How do small things make a big difference?

Microbes, ecology, and the tree of life

Lesson 2: What is the current tree of life model?

I. Overview

In this lesson, students take an in-depth look at the current molecular three-domain tree of life, a recent and significant scientific development. First, to model how molecular evidence is used to formulate a tree of life, students examine similarities and differences between simulated DNA sequences of a diverse set of organisms to determine relatedness. Students then engage in an important conversation about the use of the term "prokaryote" and how it can be problematic in light of Woese's discovery of archaea and the new tree of life model. Finally, students read a news article about Carl Woese's discovery of archaea and discuss different aspects of the nature of science illustrated by the story. Through these activities, the following nature of science concepts are addressed: new technologies advance scientific knowledge and science is subject to changes based on new evidence and/or reinterpretation of existing evidence.

Connections to the driving question

This lesson provides students with necessary background for a unit about microbes by first placing microbes within the context of all living organisms—within the tree of life. Woese's discovery of archaea and the new three domain tree of life led to an explosion of research in the field of microbiology. Since that time scientists have made significant advances in better understanding the roles and diversity of microbes and discovering and classifying numerous new species.

Connections to previous lessons

This lesson continues the story of the tree of life timeline by covering different aspects of the current tree of life model. The activity for analyzing simulated DNA sequences is a simple illustration of how molecular evidence is used to determine relatedness. The discussion about the term "prokaryote" gives students an opportunity to use information from the previous lesson and this lesson to develop an argument based in evidence. Finally, the reading about Woese's discovery that led to the model gives students a closer look at the nature of science concepts that came into play in this particular revision of the model as well as what the new model meant for the field of microbiology.

II. Standards

National Science Education Standards

- The millions of different species of plants, animals, and microorganisms that live on earth today are related by descent from common ancestors. (Grades 9-12 Biological evolution 3.4)
- Biological classifications are based on how organisms are related. Organisms are classified into hierarchy of groups and subgroups based on similarities which reflect their evolutionary relationships. Species is the most fundamental unit of classification. (Grades 9-12 Biological evolution 3.5)
- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used. (Grades 9-12 Understandings about scientific inquiry 2.3)

Benchmarks for Science Literacy

The Nature of Science: The Scientific Worldview

- In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to a better understanding of how things work in the world but not to absolute truth. (1A/H3bc*)

The Nature of Science: Scientific Inquiry

- In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. (1B/H6a)

The Living Environment: The Diversity of Life

- The degree of relatedness between organisms or species can be estimated from the similarity of their DNA sequences, which often closely match their classification based on anatomical similarities. (5A/H2*)
- A classification system is a framework created by scientists for describing the vast diversity of organisms, indicating the degree of relatedness between organisms, and framing research questions. (5A/H5** (SFAA))

The Living Environment: The Evolution of Life

- Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another. (5F/H2)

III. Learning Objectives

Learning objective	Assessment Criteria	Location in Lesson
Draw and label an accurate sketch of the current molecular tree of life indicating the three domains and their evolutionary relationships	Student representations should illustrate the following information: • There are three domains in the current tree of life: bacteria, archaea, and eukarya. • All three domains branch off separately form the origin with archaea and eukarya more closely related to each other (have a more recent common ancestor) than they are to bacteria.	Throughout
Explain the major concepts of molecular methods and how they work.	Students are able to explain: • Molecular methods involve comparing organisms' genetic code (e.g. DNA sequences). • DNA sequences are compared to see how much of the genetic sequence is common between organisms. • The more DNA sequence organisms share, the more closely related they are.	Activities 1 & 3
Construct an argument regarding the use of the term "prokaryote" and its implications.	Students' arguments address: • Prokaryote was a term used in older models of the tree of life and the distinction no longer applies in the current tree of life. • The term suggests that bacteria and archaea are the most closely related since they are both prokaryotes by the "no nucleus" definition. • Prokaryote is misleading in that it implies that eukaryotes evolved from prokaryotes.	Activity 2
Explain how Woese's discovery affected the scientific community	Students' explanations include: • The scientific community had mixed responses to the discovery. • More people agreed to the new model as more evidence in support of it accumulated. • Woese's discovery and the new model led to a boom in microbiology research.	Activity 3

IV. Adaptations/Accommodations

For this lesson, students will also do an activity of DNA comparisons which has a strong puzzle-solving element to it. Students may require different levels of support which can be done by adjusting the balance between how much additional information ("hints") the students are given and how much of the puzzle solving process they will need to figure out on their own. They are also required to read an article from the New York Times. This reading can be modified to accommodate readers of different levels by decreasing its length and/or simplifying the language.

