How do small things make a big difference?

Microbes, ecology, and the tree of life

Lesson 1: How did the tree of life change through history?

I. Overview

Students learn about the nature of science as they examine how models of the tree of life have changed through history. Students begin with an activity that introduces the classification systems of past scientists (including Carl Linnaeus, Ernst Haeckel, and Robert Whittaker) to recreate the historical timeline of different taxonomies using original scientific drawings and excerpts from scientists' writings to support their model. For each different taxonomic model students examine, they address questions such as "What information did the scientist use to create this taxonomy?" and "What are some of the defining characteristics of each of the groups of organisms?" These progressions of scientific thought and models over time illustrate some key nature of science concepts: scientific knowledge is a result of human endeavors and has a history that includes the refinement of, and changes to ideas over time.

Connections to the driving question

The history of microbiology and the history of the shifting model of the tree of life are closely intertwined. This lesson encourages students to begin thinking about how the place of microbes in the tree of life has been modified over time as technology advances and more evidence and information accumulates.

II. Standards

National Science Education Standards

- Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists. (Grades 9-12 Understandings about scientific inquiry 2.1)
- 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)
- Scientific explanation must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible

modification; and it must be based on historical and current scientific knowledge. (Grades 9-12 Understandings about scientific inquiry 2.5)

- 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)

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*)

III. Learning Objectives

Learning objective	**Assessment Criteria**	**Location in Lesson**
Explain how and why scientific models can change over time (within the context of the changing tree of life model)	Student explanations include: • Science is not static. Instead, scientific ideas and models change over time as new information is acquired. • There have been a number of different models of the tree of life throughout history. • Each tree was based on the information scientists had at the time and as new discoveries were made, the model was modified to incorporate the new knowledge.	Throughout lesson
Explain the role of technology in the advancement of science	• New technology allows for new discoveries and knowledge, therefore modifying existing scientific models and advancing science.	Throughout lesson

Explain how the model of the tree of life changed throughout history	Student explanations include: • Major groupings of organisms in models of Linnaeus, Haeckel, Whittaker, and Woese • The technological advancements and evidence that prompted revisions of the tree of life model • The major changes that the tree of life model underwent	Throughout lesson

IV. Adaptations/Accommodations

Throughout the lesson, students will be asked to develop and revise their models of the tree of life. Students can be given varying levels of support in this activity depending on their abilities and level of background knowledge.

Safety

There are no additional safety concerns associated with this lesson.

V. Timeframe for lesson

Opening of Lesson

- 10 minutes

Main Part of Lesson

- Activity 1: 40 minutes

Conclusion of Lesson

- 10 minutes

VI. Advance prep and materials

Activity 1: The story of the tree of life

Materials:

- Tree of Life Activity Cards: *U9_L1_Cards_TreeOfLifeActivity.pdf* (includes organism cards)
    - 1 copy per every 3 students
- Tree of Life Activity Prompts: *U9_L1_Prompts_TreeOfLifeActivity.pdf* (includes prompts, tree of life model cards and descriptions)
    - 1 copy per every 3 students
- 6"X9" envelopes (8 per set) -- 1 set per every 3 students

- Student Sheet: The Changing Tree of Life Model (*U9_L1_StudentSheet_TheChangingTreeOfLifeModel.docx*)
    - 1 copy for each student or group of 3
- Laminate sheets

Preparation:

- Each set of materials contains 8 envelopes. Label each of the 8 envelopes of each set with each of the following dates: 1758-A, 1758-B, 1866-A, 1866-B, 1969-A, 1969-B, 1990-A, and 1990-B. (Envelopes 1990-A and 1990-B will be used in Lesson 2.)
- Print the Tree of Life Activity Cards and Prompts documents. Together, these contain the materials for one set.
- Laminate the organism cards. Cut where indicated by dashed lines.
- Laminate the cards labeled “Illustrated interpretation of…” the different tree of life models (optional). Cut where indicated by dashed lines.
- Be sure to keep each set of pages separate for easy sorting. Assemble each set by placing the components of the document into the correct envelope as designated by the date in the lower or upper right corner of each card or page.
- Make copies of the student sheet, “The Changing Tree of Life Model”. One copy per each student or group.

