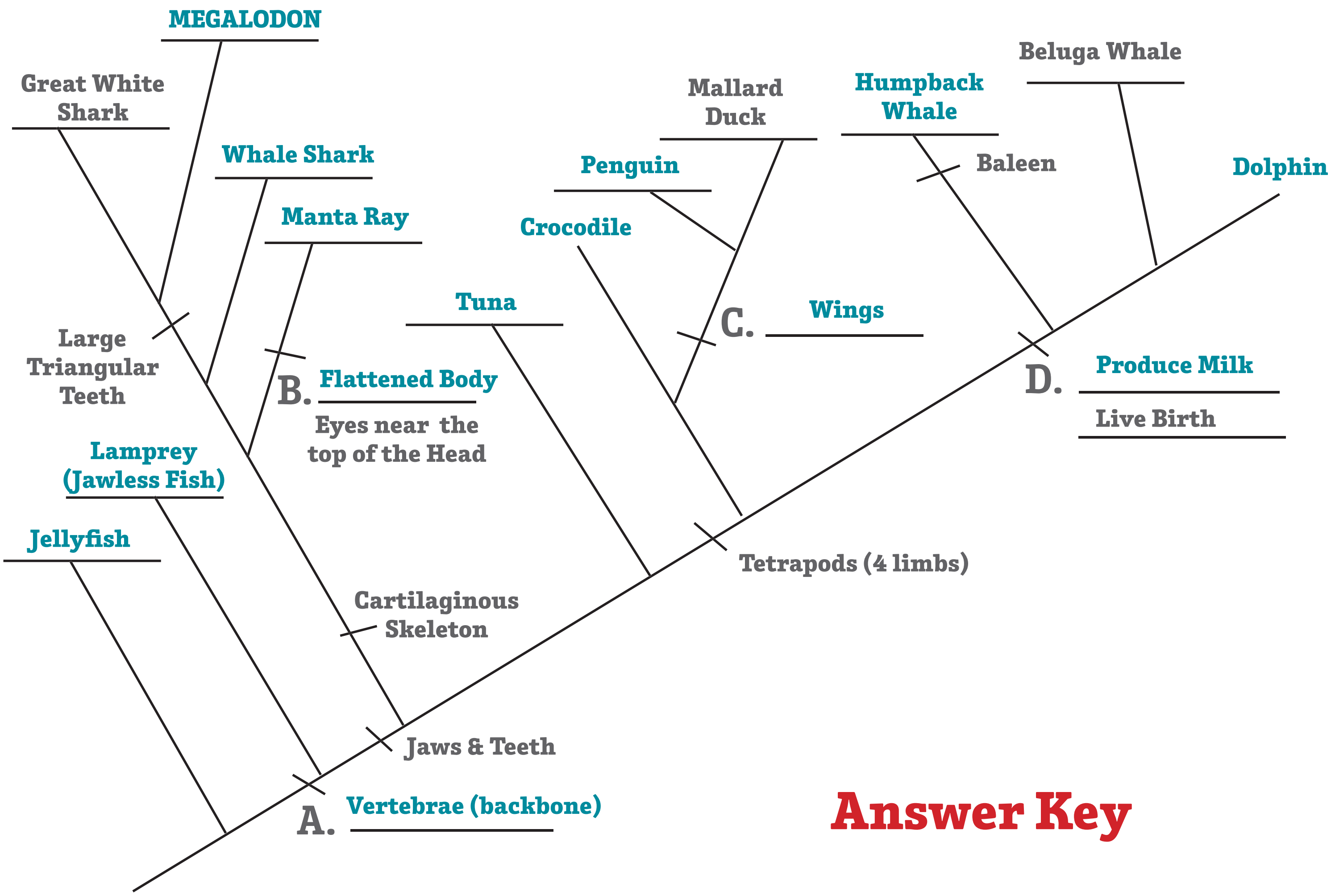
Who was Megalodon related to?

Part II - Cladogram



Student Activity 6: Answer Key
Who was Megalodon related to?