Safety

There are no additional safety concerns associated with this lesson.

V. Timeframe for lesson

Opening of Lesson

- 5 minutes

Main Part of Lesson

- Activity 1: 40 minutes
- Activity 2: 15 minutes
- Activity 3: 25 minutes

Conclusion of Lesson

- 5-10 minutes

VI. Advance prep and materials

Activity 1: Comparing DNA sequences

Materials:

- Cards: Organism Sequences *(U9_L2_Cards_ OrganismSequences)*
- Three-Domain Tree Map *(U9_L2_ThreeDomainTreeMap)*
- Three-Domain Tree Map Answer Key *(U9_L2_ThreeDomainTreeMap_ANSWERS)*
- Legal size laminate sheets
- Letter size laminate sheets
- Stick on Velcro strips or circles (optional)
- Student sheet: The changing tree of life model: The current model (*U9_L2_StudentSheet_TheCurrentTreeOfLifeModel).*
    - 1 copy per group or individual student
- 1990-A and 1990-B envelopes (from Lesson 1)
    - 1 set per group

Preparation:

- Print and laminate the Organism Sequence Strips – 1 copy per every 2-3 students
- Cut out the organisms sequence strips as indicated by the dashed lines. One copy of the file is one set of strips.
- Print and laminate the Three-Domain Tree Map on legal size paper (be certain to select "Actual size" in the print options) – make 1 per every 2-3 students
- Place Velcro on the ends of the branches on the three-domain tree map. On the ends of the organism sequence strips, place the complimentary side of the Velcro. (The advantage of the Velcro is to let student keep track of their work and easily move it around but also to be able to revise their model by moving the strip. However, the activity can also be done without the use of Velcro.)
- Print one or several copies of the Three-Domain Tree Map Answer Key. This can be used only as reference by the teacher or students can be given the key to compare their responses.
- Make copies of the student sheet:" The current tree of life model"
- Have the "1990-A" and "1990-B" envelopes prepared in the previous lesson ready to hand out to students.

Activity 2: To use or not to use "prokaryote"?

Materials:

- Images in file *U9_L2_Images*

Preparation:

- Prepare to project the images for all students to see.

Activity 3: Carl Woese's discovery

Materials:

- "Carl Woese's Discovery" (*U9_L2_Reading_CarlWoese'sDiscovery*)

Preparation:

- Make one copy per student

VII. Resources and references

Teacher resources

- Baumgartner, L.K. & Pace, N.R. (October 2007). Current taxonomy in classroom instruction: How to teach the new understanding of higher-level taxonomy. *The Science Teacher*. 46-51.
- Blakeslee, S. (October 1996). Microbial Life's Steadfast Champion. *New York Times.* Retrieved from: http://www.nytimes.com/1996/10/15/science/microbial-life-s-steadfast-champion.html?pagewanted=all&src=pm

- Goldsmith, D.W. (November/December 2003). The great clade race – Presenting cladistics thinking to biology majors & general science students. *American Biology Teacher.* 679-682.
- Yardley, W. (December 2012). Carl Woese Dies at 84; Discovered life's 'Third Domain'. *New York Times.* Retrieved from: http://www.nytimes.com/2013/01/01/science/carl-woese-dies-discovered-lifes-third-domain.html
- The Institute for Genomic Biology. Hidden before our eyes: Archaea & evolution. *University of Illinois Urbana-Champaign.* Video lectures retrieved from: http://archaea.igb.illinois.edu/index.php

References

- Baumgartner, L.K. & Pace, N.R. (October 2007). Current taxonomy in classroom instruction: How to teach the new understanding of higher-level taxonomy. *The Science Teacher*. 46-51.
- Blakeslee, S. (October 1996). Microbial Life's Steadfast Champion. *New York Times.* Retrieved from: http://www.nytimes.com/1996/10/15/science/microbial-life-s-steadfast-champion.html?pagewanted=all&src=pm
- Goldsmith, D.W. (November/December 2003). The great clade race – Presenting cladistics thinking to biology majors & general science students. *American Biology Teacher.* 679-682.
- Pace, N.R. (May 1997). A molecular view of microbial diversity and the biosphere. *Science.* 276(5313), 734-740.
- Yardley, W. (December 2012). Carl Woese Dies at 84; Discovered life's 'Third Domain'. *New York Times.* Retrieved from: http://www.nytimes.com/2013/01/01/science/carl-woese-dies-discovered-lifes-third-domain.html

VIII. Lesson Implementation

Opening of Lesson

Begin the lesson by reviewing the timeline of the tree of life that students put together in the previous lesson. Ask them questions such as:

- What were the different models of the tree of life that we've looked at so far?
- What happened at each stage that required revision of the model?
- What was the last model we looked at?