Activity 2: Telling the story

Materials:

- Posterboard or whiteboards (1 per every 2-3 students)
- Double sided tape (optional)
- Markers

Preparation:

- Have these readily available for students to use.

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.
- 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.
- Chatton, E. 1938. *Titre et travaux scientifique (1906-1937) de Edouard Chatton.* Sottano, Italy: Sette.
- Haeckel, E. 1866. *Generalle morphologie der Oganismen*. Berun, Germany: George Kelmer.
- Linnaeus, C. 1735. *Systema naturae.*
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
- Sapp, J. 2005. The prokaryote-eukaryote dichotomy: Meanings and mythology. *Microbiology and Molecular Biology Reviews* 69(2): 292-305. *www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1197417.*
- Whittaker, R.H. (1969). New concept of kingdoms of organisms. Science. 163: 150-163.
- Woese, C.R., Kandler, O. & Wheelis, M.L. (1990). Towards a natural system of organisms: Proposal for the domains archaea, bacteria, and eucarya. Proceedings of the National Academy of Sciences of the United States of America 87: 4576-4579.

VIII. Lesson Implementation

Opening of Lesson:

Begin the lesson by getting an idea of students' existing knowledge of the topics that will be covered in this lesson.

Ask students to take out a piece of paper and draw what they think of when they hear the term "tree of life". They can work individually, with a partner, or in small groups. Some of the students may have learned about the tree of life in previous classes—what all can they remember about it? As students are discussing and drawing, walk around to see students' existing ideas about the topic. Once students have drawn their model of a tree of life, ask them to consider and discuss in pairs the following questions and apply it to their model:

1) What types of information is needed to create the tree of life?
2) What information does the tree of life convey?

Once students have discussed these questions, ask some students to share their ideas with the class. The students are not expected to get the right answers at this point in the lesson but just to begin thinking about these concepts.

Then, propose the following question to the students: What would happen if the information on which you are basing your tree was no longer accurate and new information has taken its place? (Here, it would be good to provide a concrete example based on one of the student responses to question 1 above. i.e. If a student group says they based their tree on what organisms look like, ask what would happen if the field of cell biology actually revealed that ants and hamsters (for example) have more similar cell types?)

Students should begin to realize that their model would likely change based on this new information. Ask: Do scientific models change? Do you think the model of the tree of life has changed throughout history? Collect some of the students' thoughts and ideas on the dynamic nature of science.

Before beginning the main part of the lesson, lead a discussion about the use of models in science. Ask students questions such as:

- What are models in science?
- What are scientific models used for?

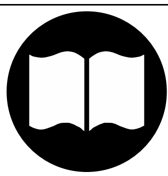
Scientific Practices: Developing and using models

Students will be asked to develop, use, and evaluate models throughout this unit. Therefore, this initial discussion will be important for establishing an awareness and common understanding of the role of models in science. Student should begin to think about what scientific models are, how they are used in science, and how students will

	use them in their science classroom. As students work through each of the following lessons, they will continue to develop their ability to work with scientific models. Throughout the unit, students should continue to discuss scientific models as they consider the following types of questions about the models they build: • What does this model communicate about the scientific phenomenon? • How can we use this model to explain/to predict? • What are the advantages/limitations of this model?

Building on student responses, help students to discuss and understand that scientific models are ways in which to represent, visualize, and understand scientific phenomena. Models can come in many different forms such as computer simulations, diagrams, physical reconstructions, mathematical representations, and even analogies. Scientists develop models based on their current understanding of a phenomena and use those models to further study that phenomena by developing questions and explanations, and to communicate their ideas to the other scientists and the public (NRC, 2012).

Explain to students that they will be developing and revising models of the tree of life to study how the tree of life model changed over time.

