Teaching Guide for: Archaea and the Tree of Life

Speaker: Dipti Nayak
Video link: https://www.ibiology.org/microbiology/archaea/

Major topics

- Microbiology
- Evolution

Overview

Before 1977, all life on Earth was classified into two groups: single-celled microorganisms and complex cellular life such as fungi, plants, and animals. A groundbreaking discovery in 1977 rewrote the tree of life and introduced a whole new domain of organisms known as the archaea - mysterious microbes that are genetically distinct from bacteria. Fast forward to the 21st century, and again new discoveries about archaea are leading scientists to reshape the tree of life and rewrite the evolutionary history of complex organisms. Dr. Dipti Nayak introduces the fascinating organisms known as archaea and explains how they are helping scientists answer the question *Where do we come from?*.

Learning objectives

1. List the similarities and differences between prokaryotic and eukaryotic cells.
2. Identify archaea as a distinct domain of life and name some of their characteristics.
3. Describe how scientists use DNA sequences to understand evolutionary relationships and differentiate between microorganisms.
4. Discuss how scientific theories change as new evidence is collected, with a focus on the tree of life.

Sub topics

1. Prokaryotes and eukaryotes
2. Archaea
3. Phylogenetics
4. Evolution of eukaryotes
5. Process of science

Video chapters

Chapter 1: Introduction - Archaea and the Tree of Life (0:00-1:48)
Learning objective(s) covered: 1
Sub topic(s) covered: 1
Suggested review question: Compare and contrast prokaryotes and eukaryotes.

Chapter 2: A New Branch (1:49-7:38)
Learning objective(s) covered: 2, 3
Sub topic(s) covered: 2, 3
Suggested review question: Describe what information scientists use to differentiate between archaea and bacteria, even though they look very similar under a microscope.

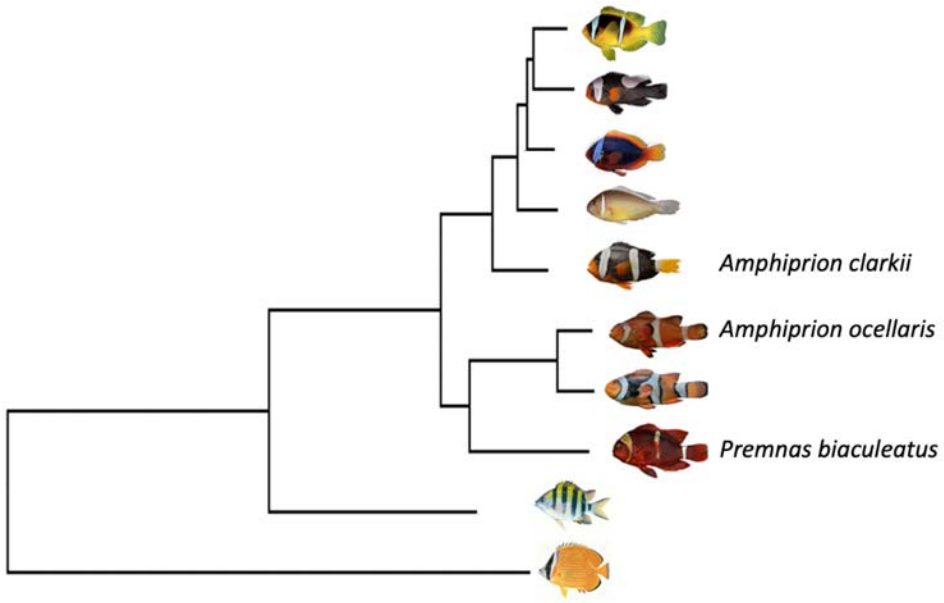
Chapter 3: A New Tree: Asgard-Loki (7:39-12:38)
Learning objective(s) covered: 4
Sub topic(s) covered: 4, 5
Suggested review question: Using a diagram, compare and contrast Woese's 3-domain tree with the 2-domain tree that emerged after the discovery of the Asgard archaea. Describe the evidence scientists used to support each of the trees.

Additional review and extension questions

1. The image below contains DNA sequence information for a protein-coding gene that is common to three different organisms. The sequences have been aligned so that they can be directly compared between organisms.
   a. Based on the DNA sequence information below, do you predict that Organism 1 is more closely related to Organism 2 or Organism 3? Explain your answer.
   b. Draw an evolutionary tree placing Organisms 1, 2 and 3 relative to each other based on your determination. The bottom of the tree should be labeled "shared common ancestor."
   c. What extra information would make you more confident about your answers above?

2. Using a diagram, explain how scientists think the first eukaryotic cell evolved. Be sure to incorporate the three domains of life described in Carl Woese's research in your drawing.
3. a. Using the tree of life as an example, describe how scientific understanding changes as new evidence is collected by scientists.
   b. Scientists develop hypotheses and theories based on what is known as the "best available evidence." Does this mean that when new evidence is collected and theories change, such as going from a 3-domain back to a 2-doman tree, that scientists like Carl Woese were wrong? Explain your answer.
   c. Name and describe another example of our changing understanding of science.

4. Below is a phylogenetic tree of tropical fish. Based on the tree's structure, is the fish *Amphiprion ocellaris* more closely related to *Premnas biaculeatus* or to *Amphiprion clarkii*? Explain. You may number the vertical branches and refer to those numbers in your reasoning.



Adapted from Li et al. PLoS ONE 2015

5. In Chapter 3 "A New Tree: Asgard-Loki," Dipti Nayak describes how scientists found eukaryotic signature proteins (ESPs) in both eukaryotes and in Asgard archaea. This evidence was used to support the new hypothesis that eukaryotes evolved from within archaea, and are in fact close relatives of the Asgards.
   a. Is it possible for two organisms to share similar traits (for example, proteins with similar functions) but be evolutionarily distant from each other? If so, do you know the name of this phenomenon?
   b. In the case of ESPs, how do you predict that scientists confirmed that the ESPs found in the Asgards shared an evolutionary origin with the ESPs known to exist in eukaryotes?
6. Reflect on the role that serendipity can play in the scientific process. For example, how might our understanding of the tree of life have been different if Carl Woese's colleague down the hall happened to study an extremophile bacteria rather than an archaea?

Relevant literature

Woese C and Fox GE. 1977. Phylogenetic structure of the prokaryotic domain: The primary kingdoms. *Proceedings of the National Academy of Sciences* 74(11): 5088-5090.

Woese C, Kandler O, & Wheelis M. 1990. Towards a natural system of organisms: Proposal for the domains Archaea, Bacteria, and Eucarya. *Proceedings of the National Academy of Sciences* 87: 4576-4579.

Spang A et al. 2015. Complex archaea that bridge the gap between prokaryotes and eukaryotes. *Nature* 521(7551): 173-179.

Eme L et al. 2017. Archaea and the origin of eukaryotes. *Nature Reviews Microbiology* 15(12): 711-723.

Related resources

What are prokaryotes? Explainer video from XBio
What are eukaryotes? Explainer video from XBio
What is evolution? Explainer video from XBio
What are genes? Explainer video from XBio
Membrane organelles. Multimedia narrative from XBio
Creating phylogenetic trees from DNA sequences. Student activity from HHMI BioInteractive.

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