Part II - Cladogram

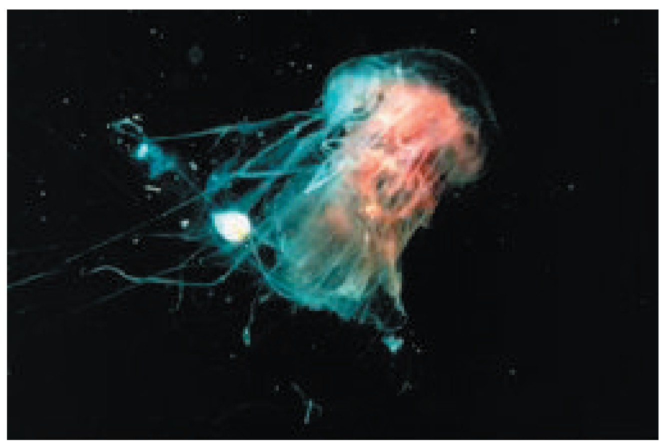


Who was Megalodon related to?

Emperor Penguin Colony
© Image courtesy of Michael Van Woert, NOAA NESDIS, ORA

Pacific White-sided Dolphin
© Image courtesy of NOAA/ MBARI

Humpback Whale
© Image courtesy of Dr. Louis M. Herman



Cyanea
© Image courtesy of OAR/National Undersea Research Program (NURP): University of Connecticut

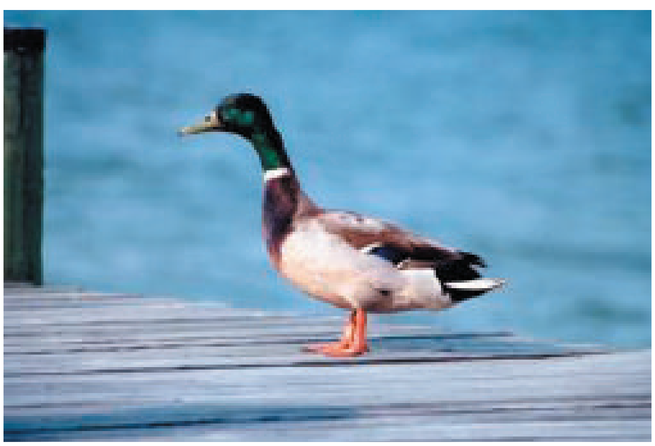
Who was Megalodon related to?

School of Yellow Fin Tuna

© Image courtesy of OAR/National Undersea Research Program (NURP)

Manta Ray

© Image courtesy of Dr. Dwayne Meadows, NOAA/NMFS/OPR



Mallard Duck

© Image courtesy of Mary Hollinger, NESDIS/NODC biologist, NOAA

Beluga Whales

© Image courtesy of Connecticut, Mystic

Who was Megalodon related to?

Sea Lamprey
© Image courtesy of U.S. Fish and Wildlife Services (USFWS)

Whale Shark
istock.com

Saltwater Crocodile
© Image courtesy of Larisa R.G. DeSantis

Great White Shark
istock.com

Who was Megalodon related to?

Megalodon
© *Illustration by Merald Clark*

Megalodon Tooth
© *Image courtesy of the Florida Museum*

Megalodon Jaw
© *Image courtesy of the Florida Museum*

Megalodon Centrum
© *Image courtesy of the Florida Museum*

Educator information for Activity 7:
Why is Megalodon important? *(page 1 of 3)*

Grade Level: K-12
30-50 minutes

Lesson Summary:
Students are asked to think out of the box and communicate scientific information to others via creative advertising campaigns. Here students learn that sharks are important to ecosystem functions, however, they also become aware of potential threats to shark and ocean health. This lesson allows students to express their creativity while communicating the importance of both fossil (e.g., Megalodon) and living sharks!

STEM Subjects: anatomy, chemistry, earth sciences, life sciences, mathematics, marine biology, physics, physiology

STEM Concepts & Skills: food web dynamics, ecology, ecosystem feedback mechanisms, environmental sustainability

Non-STEM Subjects: anthropology, economics, english, history, social sciences

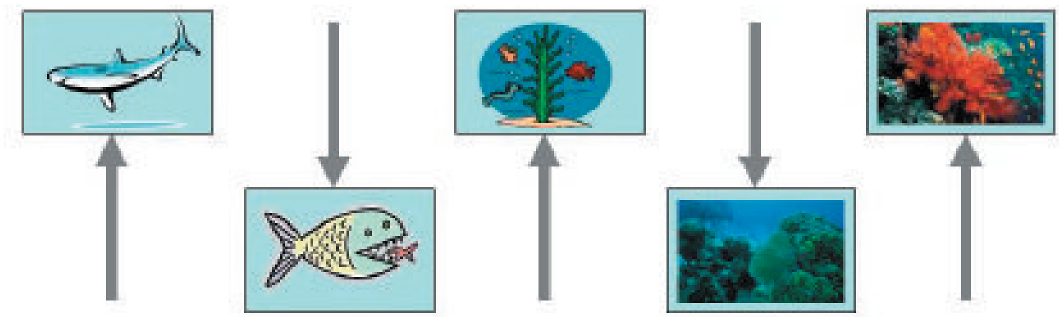
Vocabulary: carnivore, community service, ecology, environmental contaminants, food webs, herbivore, macroevolution, ocean nutrification, over-fishing, pollution, storm drains, sustainability, trophic levels