	**Teacher pedagogical content knowledge** In this lesson, students will be looking at different models of the tree of life. While some background on how to read phylogenetic trees or cladograms would be helpful, it is not absolutely necessary. If students have no prior experience with phylogenetic trees or cladograms or need to review the ideas, it may be helpful to spend some time talking with students about some of the following basic key concepts: • Branches indicate different groups of organisms or species (depending on the level of branching that is shown) • Nodes of trees indicate a common ancestor • A more recent common ancestor indicates a closer relatedness between the organisms

Main Part of Lesson

Activity 1: The story of the tree of life

In this activity, students examine the different models of the tree of life throughout history. The activity switches back and forth between group work and teacher facilitated whole class discussion.

Ask the students to work in groups of 3. Hand out one set of envelopes to each group. (One set for this lesson includes one of each of the following envelopes: 1758-A, 1758-B, 1866-A, 1866-B, 1969-A, 1969-B. Envelopes 1990-A and 1990-B will be used in the next lesson.) For the student sheet “The Changing Tree of Life Model”, hand out one packet per student or one per group.

Begin the activity by asking students to open the first envelope (Year 1758-A). In the envelope, they will find a prompt (or note) and a set of organism cards (plants and animals only). The prompt will give a bit of information on how people organized living things in the 1700s and then will ask students to develop what their model of organism classification would look like at that time.

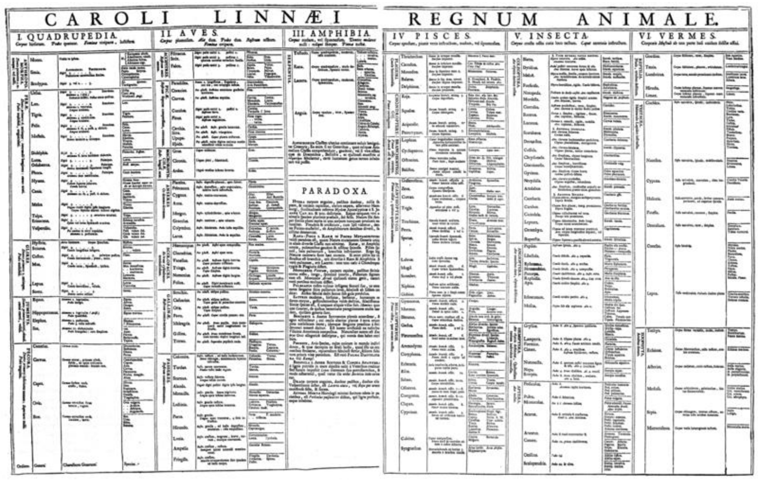
Ask students to follow the instructions on the prompt and organize their set of cards. Give the students approximately 5 minutes (it may be appropriate to set a timer) to group the organisms and to be prepared to discuss the discussion questions. As students work through the activity, walk around to each group to see how/what they are doing. Once students have grouped the organisms and the time is up, ask students to stop. Facilitate a class discussion around the discussion questions included in the student sheet.

- How many groups did you make?
- What are the main groups?
- What information did you use to group the organisms?
- What are the defining characteristics of each group?

Most students will likely say they used the organisms’ physical traits to categorize them. Some may have used different criteria. At least some of the groups may have divided up the animals and the plants to form two large groups. Use these student ideas and groupings to lead into the work of Linnaeus.

Ask students to open the envelope labeled “1758-B”. Explain that in his book “Systema Naturae” (1st edition published in 1735 and 10th edition in 1758) Carolus Linnaeus classified organisms into two major groups that were called “kingdoms”: *Animale* and *Vegetabile* (or animals and plants). Some of the student groups may have further categorized their organisms within these major kingdoms. Figure 1 shows how Linnaeus further divided the kingdom of Animalia into classes such as “Quadrupedia”, “Aves” and “Amphibia”.

Instruct students to read the 1758-B prompt and complete the associated questions on the student sheet.


CAROLI LINNÆI REGNUM ANIMALE.

