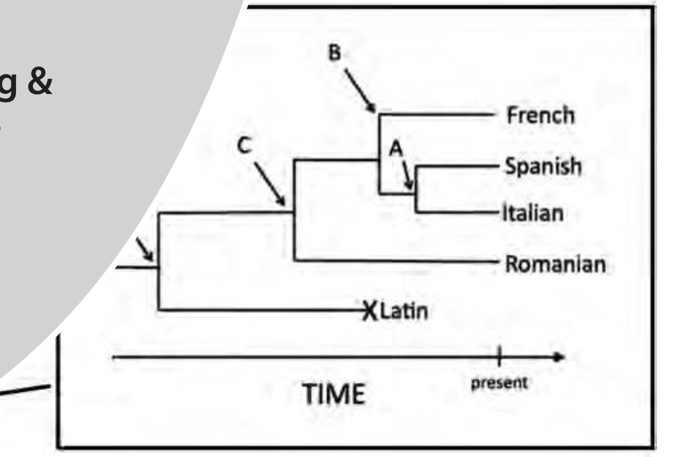
Investigating Tree Thinking & Ancestry with Cladograms



KD DAVENPORT, KIRSTIN JANE MILKS, REBECCA VAN TASSELL

Abstract

Interpreting cladograms is a key skill for biological literacy. In this lesson, students interpret cladograms based on familial relationships and language relationships to build their understanding of tree thinking and to construct a definition of "common ancestor." These skills can then be applied to a true biological cladogram.

Key Words: *Tree thinking; phylogeny; evolution.*

○ Introduction

Tree thinking was defined by O'Hara (1997) as a way of understanding taxa not as "independent replicates within a class" but as "interconnected parts of an evolutionary tree." Evolutionary trees, known variously as cladograms, phylogenies, phylogenetic trees, and genetic trees, are representations of evolutionary biologists' working hypotheses. We agree with Baum and Offner's (2008) claim that familiarity with tree thinking is "required for biological literacy."

As practicing high school teachers, we can confirm that students' misconceptions about evolutionary trees can be deep and difficult to eradicate (Baum et al., 2005). Catley and Novick (2008) said that "undergraduates, even those with stronger backgrounds in biology, encounter difficulties with tasks involving the interpretation of cladograms." They attributed these difficulties to the poor treatment these diagrams receive in high school biology resources. Catley and Novick found that although cladograms are common in high school biology textbooks, these textbooks made "virtually no attempt to explain their structure and theoretical underpinnings." Thus, if students are to be prepared for college biology, robust supplementary resources are required to help them learn to understand and interpret these diagrams.

Both the Advanced Placement and International Baccalaureate Biology programs include interpreting and creating cladograms as part of their curricula (International Baccalaureate Organization, 2007; College Board, 2013). Although the *Next Generation Science Standards* don't refer to cladograms specifically, they do specify that high school students should be able to "communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence" (National Research Council, 2012). Given that cladograms are "at least as important to evolutionary biology instruction as understanding natural selection" (O'Hara, 1997) and make up almost three-quarters of the evolutionary diagrams in high school biology textbooks (Catley & Novick, 2008), fluency in interpreting and creating cladograms should be seen as essential to successful communication of ideas about evolution and ancestry.

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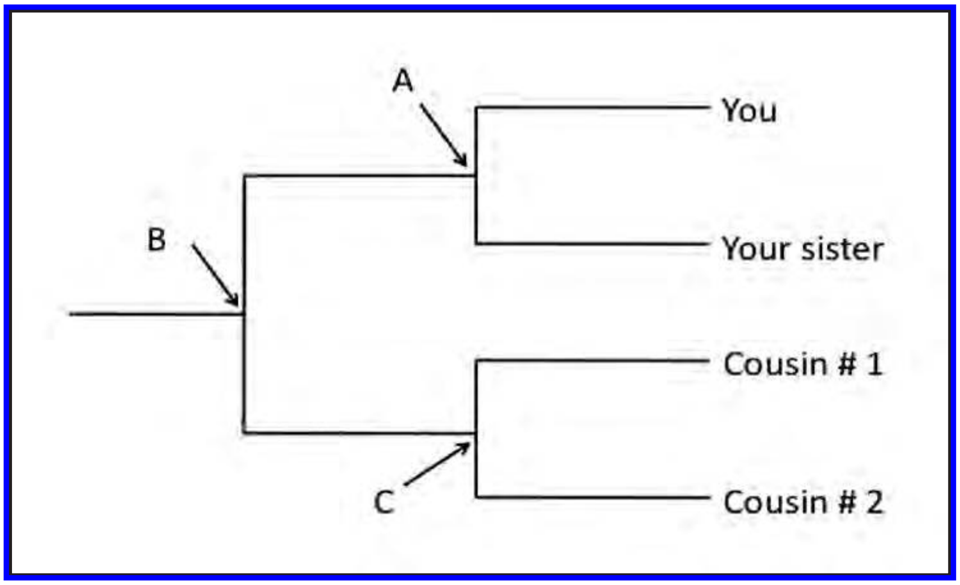
○ Our Project