Background Information:
Megalodon teaches us about shark evolution and shark conservation. Scientists can better understand macroevolution by studying Megalodon fossils – revealing how this gigantic shark evolved from smaller ancestors. Additionally, Megalodon teaches us that top marine predators can and do become extinct. Currently, several shark populations are experiencing population decline. Likely causes include commercial over-fishing, pollution, and habitat alteration. Because of the high market value of shark fins (used in shark fin soup), millions of sharks are left to drown after their fins have been removed. Pollution also kills sharks and their prey everyday. Ocean pollution can occur when trash and toxins are washed down storm drains and/or when agricultural nutrients (ocean nutrification) and/or pesticides are washed into the ocean after rainfall. Additionally, the dredging of the ocean floor and coastal development can alter ocean habitats – including shark nursing grounds.

Reef sharks are key to maintaining coral reef ecosystems. These top predators keep carnivorous fish populations down, causing herbivorous fish populations to increase. The presence of large herbivorous fish populations keeps algae (that grows on corals) in check, allowing for healthy coral reefs (see diagram below). When reef shark populations decline, coral reef ecosystems are at risk!

Educator information for Activity 7:
Why is Megalodon important? (page 2 of 3)

How does over-fishing of sharks affect coral reefs?



Healthy shark populations keep carnivorous fish populations low, allowing herbivorous fish to remain large and feed on algae-covered coral reefs; therefore, healthy coral reef populations flourish.

What would happen if these shark populations declined due to over-fishing?

(Answer: The reverse would happen. Low shark populations would cause an increase in carnivorous fish populations, which would cause low herbivorous fish populations, which in turn would cause algae-covered coral reefs, which makes the coral reefs unhealthy!)

Materials:

- **20-100 feet of string (needed for the opening demonstration)**
- **variety of arts and crafts materials to construct the advertising posters (e.g., poster paper, paint, crayons, rulers, etc...)**

Procedure:

To begin this activity, ask students why they think it is important to study Megalodon. These questions and ideas can be elaborated on in greater detail. Next, you can begin a discussion about threatened shark populations and shark conservation. Specifically you will want to discuss the case example with reef sharks, explaining how they indirectly affect the health of coral reefs (see diagram and explanation above). You may want to ask five students to come to the front of the class and have them stand up or sit down to represent high verses low populations, respectively, for each of the players (sharks, carnivorous fish, herbivorous fish, algae, coral reefs). For example, have the "shark" person stand up to indicate high population numbers, the "carnivorous fish" person sit down to indicate low population numbers, the "herbivorous fish" person stand up to indicate high population numbers, the "algae" person sit down to indicate low population numbers, and the "coral reef" person stand up to indicate high population numbers. The students can then reverse the scenario demonstrating what would happen if over-fishing reduced shark populations.

Educator information for Activity 7:
Why is Megalodon important? *(page 3 of 3)*

Another interactive example is to have everyone in the class represent an organism, connecting all organisms and their prey with a string. After all organisms are “connected,” the interconnectedness of all organisms can be demonstrated by asking one organism to decline (represented by having one person drop the string). Next, each “organism” that feels the lack of tension can then drop their string. Soon, the lack of tension is felt by all “organisms” in the “ecosystem.”

Once students are comfortable with these concepts and the vocabulary words listed above, you can begin discussions about effective science communication. This conversation can be very basic, talking about the importance of informative pictures and phrases. Additionally, this conversation can also include the examination of current advertising campaigns on ocean health such as those available at www.shiftingbaseline.org.

In conclusion, ask students to design poster advertising campaigns that communicate why sharks are important, why many are at risk, and what we can do to help improve living shark populations.

Discussion Questions:

- **Why is Megalodon important?**
- **How can Megalodon help scientists learn about macroevolution?**
- **Do top predators go extinct?**
- **What are current threats to living shark populations?**
- **What can we do to prevent the decline of shark populations?**
- **Why are living sharks important to ecosystem function (e.g. coral reef health)?**

Extension Activities:

Although the goal of this activity is to create an advertisement poster within one to two class periods, this activity can be expanded to include the development of skits, radio or video advertisements, and internet campaigns. Students can also evaluate the effectiveness of their advertising campaigns by surveying students in other classes. These surveys can be statistically analyzed and results discussed. Numerous discussions about effective science communication can also be integrated into extension activities.