I. QUADRUPEDIA. II. AVES. III. AMPHIBIA. IV. PISCES. V. INSECTA. VI. VERMES.

PARADOXA

Figure 1: Excerpt from Systema Naturae

Teacher pedagogical knowledge

As students open each envelope throughout this activity, they will be tracing the changes to the tree of life model over time. To help students maintain the larger picture of how the science progressed, have students begin to create a visual timeline of events. Using the posterboard, have each group of students begin drawing a timeline. On this timeline, they can tape the image of the tree model they just learned about and write some information about it (e.g. Who developed it? Based on what new information? Etc.) After each "-B" envelope, students should add the next tree model and information they have just learned to their timeline. Additionally, to add more perspective and context to the timeline, students can add to the timeline other major historical events that happened at the time (e.g. other major scientific advancements, major wars etc.) This will encourage students to think about science as a human endeavor that is embedded in and influenced by culture and society. If preferred, students can draw their timelines at the end of the lesson as a way to pull together and organize all the main ideas from the activity.

Now ask students to mentally fast forward to the year 1866 and open the envelope labeled 1866-A. This envelope contains cards of microbes (that they will add to their previous model) and another prompt. The prompt describes some key scientific advancements that occurred in the 1600s and 1800s such as Leeuwenhoek's seminal observations of microbes and Darwin's new theory of evolution. As stated in the prompt, have students evaluate and revise their previous model based on these new pieces of information.

Give students a few minutes to incorporate the new pieces of information into their existing model. As students work, ask them the following types of questions:

- How do the new organisms fit into your previous classification system?
- What information are you using to form the groups?
- How would Darwin's ideas affect the way living things are organized?
- What would the new tree of life look like?

Most of the students will likely say that the microorganisms would be in their own separate third group. This reasoning would be similar to what they did previously in that the visible physical characteristics of the organisms would decide the groups.

Scientific Practices: Developing and using models

Throughout this activity, it is important that students experience the process of revising existing models based on new information. Therefore, students should not clear their models (arrangement of organism cards) after each step but rather have them add to and modify their model as they incorporate the new information. The discussion questions in the student packet draw further attention to this process by asking students to explain how and why their model was revised.

After the students have formed their new organism groupings, have some, or all, of the groups share out their responses to the discussion questions. Once some of the groups have explained how the microorganisms fit into the groupings they chose and why, ask students to open envelope "1866-B".

Ask students to interpret Haeckel's tree of life, drawing inferences and conclusions based on his diagram (Figure 2). Ask students to discuss within their groups and answer the following questions on their student sheet:

- How is Haeckel's model the same or different from how your group organized the organism cards?
- How is Haeckel's grouping of organisms the same or different to Linnaeus' major groups.
- How did Darwin's theories about evolution impact how Haeckel organized living things and how he drew his model?
- What do you notice at the very bottom of the tree in Haeckel's drawing?
- What does the placement on the tree suggest about how the organisms evolved over time?

