

Evolutionary Trees I

AN INTRODUCTION

"An overwhelming body of evidence supports the conclusion that every organism alive today and all those who have ever lived are members of a shared heritage that extends back to the origin of life some 3.8 billion years ago."

This is an overview lesson that provides children with a simple introduction to the structure of the 'Tree of Life' and the early evolution of species. A few things to know about evolutionary trees:

1. The terms evolutionary tree, branching diagram and phylogeny are all used for a family tree of life. We do not distinguish between these terms in this album, but rather use them interchangeably.
2. The charts of the Tree of Life represent the whole of Life's evolutionary history, and are necessarily an abbreviation.
3. The Tree of Life diagrams the evolution of living (extant) species. There were many other species that lived and died, but are not included because they have no extant relative.
4. In the Tree of Life, there is no build-up to a more advanced species. The "Great Chain of Being" concept is obsolete. Humans are a branch on the tree of life, *not the point of it*. All species that are currently living have the same amount of evolutionary history behind them.
5. The branches of the diagrams may be rotated to the left or right or up or down. There is no absolute order in which to place the extant species. For our purposes, we use the order and organization as given in Dr. Spears' Tree of Life.
6. The Tree of Life is a work in progress: *"...it is impossible to know with certainty that any given phylogeny is historically accurate. As a result, any reconstructed phylogenetic tree is a hypothesis about relationships and patterns of branching and this is subject to further testing and revisions with the analysis of additional data. Fully resolved and uncontroversial phylogenies are rare, and as such, the generation, testing, and updating of phylogenetic hypotheses remain an active and sometimes hotly debated area of research"* (Gregory, 2008).

Basic construction of an evolutionary tree:

1. Root: The tree begins at a root.
2. Branches: A line drawn connecting related species; branches diverge at a node, a time of genetic alteration
3. Nodes: A point where branches diverge; a common ancestor for diverging branches
4. Terminal Nodes: Extant species make up the tips, or ends, of the branches
5. Clade: If you can snip a single 'branch' of an evolutionary tree, all the subsequent branches that are connected to that branch make up the clade; biologically, the clade is one ancestor and all of its descendants
6. The pattern and relationships are determined by how closely the species are related. Organisms that share a recent ancestor are more closely related than those who share an older or more distant ancestor.

REFERENCE:

Gregory, Ryan T (2008, February, 12). *Understanding evolutionary trees*. Retrieved from Evolution Education and Outreach, February 2011.

BUILDING A TREE OF LIFE—BASIC VERSION

PRIOR KNOWLEDGE: Timeline of Life

Alternate presentation: Building the Tree of Life

MATERIAL: Colored markers (brown, green, blue-green, yellow), large paper to draw on (could also use watercolors on watercolor paper), Clock of Eras

1. Invite the children to a lesson.
2. Scientists try to understand where life came from, how life evolved, and how all the living things today are related to one another.
3. Draw the trunk of a tree with jagged lines indicating roots in the ground.
4. At the very beginning of our diagram, we find the earliest forms of life. Scientist believe that life evolved from an ancient common ancestor. They call that ancestor L.U.C.A: Life's Universal Common Ancestor.
5. Draw a smooth little circle with squiggly lines inside. The circle represents the cell membrane that encloses the cell. The squiggly lines represent free-floating DNA strands that contained all the information for how to make that cell. First life was made up of single cells like this, called *Prokaryotes*.
6. Some prokaryotes may have evolved in the warm water near volcanic ocean vents. However, these earliest origin stories are still a mystery.
7. One group of cells, the **Archaea**, had many species that survived and thrived in many different environments, some of them very extreme (draw and write on chart, branching off to the lower right). Today many, many Archaea organisms exists.
 - a. Some love high heat: Hyperthermophiles (a hot ocean vent)
 - b. Some love salty areas: Halophiles (a pink square for the 'little salt box)
 - c. Some live in our guts and even in the rumens of cows: Methanogens (cow)
8. Another group of prokaryotic cells, the **Bacteria**, they perform the same tasks, but differently than Archaea.
 - a. One little bacterium found the key to capturing energy from the sun, our ultimate energy source, and making it available for life on Earth (blue green circle).
 - b. This group are the cyanobacteria.