Once students have reviewed the tree of life timeline that they have learned so far, draw their attention to the criteria that was used to group organisms at each stage. Ask students:

- Throughout the historical timeline they have been exploring, what kinds of information have scientists used to group organisms? Student responses may include: what they look like, where they live, what they eat etc.

To get students thinking about the next activity and the next tree of life model, ask them:

- Can you think of any new discoveries or technology we have now that might have changed the tree of life model after Whittaker?
- Can you predict how these new discoveries or technology might change the tree of life model? What do you think the current model looks like?

Main Part of Lesson

Optional activity to introduce evolutionary relationships: The Great Clade Race

In Activity 1 of this lesson, students compare simulated DNA sequences to determine evolutionary relationships between organisms. If students need more background on how DNA can be used to determine evolutionary relationships, The Great Clade Race activity can be done with students before they begin Activity 1. The Great Clade Race activity, published in the *American Biology Teacher* (Goldsmith, 2003), introduces students to evolutionary relationships and cladistic thinking. In this activity, groups of students imagine a race through the woods. The runners in the race share the same starting point but they can take different paths through the woods as they reach different forks along a path. Along each path, runners will pass different stations where they will have their running card stamped (each station has a distinct symbol).

To complete this activity, students must figure out the path each runner has taken by looking at the symbols on each runner's stamped card. Students then draw the paths of each runner on a large piece of paper creating, in essence, a cladogram. The activity leads to a class discussion on evolutionary relationships as students can observe that runners that have more symbols in common followed similar paths (have a shared history) compared to runners that had very different symbols.

Activity 1: Comparing DNA sequences

In this activity, students explore some of the concepts behind how molecular methods are used to create phylogenetic trees. The activity is made up of two parts. Students begin by looking at 3 real DNA sequences and then they go on to compare generated sequences of a number of organisms to figure out their branching order on the three-domain tree of life model.

Teacher Pedagogical Content Knowledge

In this activity, students first look at a set of real sequences of three organisms to recognize the complexity of the task of comparing real DNA. They then work with the simplified simulation in order to experience the underlying concepts and puzzle-solving and pattern-finding nature of the process of comparing DNA sequences to determine relatedness. Real DNA sequences are often very long and have gaps or other complexities making them difficult to compare to determine relatedness. When researchers work on phylogenetics, they use sophisticated algorithms and technology to deal with the complexities of comparing DNA sequences. Therefore, the DNA sequences used in this activity are not real but are rather generated based on the known phylogenetic tree of the organisms when comparing 16SrRNA DNA sequences. Comparison of these generated sequences will still produce an accurate representation of the relatedness of these organisms while being simple enough for students to compare visually. The sequences also include a bolded line every 5 nucleotides to make visual scanning and tracking along the sequence easier.

As students compare the simulated DNA sequences, it will be important to discuss with the students the importance of pattern matching and what the genome pattern represents. Also discuss how to go about figuring out the "puzzle" of determining relatedness through DNA sequences. For example, all organisms on the same branch should share the same pattern in a portion of their DNA.

Begin by handing out envelope 1990-A, or by simply projecting the following 1990-A prompt for the whole class to see:

> *In the 1970s, advances in science and technology allowed scientists to examine genetic information found in DNA or RNA to determine the relationships between species. Using the reasoning that groups of organisms with a lot of genetic information in common are more closely related to each other than others that have less in common, scientists began to reorganize the tree of life…*
>
> *Using the simulated DNA sequences determine how the organisms are related. Observe how this new information influences the tree of life model.*

Explain to students that they will work with a new set of cards that includes a subset of the organisms they have been working with thus far. However, this time, they will have molecular information about each organism.

A brief activity to address the question: What makes molecular evidence stronger evidence than other types of comparisons (i.e. morphology/physical traits, habitat, diet etc.) for determining relatedness between organisms?