Educator information for Activity 8:
Megalodon on Exhibit! *(page 1 of 2)*

Grade Level: K-12
50-150+ minutes

Lesson Summary:
This culminating activity allows students to demonstrate their understanding of all Megalodon topics discussed and completed activities. Students construct exhibits on each of the questions posed throughout this guide, as groups of 2-5. These exhibits can be put on display in the classroom (or in another school area) and students can lead tours or be exhibit explainers for visiting students and/or parents.

STEM Subjects: anatomy, chemistry, earth sciences, life sciences, mathematics, marine biology, physics, physiology

Non-STEM Subjects: anthropology, economics, english, geography, history, social sciences

Vocabulary: potentially all of the words listed under Useful Vocabulary

Background Information:
Megalodon is the largest shark to have ever lived! Megalodon is a fascinating fossil shark that is found all over the world, lived during the last 17-2 million years, ate vast quantities of marine animals, may have been up to ~60 feet in length, is related to a diverse array of extinct and modern sharks, and was likely critical to the stability of marine ecosystems – as top predators are today.

See background information listed under each of the Megalodon Activities for more information related to the questions listed below.

Materials:
- **variety of arts and crafts materials to construct the mini-exhibits (e.g., poster paper, paint, crayons, rulers, etc...)**

Procedure:
The construction of mini-exhibits can be done as a culminating activity or can be made upon the completion of each Megalodon activity. These mini-exhibits should focus on answering the discussion questions listed below (the Educator's Guide questions). However, each exhibit should aspire to communicate an appropriate level of detail and insight on the respective topics. For example, elementary school students may want to focus on reconstructing Megalodon's teeth, centra, and body length – all to scale. High school students may instead want to discuss the detailed problems with Megalodon body size estimates (e.g. extending the graph to the far right without knowing the shape of the regression – linear, exponential, etc.).

Megalodon on Exhibit! *(page 2 of 2)*

It is highly encouraged to have exhibit visitors, as students can then articulate what they have learned. Additionally, students are provided with the opportunity to share their enthusiasm for Megalodon and related disciplines with other students.

Discussion Questions:

- **How big was Megalodon?**
- **How long did Megalodon live?**
- **What did Megalodon eat?**
- **When did Megalodon live?**
- **Where did Megalodon live?**
- **Who was Megalodon related to?**
- **Why is Megalodon important?**

Extension Activities:

Potential extension activities include: recruiting visitors to the exhibit, providing student guided tours, and exhibiting the mini-exhibits in a visible place in your educational institution. Additionally, the mini-exhibits may serve as a spring board for individual or group research projects. Students may find a question or topic of particular interest. Fostering this interest through individual or group research projects could be a useful formal assignment, or the beginnings of an extra curricular science project.

Educator information for the *Megalodon Field Journal* *(page 1 of 2)*

Grade Level: K-12
40-90 minutes

Lesson Summary:
During your field trip to the Megalodon exhibit, students will actively engage in the Megalodon exhibit through their participation in a field journal. Two field journals are available for different grade or ability levels, K-4 and 5-12.

In the K-4 field journal, students are asked to reconstruct a variety of specimens and record key information. In the 5-12 field journal, students are asked to articulate the answers to many of the questions posed throughout the Educator's Guide.

STEM Subjects: anatomy, chemistry, earth sciences, life sciences, mathematics, marine biology, physics, physiology

Non-STEM Subjects: anthropology, economics, english, geography, history, social sciences

Vocabulary: potentially all of the words listed under Useful Vocabulary

Background Information:
Megalodon is the largest shark to have ever lived! Megalodon is a fascinating fossil shark that is found all over the world, lived during the last 17-2 million years, ate vast quantities of marine animals, may have been up to ~60 feet in length, is related to a diverse array of extinct and modern sharks, and was likely critical to the stability of marine ecosystems – as top predators are today.

Materials:
- **copies of the field journals**
- **pencils (NO PENS!)**
- **clip-boards or notebooks (optional, but very helpful)**

Procedure:
Pass out the field journals, pencils, and clipboards to all students. Provide them with a time frame to view the exhibit and complete the field journal. The field journal is meant to improve the visitors experience by actively engaging them in the exhibit. Please remind students of this and preferably assess their participation within the context of their grade level and time provided in the exhibit.