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- c. It captured energy from the sun through the process of photosynthesis (yellow 'blaze). They then released oxygen as a waste product into the atmosphere (cloud with O₂ molecule).
 - i. Cyanobacteria came to live in colonies with other organisms called stromatolites.
9. In time a third type of cell developed, though scientists still don't know how. What they do know is that some point cells developed a membrane that contained their DNA. These cells seem to share certain characteristics of both Archaea and Bacteria, but had additional and unique features that were not found in either of those cells. (Extend the trunk of the tree vertically above the branching of the Bacteria and Archaea. Draw and label the eukaryotic cell in the center of the trunk.)
 - a. Eukaryotes were cells that could eat!
 - b. All of us evolved from these early eukaryotic cells, as well as almost all of the visible life on Earth.
10. The three Domains of the Tree of Life are: **Bacteria**, **Archaea** and **Eukarya**
These represent all the living organisms on the Earth.
11. Some of the eukaryotic cells didn't bother making their own food; with their new ability to engulf their dinner, they simply ate other cells. It was a very profitable enterprise.
 - a. One day a very hungry eukaryotic cell engulfed a bacterial cell.
 - b. This had probably happened millions of times before to other delicious looking bacterial cells.
 - c. But this time, something very, very unusual happened. Instead of digesting the bacterium and using *it* for energy, the eukaryote didn't digest the bacterium at all.
 - d. Instead, the bacterial cell was put to work. The eukaryote used the energy that the bacterium extracted to *fuel itself*.
 - e. It happened that this particular bacterial cell was extremely good at extracting energy from food. It used all that free oxygen in the atmosphere to do it. (Draw a dashed line with mitochondria in yellow showing it being engulfed by the eukaryotic cell in the center of the tree.)
 - f. In time this special bacterial cell became the mitochondria in our own cells. Mitochondria are the powerhouses of the cell.
12. If this hadn't happened we would not be alive, and neither would any other multi-cellular life.

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13. Life continued to experiment and many different lineages of eukaryotic cells developed.
14. Unikonts: In time one of the lineages that developed was comprised of cells with a single flagellum, called unikonts (*uni* for one, *kont* from the Greek: paddle).
15. From these unikonts single celled organisms like amoebas and slime molds evolved.
16. One branch of the unikont eukaryotes became the FUNGI (draw a branch to the right of the tree and write 'Fungi').
 - a. Fungi are considered a true kingdom.
17. Other organisms that evolved from unikonts were the ANIMALS (draw a branch that goes beyond fungi to the right and label it 'animals').
 - a. Animals are considered a true kingdom.
18. The unikonts were not the only branch of eukaryotes, for there were many other branches.
19. Bikonts: On the left of the great tree were a branch of organisms that tended to have two or more flagella, which were found on the front of their cells, rather than on the back. These are called bikonts (*bi* for two and *kont* from the Greek: paddle).
 - a. One day a very hungry eukaryote engulfed a bacterial cell.
 - b. This had probably happened millions of times before to other delicious looking bacterial cells.
 - c. But this time, something very, very unusual happened. Something even more rare than our earlier event with the mitochondria.
 - d. Instead of digesting the bacterium and using *it* for energy, the eukaryote didn't digest the bacterium at all.
 - e. Instead, the bacterial cell was put to work. The eukaryote used the bacterium as its very own food factory.
 - f. It happened that this particular bacterial cell was a cyanobacterium. Cyanobacteria could photosynthesize, or use the sun's energy to put together their food.
 - g. In time this special bacterial cell became the chloroplast in all algae and plants.
 - h. It is from these cells that the PLANT kingdom evolved. (Draw a large branch to the left of the tree and write: plant kingdom.)
20. Now, you might notice that there is something missing in my tree (center spot is empty). There are no other true kingdoms, but there is a 'kingdom of

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convenience' here. We call these the "Protists" (Make branches between plants and amoeba).

- a. We already have some protists labeled on our tree:
 - i. Amoeba, slime molds
 - a. Other examples of protists are:
 - i. Paramecium: The slipper-shaped *ciliate* that moves with little hair-like structures (cilia) (in the middle)
 - ii. Green algae: ancestors to the modern plants (on the far left)
 - iii. Giant sea kelp: There are some multicellular protists, such as the giant sea kelp, an algae.
21. Review the Tree that has been created and notice the following:
- a. The three domains: **Archaea**, **Bacteria** and **Eukarya**. These classify all life.
 - b. The three true kingdoms: FUNGI, ANIMAL, and PLANT.
 - c. The Protists, which are not a true kingdom *because they do not include all the descendants of a common ancestor*. Protists include some, but not all, of the eukaryotic cells descendants.
22. In Tree of Life all living organisms have a family and a home.