Have students do the following simple activity to demonstrate how “muddy” analysis of morphological data can be. On the board, write the following list of animals: pigeon, bat, bear, whale, and tuna. Ask students to work in their groups to sketch a simple phylogenetic tree to show how they think these animals are related using any criteria but molecular data (as scientists would have done before molecular methods became available). They should be able to explain why they arrange the animals the way they do. Once students have drawn their trees ask different groups to share out their arrangements and reasoning. Different groups will likely have come up with different arrangements. Explain to students that their different arrangements is similar to what happens in the scientific community—different scientists or labs arrive at different conclusions based on what traits they choose to measure.

Note: To ensure that students come up with different trees in this activity, each group can be directed to only focus on one specific characteristic such as the presence of wings or fins, the presence of hair, reproductive process (laying eggs vs. live birth) etc.

In light of this example of using morphological data, have students think about how molecular methods and data can be more reliable and compelling evidence for determining relatedness between organisms. What about in the case of microbes (many of them look very similar)? Some of the reasons that molecular data outweighs other determinants of evolutionary relationships are the following:

- Comparisons of morphology can be messy and insufficient evidence of relatedness for the following reasons:
  - Different trees can result when different traits or combinations of traits are compared.
  - Comparisons of physical traits, habitat, diet etc. don’t paint the whole picture (or paint conflicting pictures) of how two organisms evolved or are related.
  - Some animals can look very similar, such as a whale and a shark, but not actually be closely related (as in the case of convergent evolution).
  - Some traits can arise several times independently of each other, so two organisms with the same traits do not necessarily have a more recent comment ancestor.

- Molecular data is valuable in that
  - DNA/RNA contains the code to the organisms’ evolutionary histories.
  - DNA/RNA comparisons provide more objective data and therefore, determining relatedness among organisms can be a more experimentally grounded process (though even this can sometimes yield different phylogenetic trees for the same organisms).

- Even when organisms look very similar and distinctions are difficult to make, as in the case of microbes, molecular data allows for comparisons between organisms as well as identification of new species.

To begin discussing molecular data, hand out the "Real DNA Sequences – 16SrRNA" student sheet. (This sheet can also be simply projected in front of the class if all students are able to see.) Have students work together to figure out what information is provided to them in this DNA sequence comparison. Ask questions such as:

- How do scientists use this information to determine relatedness of organisms?
- Do you think you can figure out which two of these organisms are more closely related?
- What if you had to compare sequences from many more organisms?
- What makes this a difficult task?

Students should recognize that real DNA sequences can be difficult to analyze and compare because of their length and other complexities such as gaps in the sequence. Scientists use sophisticated algorithms and technology to work through these complexities of comparing sequences to produce phylogenetic trees.

Explain to students that due to the difficulties in analyzing real DNA sequences, they will be working with computer generated DNA sequences as a simple simulation of the basic principles of comparing genetic code to determine relatedness. Though these sequences are not the real sequences from these organisms' DNA, their comparisons will still result in the correct branching order of organisms.

Ask students to work in groups of three. Hand each group of students a set of DNA sequences from different organisms *(U9_L2_Cards_OrganismSequences)*. Make sure the organism sequences are shuffled before giving them to the students. Explain to students that their first task is to sort the organisms into major groups based on their DNA sequences. They will need to compare the DNA sequences of the different organisms in order to figure out how they are evolutionarily related. Students can be given the following hint: they should be able to determine the big groupings by looking at only the first 6 nucleotides.

When students are finished, ask them how many groups they determined and why. Students should find that there are 3 major groups that all the organisms fit into. Each of these groups has the following conserved sequences:

ACATTA ● AGGGTT ● AGGGTA

Explain that their next task is to organize this same set of organisms on the tree of life based again on similarities in their DNA sequences—but this time they will need to look at the whole sequence. Hand out the map of the three domain tree of life (*U9_L2_ThreeDomainTreeMap)* and the student sheet "The changing tree of life model: The current model" (*U9_L2_StudentSheet_TheCurrentTreeOfLifeModel).*

Explain to students that they will need to compare the DNA sequences of the different organisms in order to figure out how the organisms are related and where they should be placed on this tree. Each organism fits on one of the branch ends. Also explain the tree diagram that they will be mapping these organisms onto. Review with students by asking them questions and explaining how to read a phylogenetic tree and go over some examples such as the following:

- If two organisms are more closely related to each other (share the most DNA sequence) than any other organism they would go on branches right next to each other.
- If two organisms have a lot of differences in the sequence of nucleotides, they likely go on different major branches of the tree.