Educator information for the
Megalodon Field Journal *(page 2 of 2)*

Extension Activities:
Students are often limited in the amount of time they can spend on their field journal while at the museum. You may want to provide time for them to elaborate on their field journal, either as homework or in class. Additionally, students can be asked to present on unique aspects of their field journals. For example, students may want to present on their favorite shark while sharing their drawings. Mini-research projects on some aspect of marine biology, evolution, Megalodon's life history characteristics, conservation, or a variety of other relevant topics can be done with students of diverse ages. These reports can be highly interdisciplinary, especially if they incorporate social or historical perspectives.

Megalodon Field Journal *(page 1 of 2)*

Grade Level: K-4

Find a Megalodon tooth. Draw the tooth in the space below.

Is this tooth bigger or smaller than your teeth? Why do you think that is? ______________________________

____

____

____

Megalodon was the largest shark that ever lived! On average, how much did it eat per day in pounds

____________ and in tuna cans ____________?

Where did Megalodon live? List three places Megalodon lived:

1. ____

2. ____

3. ____

Megalodon Field Journal *(page 2 of 2)*

Grade Level: K-4

Find your favorite shark or shark relative in the Megalodon exhibit (it does not have to be Megalodon). Draw it below.

Write three new facts you learned about Megalodon.

1. ____

____

2. ____

____

3. ____

____

Megalodon was the largest shark ever!

What is the estimated body length of Megalodon? ______________________________
(Hint: Use the sliding graph - inside Megalodon.)

How many of you (use your height) would it take to equal one Megalodon? ______________

Find a Megalodon centrum (backbone) and determine its age. ________

Do you think it grew faster than other sharks or just lived longer? Why?
(Hint: Use the centra to answer these questions)

____

____

____

What did Megalodon eat? ____

On average, how much did it eat per day in pounds ________ and in six-ounce tuna cans ______?

Could Megalodon ever eat humans? Why or why not? (Hint: Look at when Megalodon lived.)

____

____

Where did Megalodon live? List three places Megalodon lived:

1. ____

2. ____

3. ____

Megalodon Field Journal *(page 2 of 2)*

Find your favorite shark or shark relative in the Megalodon exhibit (it does not have to be Megalodon). Draw it below.

What is the name of the animal drawn above? ________________________________

How is it related to Megalodon? ________________________________

____

What is one interesting fact about this animal? ________________________________

____

Why are Megalodon and living sharks important? ________________________________

____

Why are they at risk? ________________________________

____

What can we do to prevent their decline? ________________________________

____

Explain how reef sharks affect the health of coral reefs?
(Feel free to use drawings in your explanation.)

National Science Education Standards
(Grades K-4)

	How big was Megalodon?	How long did Megalodon live?	What did Megalodon eat?	When did Megalodon live?	Where did Megalodon live?	Who was Megalodon related to?	Why is Megalodon important?	Megalodon on Exhibit!	Megalodon Field Journal
UNIFYING CONCEPTS AND PROCESS									
Systems, order, and organization	X	X		X		X	X	X	X
Evidence, models, and explanation	X	X	X	X	X	X	X	X	X
Change, constancy, and measurement	X	X	X	X	X	X	X	X	X
Evolution and equilibrium	X			X	X	X	X	X	X
Form and function	X	X	X				X	X	X
SCIENCE AS INQUIRY									
Abilities necessary to do scientific inquiry	X	X	X	X	X	X	X	X	X
Understanding about scientific inquiry	X	X	X	X	X	X	X	X	X
PHYSICAL SCIENCE									
Properties of objects and materials	X	X	X			X	X	X	X
LIFE SCIENCE									
Characteristics of organisms	X	X	X	X	X	X	X	X	X
Life cycles of organisms	X	X	X	X		X	X	X	X
Organisms and environments	X	X	X	X	X	X	X	X	X
EARTH AND SPACE SCIENCE									
Properties of earth material	X	X	X	X	X	X	X	X	X
Changes in earth and sky				X	X		X	X	X
SCIENCE AND TECHNOLOGY									
Abilities of technological design				X	X		X	X	X
Understanding about science and technology								X	X
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES									
Characteristics and changes in populations							X	X	X
Types of resources							X	X	X
Changes in environments	X	X	X	X	X	X	X	X	X
Science and technology in local challenges							X	X	X
HISTORY AND NATURE OF SCIENCE									
Science as a human endeavor	X	X	X	X	X	X	X	X	X