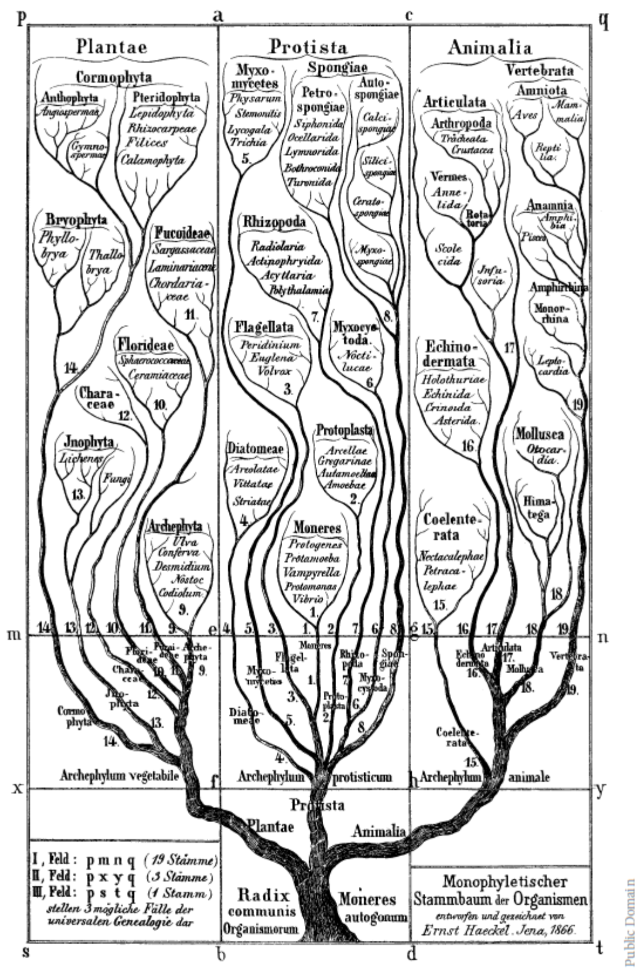


Figure 2: Haeckel's tree of life model

As students work on the questions in their student sheet, help them come to the following understandings about Haeckel's tree of life through group discussions and whole-class teacher-led discussions.

- According to Haeckel, there were three main kingdoms indicated in his figure by the three main branches of the tree: Plantae, Protista and Animalia.
- Haeckel's drawing implies that all living organisms evolved from "Monera" (shown at the base of the tree) a group of tiny organisms that were not well understood and Haeckel also grouped into the kingdom Protista.
- Additionally, the point of branching near the base of the tree might also suggest that Protista and Animalia are more closely related to each other than to the Plantae.
- Ask students why they think Haeckel represented information as a tree whereas Linnaeus made tables? What important scientist and theory may have influenced Haeckel?

- Darwin published *On the Origin of Species* in 1859 in which he described his theory of evolution by natural selection. Haeckel was greatly influenced by Darwin's ideas and tried to describe the possible evolutionary relationships between different types of organisms as indicated by the branching patterns.
- From this point onward nearly all who proposed models of the tree of life considered and accounted for evolutionary relationships between organisms.

Now, explain to students that they're going to fast forward again to the year 1969. Ask them to open the envelope labeled, "1969-A". This envelope contains another set of microorganisms (to indicate the discovery of more microbes) and another prompt. The prompt explains how Edouard Chatton in 1928 established a distinction between "eukaryotic" and "prokaryotic" cells. It also includes a list of whether each of the organisms on the cards is a prokaryote or eukaryote. Students use this information to evaluate and revise their previous model.

Give students a few minutes to rearrange their groupings to incorporate the new piece of information. When finished, ask students to again explain their reasoning and the information they used to form the new groups of organisms. What are the defining characteristics of each group now?

Crosscutting Concepts: Patterns

At this point, students should begin to recognize the crosscutting concept of patterns as it relates to the nature of science. As students develop and revise models based on new evidence, they are simulating the processes that science as a field undergoes as new technology and findings drive scientists to develop and adopt better explanatory models of scientific phenomena.

Linking to student responses, explain that a French biologist named Edouard Chatton in 1938 postulated that the tree of life consisted of two large "empires": the prokaryotes (cells with no nucleus) and eukaryote (cells with a nucleus). All organisms fell into one of these two groups.

Have students open the envelope labeled "1969-B". In 1969, another biologist, Robert Whittaker incorporated Chatton's idea of prokaryote and eukaryote groupings and proposed a five-kingdom tree (Figure 3). Whittaker's tree showed three levels of five kingdoms: 1) Monera (the prokaryotes/bacteria), 2) Protista (unicellular eukaryotes), 3) Plantae, 4) Fungi, and 5) Animalia (groups 3-5 are multicellular eukaryotes).