BUILDING A TREE OF LIFE—ADVANCED LEVEL

PRIOR KNOWLEDGE: Timeline of Life

Presentation I: Building the Tree of Life

MATERIAL: Colored markers (brown, green, blue-green, yellow), large paper to draw on (could also use watercolors on watercolor paper), Clock of Eras

1. Invite the children to a lesson.
2. Scientists try to understand where life came from, how life evolved, and how all the living things today are related to one another.
3. In order to imagine how this great family of humans and dogs and giraffes and whales and cacti and bacteria and oak trees and squirrels and a mushroom came to be, they use a particular image to help it make sense. I am going to share that image with you today and talk about how life may have evolved from the first, tiny living things, to all the life around us today.
4. Draw the trunk of a tree with jagged lines indicating roots in the ground.
 - a. These jagged lines show that scientists are not sure how life evolved at first. It probably started and stopped many times before the first life forms survived that were to be our ancestors. Life went through many experiments before the combination for life as we know it was reached.
5. At the very beginning of our diagram, we find the earliest forms of life. Scientist believe that life evolved from an ancient common ancestor. They call that ancestor L.U.C.A: Life's Universal Common Ancestor.
 - a. It is possible that LUCA was not one single organism, but for our purposes we use it to symbolize the first living cells that emerged around 3.8 billion years ago.
6. Draw a smooth little circle with squiggly lines inside. The circle represents the cell membrane that encloses the cell. The squiggly lines represent free-floating DNA strands that contained all the information for how to make that cell.
 - a. First life was made up of single cells like this, called *Prokaryotes*. (Prokaryotes is a level of cell organization, not a taxonomic unit.)
 - b. These cells were able to reproduce by just splitting in half. One copy of the DNA went to one cell, one copy to the other.
 - c. Though we don't often see them, prokaryotes today are the most numerous of all cells on Earth. They have adapted to live in almost

every environment, and they are essential to the operations of *all* ecosystems.

7. These simple cells living in the oceans of early Earth began to change and evolve. Life was experimenting, as usual! The cells moved to new environments. Some survived and thrived in their new habitat. Others died out.
8. Some of the earliest life may have evolved in the warm water near volcanic ocean vents. However, these earliest origin stories are mysteries that remain to be solved, or they may be mysteries that we never solve.
 - a. We have so little evidence to go on, and science needs to be based on evidence. In some cases we can only speculate as to how this earliest story unfolded 3.8 billion years ago.
9. One group of cells, the **Archaea**, had many species that survived and thrived in many different environments, some of them very extreme (draw and write on chart, branching off to the lower right). Today many, many Archaea organisms exist.
 - d. Hyperthermophiles: Some modern Archaea live on the ocean floors, by volcanic vents that put out plumes of superheated minerals. They use the sulfur minerals as food. They are called hyperthermophiles (*lovers of high heat*).
 - e. Halophiles: These Archaea live in very salty environments. They are the halophiles, or *salt-lovers*. They form some very interesting shapes, and one, known as the 'little salt box,' has some very unusual square cells.
 - i. You can see their pinky-red color in the salt drying ponds in the east part of the San Francisco Bay where evaporation makes the water extra salty.
 - f. Methanogens: These Archaea live in methane-rich environments. In fact, you have methanogens living inside of you, in your gut and your gums. They also live in the rumens of cows, and when they belch, they release methane gas into the atmosphere. Methane gas is a greenhouse gas.
 - a. Humans use methanogens to break down contaminants in our sewage treatment plants.
10. Other facts:
 - a. Enzymes from some modern Archaea are being used by scientists to copy DNA strands for sequencing.