National Science Education Standards (Grades 5-8)

	How big was Megalodon?	How long did Megalodon live?	What did Megalodon eat?	When did Megalodon live?	Where did Megalodon live?	Who was Megalodon related to?	Why is Megalodon important?	Megalodon on Exhibit!	Megalodon Field Journal
UNIFYING CONCEPTS AND PROCESS									
Systems, order, and organization	X	X		X		X	X	X	X
Evidence, models, and explanation	X	X	X	X	X	X	X	X	X
Change, constancy, and measurement	X	X	X	X	X	X	X	X	X
Evolution and equilibrium	X			X	X	X	X	X	X
Form and function	X	X	X				X	X	X
SCIENCE AS INQUIRY									
Abilities necessary to do scientific inquiry	X	X	X	X	X	X	X	X	X
Understanding about scientific inquiry	X	X	X	X	X	X	X	X	X
PHYSICAL SCIENCE									
Properties and changes of properties in matter		X							
Transfer of energy			X				X		
LIFE SCIENCE									
Structure and function in living systems	X	X	X			X	X	X	X
Reproduction and heredity						X	X	X	X
Regulation and behavior	X	X	X		X	X	X	X	X
Populations and ecosystems			X				X	X	X
Diversity and adaptations of organisms	X	X	X	X	X	X	X	X	X
EARTH AND SPACE SCIENCE									
Structure of the earth system				X	X		X	X	X
Earth's history	X	X	X	X	X	X	X	X	X
SCIENCE AND TECHNOLOGY									
Understanding about science and technology							X	X	X
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES									
Personal health							X	X	X
Populations, resources, and environments							X	X	X
Nature hazards							X	X	X
Risks and benefits							X	X	X
Science and technology in society					X		X	X	X
HISTORY AND NATURE OF SCIENCE									
Science as a human endeavor								X	X
Nature of science	X	X	X	X	X	X	X	X	X
History of science					X		X	X	X

National Science Education Standards (Grades 9-12)

National Science Education Standards (Grades 9-12)	How big was Megalodon?	How long did Megalodon live?	What did Megalodon eat?	When did Megalodon live?	Where did Megalodon live?	Who was Megalodon related to?	Why is Megalodon important?	Megalodon on Exhibit!	Megalodon Field Journal
UNIFYING CONCEPTS AND PROCESS									
Systems, order, and organization	X	X		X		X	X	X	X
Evidence, models, and explanation	X	X	X	X	X	X	X	X	X
Change, constancy, and measurement	X	X	X	X	X	X	X	X	X
Evolution and equilibrium	X			X	X	X	X	X	X
Form and function	X	X	X				X	X	X
SCIENCE AS INQUIRY									
Abilities necessary to do scientific inquiry	X	X	X	X	X	X	X	X	X
Understanding about scientific inquiry	X	X	X	X	X	X	X	X	X
PHYSICAL SCIENCE									
Structure and properties of matter		X						X	X
LIFE SCIENCE									
The cell				X					
Biological evolution	X	X	X	X	X	X	X	X	X
Interdependence of organisms			X			X	X	X	X
Matter, energy, and organization in living systems	X	X	X	X		X	X	X	X
Behavior of organisms	X	X	X		X	X	X	X	X
EARTH AND SPACE SCIENCE									
Energy in the earth system				X	X			X	X
Geochemical cycles				X	X			X	X
Origins and evolution of the earth system	X	X	X	X	X	X	X	X	X
Origins and evolution of the universe				X				X	X
SCIENCE AND TECHNOLOGY									
Understanding about science and technology					X		X	X	X
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES									
Personal and community health							X	X	X
Population growth							X	X	X
Natural resources							X	X	X
Environmental quality							X	X	X
Natural and human-induced hazards							X	X	X
Science and technology in, local, national, and global challenges							X	X	X
HISTORY AND NATURE OF SCIENCE									
Science as a human endeavor								X	X
Nature of scientific knowledge	X	X	X	X	X	X	X	X	X
Historical perspectives					X		X	X	X

Bibliography & Additional Resources

Books

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Carrier, Jeffrey C., Musick, John A., and Heithaus, Michael R. (Editors). 2004. *Biology of Sharks and Their Relatives.* CRC Press: Boca Raton, FL.