Before letting the students begin, the task can be demonstrated by showing students how to compare DNA sequences and placing one or two organisms on the tree. Once students understand the goal of the activity and how to compare sequences, allow them to work together in their groups to place the organisms on the tree.

As students work, walk around to each group to encourage equal involvement from all students in the task, to see how they are thinking about things throughout the activity, and to support their understanding of the concepts. Allow students to try organizing the cards in different ways but also guide them toward the correct final placement of the cards through questions such as the following:

- Why did you place those two organisms near each other on the tree?
- How can you tell those organisms are on different parts of the tree?
- How can DNA sequences be used to determine relatedness of organisms?

Crosscutting Concepts: Patterns

The activity of comparing DNA sequences is a good opportunity to highlight patterns in science. When studying phylogenetics, scientists essentially look for patterns in the DNA sequences that allow them to determine how closely two organisms are related. When Carl Woese made his discovery, he was looking for patterns in ribosomal RNA of different organisms. He was able to distinguish archaea as a domain of life separate from bacteria and eukarya due to its unique pattern of ribosomal RNA.

Once most groups have completed or are close to completing the activity, draw the class back together for a discussion. Begin by asking each group to talk briefly about how they determined relatedness and organized the organisms on the tree. What process did they use to compare the DNA sequences? After each group has reported out to the class, project onto the board the correct layout of the organisms and ask the groups to compare it to what they have. Give students a few minutes to talk over how the two are different or the same (even if students didn't place the organisms in the exact same places on the tree, they might still be correct). Draw the class together again and ask them to consider the three-domain tree of life and molecular methods. Ask the following questions:

- Looking at the sequences, how were they able to distinguish between the different domains?
- What role does DNA play in determining relatedness? How/Why did the findings from these new molecular methods prompt another revision of the tree of life model?
- How does this simulated activity compare to the real sequences they looked at first?
- What are the limitations of the simulation? What aspects of real sequences would make them far more complex and difficult to compare?

After the discussion, hand out the "1990-B" envelope. The prompt in this envelope explains that Carl Woese, a biologist at the University of Illinois at Urbana-Champaign, used new technology and molecular methods to collect evidence that supported a different model of the tree of life (Figure 7). Ask students to read the prompt and answer the corresponding questions on their student sheet. Once students have interpreted and thought about Woese's tree of life model in their groups, gather their attention for a whole class discussion. Have students share out and discuss their responses to the following questions from their student sheet:

- What are the major groups of organisms in Woese's tree of life model?
- How does this differ from the groups of organisms in Whittaker's model?
- What does this model indicate about the evolutionary relationships between the groups of organisms?
- How does this differ from the evolutionary relationships indicated by Whittaker's model?