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- b. Archaea are found in the soils and oceans of the world. There are no known pathogenic (disease producing) Archaea.
11. Another group of prokaryotic cells, the **Bacteria**, has basic components that function in different ways than those of Archaea. Just like two computers, one a Mac and the other a PC, that perform similar basic functions but in a different way than Archaea (draw and write on chart, branching off to the lower left).
- d. There are many different kinds of bacterial cells.
 - e. Extant bacteria make up 90% of all modern prokaryotes.
 - f. Life is highly ordered and highly ordered systems need a source of energy. One little bacterium found the key to capturing energy from the sun, our ultimate energy source, and making it available for life on Earth.
 - g. These early cells lived in the warm primordial oceans of the Archaean Eon.
 - h. The atmosphere at that time was made up of mostly nitrogen, carbon dioxide and water vapor. Very little free oxygen was available.
 - i. One cell in particular captured energy from the sun and released oxygen as a waste product into the atmosphere through the process of photosynthesis. This group are the cyanobacteria.
 - j. Around 3.5 billion years ago, many cyanobacteria and other microorganisms began to live together in colonies called stromatolites. Stromatolite fossils tell us that they were common in the ancient world.
 - i. They still exist in a few sheltered environments today.
 - b. Bacteria are the only domain that developed photosynthesis. Subsequent photosynthesizers *borrowed* it.
12. In time a third type of cell developed, though scientists still don't know how. What they do know is that some point cells developed a membrane that contained their DNA. These cells seem to share certain characteristics of both Archaea and Bacteria, but had additional and unique features that were not found in either of those cells.
13. The evolutionary beginnings of the eukaryotic cell remains one of the great mysteries of science. Eukaryotic cells were very different from prokaryotes. (Extend the trunk of the tree vertically above the branching of the Bacteria and Archaea. Draw and label the eukaryotic cell in the center of the trunk.)

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- a. Eukaryotes had a complex internal structure and the ability to engulf particles. They were cells that could eat!
 - b. They may have been unusual and strange, but they were very successful. All of us evolved from these early eukaryotic cells, as well as almost all of the visible life on Earth.
14. The three Domains of the Tree of Life are: **Bacteria, Archaea and Eukarya**
These represent all the living organisms on the Earth. But evolution didn't stop there! All living things have been evolving throughout all of the Earth's history. The eukaryotes were no exception.
15. Some of the eukaryotic cells didn't bother making their own food; with their new ability to engulf their dinner, they simply ate other cells. It was a very profitable enterprise.
- g. One day it happened that one of these very hungry eukaryotic cells engulfed a bacterial cell.
 - h. This had probably happened millions of times before to other delicious looking bacterial cells.
 - i. It happened that this particular bacterial cell was extremely good at using oxygen to extract the stored energy from its food. It could extract more than 15 times as much energy from food as other cells! (Draw a dashed line with mitochondria in yellow showing it being engulfed by the eukaryotic cell in the center of the tree.)
 - j. But this time, something very, very unusual happened. Instead of digesting the bacterium and using *it* for energy, the eukaryote didn't digest the bacterium at all. Instead, the bacterial cell was put to work. The eukaryote used the energy that the bacterium extracted to *fuel itself*.
 - k. In time this special bacterial cell became the mitochondria in our own cells. Mitochondria are the powerhouses of the cell.
16. If this hadn't happened we would not be alive, and neither would any other multi-cellular life.
- l. This kind of engulfment that leads to a symbiotic relationship is called 'endosymbiosis.' There will be one more very important endosymbiosis on our Tree of Life.
 - m. The mitochondria were now working for the eukaryotic cells, and this gave them a huge advantage. Why?

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17. Hundreds of thousands of years have passed and the cyanobacteria have continued to dump their waste product, oxygen, into the atmosphere. This made more and more oxygen available to be used.
 - a. The new mitochondria-powered eukaryotic cells were not above using another species' waste product to improve themselves, and so they continued to evolve and thrive.
18. Life continued to experiment and many different lineages of eukaryotic cells developed. Starting early in the Proterozoic, eukaryotes had a long time to explore all the different ways of being.
19. In time one of the lineages that developed was comprised of cells with a single flagellum, called unikonts (*uni* for one, *kont* from the Greek: oar of a boat).
20. From these unikonts amoebas and slime molds evolved.
 - a. Amoebas move through the use of their 'pseudopod,' or fake foot. The pseudopod pushes forward like a finger, then the rest of the body of the amoeba flows forward to follow it.
21. One branch of the unikont eukaryotes became the FUNGI (draw a branch to the right of the tree and write 'Fungi').
 - b. Fungi are considered a true kingdom.
 - c. Some fungi are single-celled and some are multicellular. Fungi, the great decomposers, still exist today. If it wasn't for them we would be living in the waste products of all the life that came before. Actually, we just wouldn't be here at all. Fungi are vital nutrient cyclers in every ecosystem.
22. Other organisms that evolved from unikonts were the ANIMALS (draw a branch that goes beyond fungi to the right and label it 'animals').
 - b. Animals are considered a true kingdom.
 - c. Animals are the most mobile of all the kingdoms, movers with lots of nerve and some great muscles.
23. The unikonts were not the only branch of eukaryotes, for there were many other branches.
24. Next I am going to talk about another branch of the tree, where a little snack turned into a tremendous benefit (draw a eukaryotic cell to the left of the main tree trunk).
25. On the left of the great tree were a branch of organisms that tended to have two or more flagella, which were found on the front of their cells, rather than

on the back. These are called bikonts (*bi* for two and *kont* from the Greek: oar of a boat).