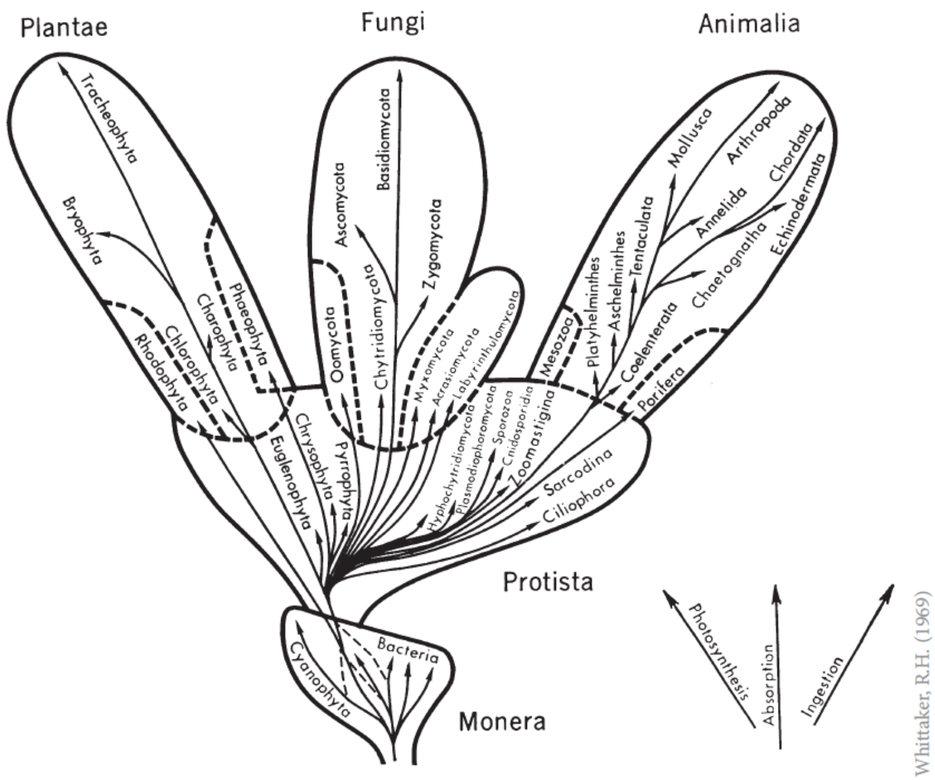


Figure 3: Whittaker's tree of life model

Ask them to carefully observe Whittaker's five kingdom tree of life and answer the related questions in their student sheet. Some students might observe that this tree resembles Haeckel's tree with new ideas incorporated such as Chatton's prokaryote vs. eukaryote distinction. Point out to students that science often goes through processes of change where scientific models, such as versions of the tree of life, are modified and improved based on new knowledge and information.

Guide students to the evolutionary aspect of Whittaker's tree of life by asking about their thoughts and responses to the questions in their student sheet:

- How does Whittaker's model of the tree differ from Haeckel's? What led to these revisions?
- What does this diagram indicate about evolutionary relationships between organisms?
- Which organisms appear to have evolved first?
- Which groups are most closely related?

Ask students whether this five-kingdom tree of life is familiar to them. Have they seen it before? Perhaps they learned about it in a previous science class? Many students may have learned this version of the tree of life as it is still sometimes taught this way. Ask students to share some of the things they may have learned before. The five-kingdom tree of life persisted for a long time and is still used by some people today even though it is no longer the generally agreed upon model. Why do they think that is?

Activity 2: Telling the story

Thus far, students have learned about three different models of the tree of life, those of Linnaeus, Haeckel, and Whittaker. In the next lesson, they will go one step further to learn about the current tree of life model. However, in this activity, they will first begin to synthesize the story they know thus far.

To do this activity, students can either place the illustrative diagrams of the tree of life models on a whiteboard or poster paper (as shown in Figure 4) or they can re-draw the models themselves. In this way, ask students to develop a descriptive timeline of how the tree of life model changed over time. Remind them to leave some space for the current model which they will discuss in the next lesson! Students should include the following information on their timeline:

- Who were the main scientists?
- What major changes were made to the tree of life model at each step?
- Why did the tree of life model change at each step? (i.e. What prompted changes to the model?)
- What were the evolutionary implications in each model?