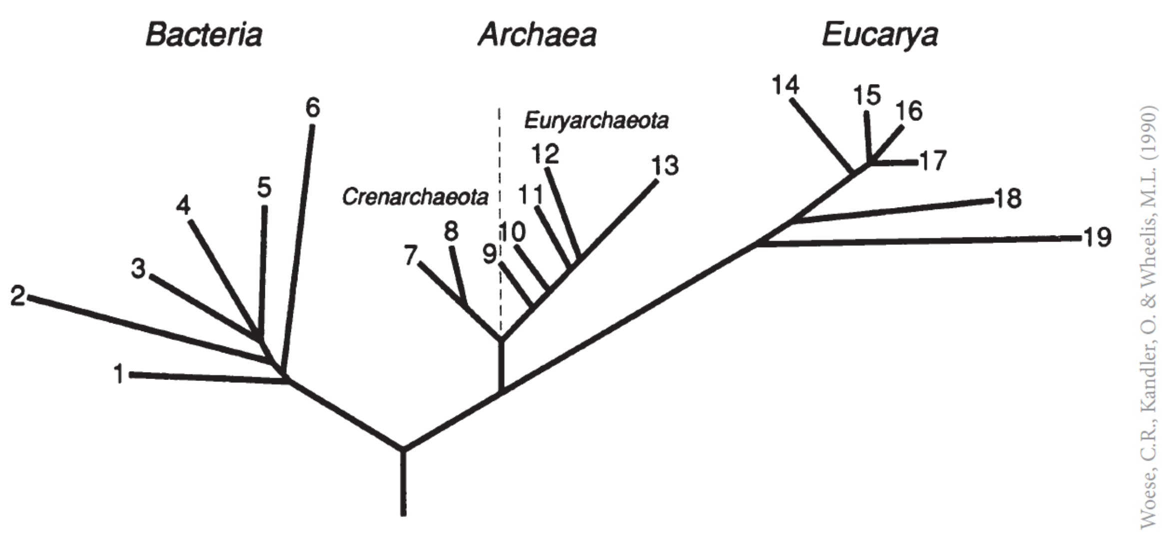


Figure 7: Woese's three domain tree of life model

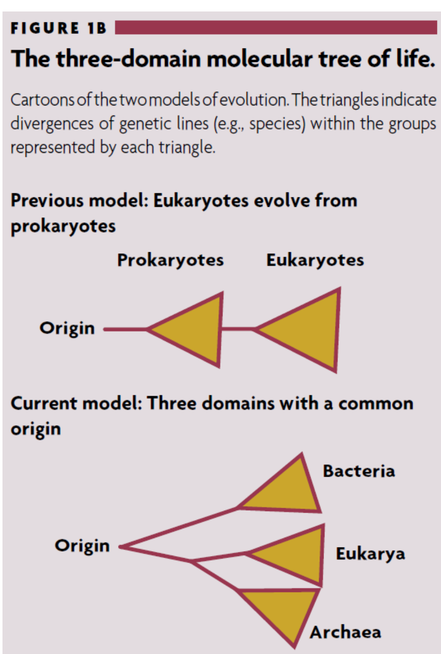
Students should recognize the following main differences between Whittaker's 5 kingdom model and Woese's 3 domain model:

- Organisms are organized into 3 larger groups ("domains") than the 5 kingdoms Whittaker proposed.
- There is a new group/domain that did not appear in the previous tree of life models: archaea.
- The three domain tree shows different evolutionary relationships between organisms:
  - Eukaryotes did not evolve from the bacteria and archaea, but rather branched off from a common ancestor.
  - What had previously been grouped together as "monera" or "prokaryotes" are actually two entirely different domains: archaea and bacteria. Based on the molecular evidence, Carl Woese and colleagues discovered that archaea were distinctly different from bacteria and could not be a part of the same evolutionary group or domain.
  - Archaea are actually more closely related to eukaryotes than they are to bacteria.

As the last step of this activity, have students add this current tree of life model to the Tree of Life Timeline poster they created in the previous lesson. It is very important for students to make this the most current tree in their timeline.

Activity 2: To use or not to use "prokaryote"?

This activity focuses on the potentially problematic use of the term "prokaryote" based on the implications of the older and current tree of life models. Project the following image on the screen for all students to see (it is included in the file: U9_L2_Images):



Baumgartner, L.K. & Pace, N.R. (October 2007)

This image shows simplified depictions of the older 5 kingdom tree of life and the current three-domain tree of life with a focus on the terms prokaryote and eukaryote. Pose the following question to the class: Which model is more accurate? Why?

Using knowledge of both models, ask students to consider the use of the term "prokaryote". Ask students to make a pros and cons list for whether it is still accurate to use the term "prokaryote". As they are making their lists they can consider some of the following questions:

- What was the term "prokaryote" originally used for?
- How might changes in the tree of life model affect the use and meaning of the term?
- Where did archaea fit in the old model as compared to the new? How does this affect what "prokaryote" means?

Ask students to share their ideas. Who thinks the term “prokaryote” should still be used? Who thinks “prokaryote” is no longer an accurate term? Students on both sides should provide the reasoning behind their ideas.

Many scientists believe that the term “prokaryote” is no longer accurate and can be misleading for the following reasons:

1) The term “prokaryote” comes from the older model and therefore, it wrongly suggests that bacteria and archaea are similar (or closely related) and evolved separately from eukaryotes
2) “Prokaryote” also misleadingly implies that eukaryotes evolved from bacteria and archaea instead of evolving from common ancestors.

Engage students in a discussion on why it may be confusing to continue to use the term “prokaryote”. The term comes from an older model and the concepts it implies are no longer accurate as shown by the findings from new molecular methods. Therefore, using the same word may lead to people having the misconceptions stated above.