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Websites

American Museum of Natural History – Cladistics Website: www.amnh.org/exhibitions/permanent/fossilhalls/cladistics/

Discovery Education's Prehistoric Sharks Website: http://school.discovery.com/schooladventures/prehistoricsharks/

Florida Museum of Natural History Website on the Megalodon Exhibit: www.flmnh.ufl.edu/megalodon/

Florida Museum of Natural History Website – Teacher Resources (Uncovering Florida's Fossil Past Module): www.flmnh.ufl.edu/education/resources.htm

Bibliography & Additional Resources *(continued)*

Guy Harvey Research Institute – Shark Conservation and Ecology Research Website:
www.nova.edu/ocean/ghri/sharkresearch.html

Ichthyology at the Florida Museum of Natural History Website (Including the International Shark Attack File): www.flmnh.ufl.edu/Fish/Sharks/sharks.htm

PBS's Evolution – Teachers & Students Website:
www.pbs.org/wgbh/evolution/educators/index.html

Reef Resilience Website – Regarding Coral Reef Conservation
www.reefresilience.org/

ReefQuest Centre for Shark Research - Biology of Sharks & Rays Website:
www.elasmo-research.org/index.html

Shifting Baselines – A Partnership Between Ocean Conservation and Hollywood Website:
www.shiftingbaselines.org/index.php

The Nature Conservancy's Marine Conservation Website:
www.nature.org/initiatives/marine/

The Paleontology Portal Website
www.paleoportal.org/

Understanding Evolution for Teachers Website
http://evolution.berkeley.edu/evosite/evohome.html

University of California Museum of Paleontology – K-12 Resources:
www.ucmp.berkeley.edu/education/index.php

Useful Vocabulary

allometry: any relationship of anatomical variables that fit an equation. For example, the relationship between shark tooth width and body length.

archaeologists: scientists who study archaeology (the study of past human cultures). Archaeologists study diverse topics pertaining to past human cultures, including the study of: their presence, culture, diet, trade routes, social interactions, occupations, and relationships to their environment.

archaeology: the scientific study of past human cultures (archaeo = ancient, ology = the study of).

avian-dinosaurs: "bird-like" dinosaurs; living and fossil birds are considered to be avian dinosaurs (e.g. ducks, mockingbirds, and penguins are all avian-dinosaurs).

cannibalism: the consumption of your own species (e.g., Megalodon consuming other Megalodon sharks, or *Homo sapiens* consuming other *Homo sapiens*).

carnivore: an organism that consumes meat as its primary diet.

cartilage: an elastic tissue, typically translucent, that forms most of the skeleton of sharks, skates, and rays. Cartilage is ossified (replaced by bone) in shark centra.

cartilaginous: composed of cartilage.

Cenozoic: a geological era that represents the time period from 65 million years ago to the present.

centrum (centra): the backbone (or backbones) of sharks that are analogous to our vertebrae.

cladistics: a method of organizing information according to similarities of features. Cladistics is typically used to understand the relationship of living and extinct organisms.

cladogram: a diagram that shows similarities of features, used to display the results of a cladistics analysis.

climate change: change in the earth's average temperature over time.

community service: individual or group assistance that improves the state of a community. Examples of environmental community service include: environmental clean-ups, recycling, and assisting with public awareness of environmental problems.

ecosystem: a community of interacting organisms and their environment.

Useful Vocabulary *(continued)*

ectothermy (or ectothermic): "cold-blooded," an organism's reliance on its external environment to maintain its body temperature.

elevation: the height of a point on the earth above sea-level.

environmental contaminants: potentially harmful substances that have entered our environment, including our food, water, air or soil.

evolution: change over time. Biological evolution, refers to the change of traits (genetic, morphology) or frequency of traits in organisms over time.

extinction: the termination of existence of a species.

food webs: describe the connections of organisms who depend on each other for energy.

fossil: the mineralized remains of a formerly living organism (e.g., animal bone, plant leaf) or evidence of a living organisms (e.g., trace fossils such as foot prints or skin prints).

fossilization: the process of turning a formerly living organism (e.g., animal bone, plant leaf) or evidence of a living organisms (e.g., trace fossils such as foot prints or skin prints) into stone – resulting in a fossil.

geological time scale: a chronological arrangement of geological events representing major eras of biological and geological activity. The geological time scale accounts for 4.6 billion years of time and is divided into major eras, periods, and epochs.

geologists: scientists who study geology (the study of rocks). Geologists study diverse topics pertaining to the earth, including: the age of the earth, fossils, natural disasters, mineral resources, etc.

geology: the scientific study of rocks (geo = rocks, ology = the study of).

herbivore: an organism that consumes plants as its primary diet.