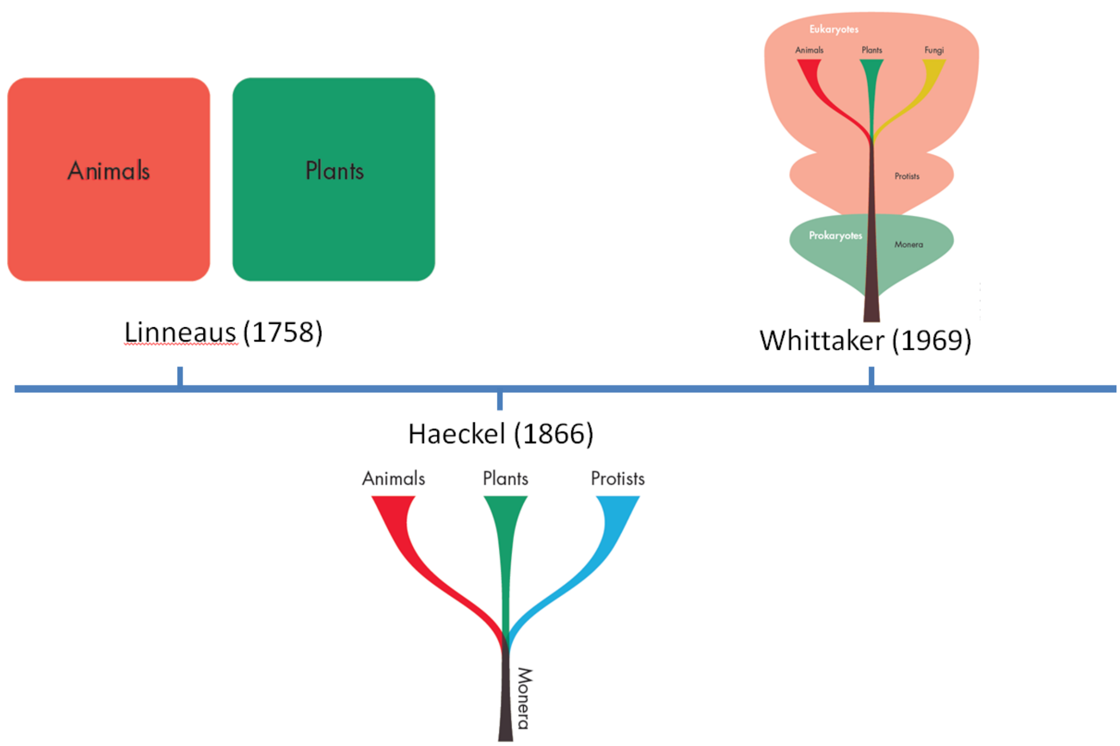


Figure 4: The tree of life model timeline

As students develop their timeline to tell the story of the tree of life model, support them in discussing and including the nature of science concepts. For this, students will really need to be able to articulate *why* the model changed. What were the new pieces of evidence or ways of thinking that propelled revision of the model? By addressing the groups as they work or the class as a whole after they have completed the timeline, lead a discussion with the following types of questions:

- Can scientific models change over time? *Yes, scientific knowledge is revised over time as new information and evidence is gathered. However a lot of scientific knowledge is strongly supported by substantial evidence and is not likely to undergo extreme revisions.*
- What kinds of things lead to the development of a new or revised scientific model? *Advances in technology and new discoveries lead to the development of new scientific models that are able to incorporate and explain new relevant information.*
- How much or what type of evidence do you think is necessary for a new scientific model to replace a previous model? *Students should understand that a new model must have high quality (sometimes this also means quantity) evidence to support it in order for the scientific community to accept it as the better, more accurate explanatory model of a given scientific phenomena.*

Conclusion of Lesson

To conclude the lesson, have students make predictions about additional modifications to the tree of life model. Ask the following types of questions to facilitate the discussion:

- Do you think Whittaker's model is still the accepted tree of life model today? Why? Why not?
- Can you think of any advances in technology since Whittaker's tree that may affect the model?
- What might be some new pieces of evidences or things we didn't know before that would cause the model to be revised?
- What might the revised (or current) tree of life model look like?

This discussion gives students an opportunity to apply some of the nature of science concepts they just learned. It also serves to motivate the next lesson which looks at the current tree of life model and how it came to be.