Scientific Practices: Engaging in argument from evidence

As new ideas come up in science, scientists constantly engage in discussions where they must make their case using evidence and reasoning. It took some time for Carl Woese’s new tree of life model to be accepted by the scientific community. However, not all points of discussion surrounding this significant shift in thinking were resolved. The appropriate use of the term “prokaryote” (or whether it should be used at all) is one such example of an ongoing debate that is spurred by the differences in the ways of thinking described by the older model versus that of the newer model. Having students engage in this debate gives them an opportunity to recognize the nature of controversies surrounding new ideas in science, to draw on what they have learned thus far to make a case, and to practice sound reasoning skills.

As an optional extension activity, students can survey textbooks or other biology sources to see how the term “prokaryote” is still used today. They can answer and discuss questions such as:

- Which model do the textbooks show?
- What terminology do the textbooks use and how? (i.e. use of the term prokaryote)
- Why might the textbooks be outdated? (Discuss how it takes time for science to trickle down and be incorporated into new editions of textbooks.)

Students could also conduct interviews to see how people think about the term “prokaryote” by asking questions such as:

- What is a prokaryote?

- Did eukaryotes evolve from prokaryotes?
- Have you heard of archaea?
- How many domains are in the tree of life?
- Of the three domains of life, *archaea, bacteria, eukarya*, which two groups are the most closely related evolutionarily?

Through these exercises, students may find that Whittaker's 5 kingdom model is still common. This might be the case even though it is a model that is no longer held to be accurate by the vast majority of the scientific community and has been replaced by the molecular three-domain tree of life. Students can share with each other what they find through the interviews, surveys, and/or biology resource evaluations. Their findings can be used to spur an interesting discussion about how science is always advancing and discovering new things and the long process by which this new information gets incorporated into textbooks and other sources and eventually becomes common knowledge.

Activity 3: Carl Woese's discovery

In this activity, students go further in depth to learn about Carl Woese's discovery and how it led to major shifts in the tree of life model. To begin, have students work in groups of 2-3 to read the article "Carl Woese's Discovery" (*U9_L2_Reading_CarlWoese'sDiscovery*) and answer the questions that follow. The article and/or questions can also be assigned for homework the night before to save class time.

Once students have discussed answers to the reading questions in their groups, facilitate a whole class discussion about the article. In addition to the reading questions, ask students questions such as:

- What did you learn from the article?
- Why was the new evidence Woese provided compelling enough to cause a shift in the model?
- Do you think it would have taken a lot of convincing for scientists to accept Carl Woese's tree of life model? Why or why not? *Yes, Carl Woese faced a scientific community of skeptics. The tree of life he proposed was so drastically different from previous models that he had to provide a significant amount of data and explanations as evidence to support his model. His model was accepted once the scientific community acknowledged that there was enough compelling evidence to support his claims for the new model.*

Pose the interesting question: Do you think the tree of life model will change significantly again in the future? Why? Why not? There is no right or wrong answer here but thinking about and discussing this question will encourage students to consider the various aspects of the dynamic nature of science that they have been learning about in these first two lessons of the unit. To further facilitate the discussion ask questions such as:

- Why is science said to be "dynamic"?
- What role does advancement in technology play in science?
- What may lead to major new scientific discoveries?
- What determines whether a new scientific model is accepted by the scientific community?

- What role does evidence play?
- What role does human nature play?

Conclusion of Lesson

To lead into the next lessons, pose the following questions:

- What was the role of microbes in the story of the changing tree of life model?
- How did Woese's findings and the three-domain tree of life model affect the field of microbiology research?
- Based on the article they read, according to Woese, why is it important to conduct more research to learn about the diversity of microbes?

Students should begin to discuss how advancements in science such as this new tree of life model pave the way for new scientific research questions and discoveries. In the case of the molecular tree of life, this new framework for organizing life put microbes front and center. Since the development of the three-domain model, microbiology research has proliferated and the diversity and importance of microbes have become increasingly apparent.

Project the question and image of the three domain tree included in the file *U9_L2_Images*. On the image of the three domain tree, draw students attention to the diversity of multicellular organisms as compared to unicellular organisms—only the very tip of the Eucarya branch are multicellular organisms and the rest are unicellular organisms, or microbes. Through the rest of this unit, students will learn about the diversity, ubiquity, and ecology of microbes.