- a. One day it happened that one of these very hungry bikont eukaryotes engulfed a bacterial cell.
 - b. This had probably happened millions of times before to other delicious looking cyanobacteria.
 - c. It happened that this particular bacterial cell was a cyanobacterium. Perhaps you recall what was special about these cells. They could photosynthesize-use the sun's energy to put together their food.
 - d. But this time, something very, very unusual happened. Something even more rare than our earlier event with the now mitochondria.
 - e. You see, instead of digesting the cyanobacteria and using it for energy, the eukaryotic cell didn't digest the bacterium. Instead, it was put to work for the cell.
 - f. The eukaryotic cell used cyanobacteria as its own food factory and this special bacterial cell became the chloroplast in all algae and plants.
 - g. This branch of life became the red and green algae. It is from these green algal organisms that the PLANT kingdom evolved. (Draw a large branch to the left of the tree and write: plant kingdom.)
26. Now, you might notice that there is something missing in my tree (center spot is empty). Some Eukaryotic cells diversified but remained relatively mostly unicellular.
27. We call these the "Protists" (Make branches between plants and amoeba). Most protists remained single-celled.
- a. Though there are many forms of protists that still exist today, protists are not considered a true kingdom. These are the leftovers of life's experiments with eukaryotic cells, they are very diverse and have many unusual ways of living.
 - b. Protists don't all descend from one common ancestor. You will notice that some evolved from unikonts, others from bikonts. They all descended from eukaryotes, however, eukaryotes are also the common ancestors for the three true kingdoms: Fungi, Animal, and Plant. Protists common ancestor is also the common ancestor of the three true kingdoms.
28. Because protists keep slithering out of their classification boxes they are not considered a true kingdom. They are a "kingdom of convenience."
- b. We already have some protists labeled on our tree:

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- i. Amoeba
 - ii. Red algae
 - iii. Green algae
 - a. Other examples of protists are:
 - i. Paramecium: The slipper-shaped *ciliate* that moves with little hair-like structures (cilia).
 - ii. Diatoms: Beautiful little microscopic organisms with a lacy glass shell, shaped as triangles, rods and even stars.
 - iii. Giant sea kelp: There are some multicellular protists, such as the giant sea kelp, an algae.
29. It is not easy to become multicellular. The only categories of multicellular life are the animals, plants, brown and red algae.
 - a. Every other organism on our tree is single-celled!
30. Review the Tree that has been created and notice the following:
 - a. The three domains: **Archaea**, **Bacteria** and **Eukarya**. These classify all life.
 - b. The three true kingdoms: FUNGI, ANIMAL, and PLANT.
 - c. The Protists, which are not a true kingdom *because they do not include all the descendants of a common ancestor*. Protists include some, but not all, of the eukaryotic cells descendants.
31. In Tree of Life all living organisms have a history and a home.

FOLLOW-UP:

1. Recreate the Tree of Life in their notebooks, or on watercolor paper; draw pictures and label the parts.
2. Create stories to describe what happened when the mitochondria or cyanobacteria were engulfed by the eukaryotic cell.
3. Imagine you are 'Life.' Tell the story of how you became so diverse.
4. Create a cartoon that shows the general evolution of Life as shown in this lesson.
5. Create a felt Tree of Life. Children can lay out and label the parts.

CONTROL OF ERROR: Teacher created Tree of Life, Tree of Life chart

POINTS OF INTEREST: Drawing the Tree of Life, colors, pictures, stories

DIRECT AIM: To explain the sequence of evolution using the Tree of Life; to create a visual representation to explain the origins of Life

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INDIRECT AIM: To provide an overview of the Tree of Life and its basic organization, to cultivate appreciation for the microorganisms that made life possible, exposure to the concept of symbiosis, to learn that, in a healthy ecological system, waste for one species is food for the next

AGE: 9-12 years

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