***Homo sapiens*:** the scientific name (referencing the genus and species) of modern humans.

ichthyologists: scientists who study ichthyology (the study of fish). Ichthyologists study diverse topics pertaining to fish and their environments, including: fish evolution, fish physiology, fish behavior, and marine ecosystems.

Ichthyology: the scientific study of fish (ichthy = fish, ology = the study of)

macroevolution: large scale evolutionary change including the evolution and extinction of species

Megalodon (*Carcharocles megalodon*): an extinct shark that lived ~17-2 million years ago. It is the largest shark that ever lived!

Mesozoic: a geological era that represents the time period from 248 to 65 million years ago.

Miocene: a geological epoch that represents the time period from 24.5 to 5 million years ago

morphology: the shape and structure of an organism

non-avian dinosaurs: dinosaurs that are not birds. Examples include Tyrannosaurus, Stegosaurus, and Triceratops.

ossification (or ossified): is the process of bone formation in which calcium is deposited. Ossified tissue is boney and has undergone ossification.

over-fishing: fishing at unsustainable levels that reduces the stock of fish to levels insufficient to allow for adequate breeding. Over-fishing results in the decline of over-fished populations.

paleontologists: scientists who study paleontology (the study of ancient life). Paleontologists study diverse topics pertaining to ancient organisms and their environments, including the study of: invertebrates (animals without backbones), vertebrates (animals with backbones), plants, their relationships to each other, and their ancient ecosystems.

paleontology: the scientific study of ancient life (paleo = ancient life, ology = the study of).

Paleozoic: a geological era that represents the time period from 570 to 248 million years ago.

Pliocene: a geological epoch that represents the time period from 5 to 1.8 million years ago

pollution: the state of being contaminated by harmful substances as a result of human activity. Pollution occurs due to the presence of toxic substances and/or the presence of large amounts of typically non-toxic nutrients in high amounts – that causes ecosystem imbalance (i.e. ocean nutrification).

Useful Vocabulary (continued)

sea-level rise: a rise in the mean surface of the sea over time. This can occur as a result of global warming that causes both glacial melting and the thermal expansion of the water.

species: living organisms that are classified based on likeness (as defined by morphological or genetic features) and/or the ability to interbreed (biological species definition)

storm drains: drains that collect excess rain water and route them to other areas such as the ocean

sustainability: the ability of an ecosystem to maintain biological diversity, ecological functions, andproductivity over time. When removing natural resources in a sustainable manner, these resources are not depleted or permanently removed over time.

tooth serrations: jagged cutting edges (like sharp triangles) that assist with the cutting of food items.

trophic levels: refers to the hierarchy of a food pyramid that consists of producers at the base, and then herbivores, small carnivores, and top carnivores. The number of trophic levels in a system can vary. Marine ecosystems often have multiple trophic levels (4+) while terrestrial ecosystems typically have no more than 3-4 trophic levels.

Megalodon Educator's Guide Evaluation Form

Name ______________________________

School/Institution ______________________________

City/State ______________ E-mail ______________

Grade Level ______________ Subject(s) ______________

Dates Used ______________ Hours Implemented ______________

1. What components of the Megalodon Educator's Guide did you find useful?

    - Megalodon In-Class Activities
    - Megalodon Field Trip – Field Guides
    - Alignment to National Science Education Standards
    - References and Resources
    - Useful Vocabulary

2. I used the following Megalodon Educator's Guide Activities.
   Please elaborate as to how, below.

    - How big was Megalodon? ______________________________
    - How long did Megalodon live? ______________________________
    - What did Megalodon eat? ______________________________
    - When did Megalodon live? ______________________________
    - Where did Megalodon live? ______________________________
    - Who was Megalodon related to? ______________________________
    - Why is Megalodon important? ______________________________
    - Megalodon on Exhibit! ______________________________
    - Megalodon Field Journals ______________________________

Evaluation Form *(continued)*

3. To what level did the activities engage the students and stimulate their curiosity and desire to learn the subjects discussed?

   Not at all 1 2 3 4 5 Highly

4. Rate the effectiveness of the materials in helping to bring the Megalodon Exhibit and relevant content into your classroom activities.

   Not at all 1 2 3 4 5 Highly

5. What did you like best about the Megalodon Educator's Guide?

6. How would you improve the Megalodon Educator's Guide?

7. Please feel free to comment on any aspect of the Educator's Guide.