Several excellent resources exist for developing college students' understanding of cladograms and tree thinking (Baum & Offner, 2008), but they may not be appropriate for high schoolers, who come to the subject with less overall biology content knowledge and less experience interpreting difficult graphical information. In this article, we present an activity that scaffolds cladogram interpretation by starting with one example that is literally *familiar* – family relationships. We then give students practice applying tree-thinking concepts to another, nonbiological, example: human languages. As Baum et al. (2005) pointed out, "the idea of tree thinking isn't necessarily tied to living things"; languages are a perfect example of nonliving entities that "are parts of a tree of inheritance and (whose) common

The American Biology Teacher, Vol. 77, No. 3, pages 198–204. ISSN 0002-7685, electronic ISSN 1938-4211.
DOI: 10.1525/abt.2015.77.3.8

Model 1



1) To whom are you more closely related, your sister or your cousin? Explain your reasoning.

2) Who is more closely related to Cousin #1, you or your sister? Explain your reasoning.

3) What individual(s) might be represented by each of the following letters:

A:

B:

C:

4) Congratulations! You have a new baby sibling! Add and label a line to Model 1 to show your sibling on Model 1. Explain why you placed your baby sibling where you did.

5) In Model 1, which tells you how closely related two individuals are: the branching pattern of the lines, or the vertical location of the tips of the branches? Justify your answer.

Figure 1. Model 1 (family tree) and accompanying questions.

characteristics can be explained by reference to their shared history." Only once students are comfortable with the logic of tree thinking does this activity present them with a true biological cladogram.

We have found that students will be better able to construct new conceptual understanding without simultaneously grappling with unfamiliar content. In our experience, students find it much easier to use inductive reasoning to construct the ideas of common ancestor and homologous structure using the examples of families and languages than when they are given biological cladograms as their first example. We have been pleasantly surprised at how quickly and thoroughly students can grasp the basics of tree thinking by using this activity.

○ Objectives

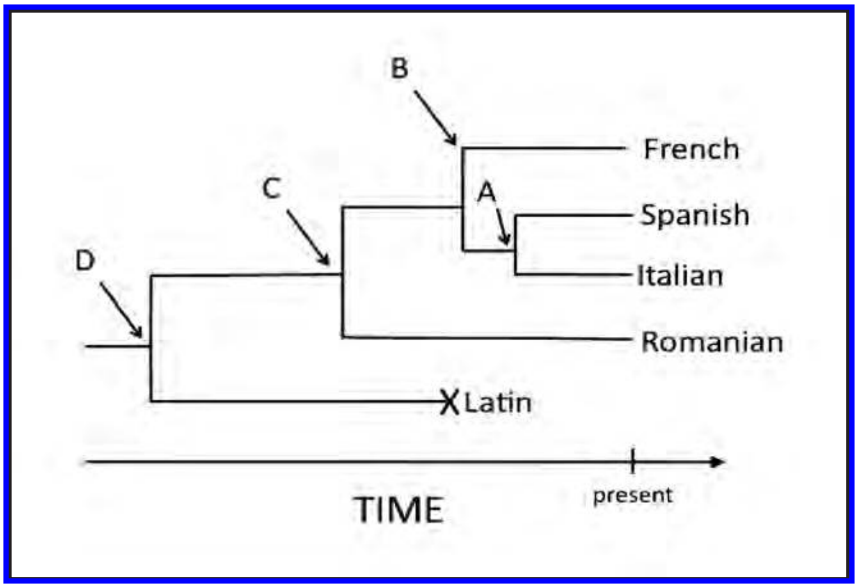
1. Students will be able to explain the concept of common ancestry and identify a common ancestor during cladogram analysis.
2. Students will interpret cladograms in order to determine how closely taxa are related through a common ancestor.

○ Methods & Materials

Begin with a Whole-Class Discussion

As a warm-up activity, ask what languages students are familiar with. Students may respond with a language they speak, one spoken by their parents or grandparents, or one they study in school. Make note

Model 2



6) Based on Model 2, what languages are still spoken in the present?

7) Why do you think is there an X at the end of the line leading to Latin?

8) Model 2 represents "relatedness" in a similar way to Model 1. Based only on Model 2, which two languages are most closely related? Justify your answer.

9) Based on Model 2, which is more closely related to French: Spanish or Italian? Explain your reasoning.

10) What can you predict about the vocabulary, grammar, and sound of Language A, compared to Spanish and Italian? Explain your reasoning.

11) Language A is the **common ancestor**of Spanish and Italian. Define **common ancestor.**

12) What is the relationship between how closely two languages are related and how recently they shared a common ancestor?

Figure 2. Model 2 (languages) and accompanying questions.

of responses so that these students can serve as resources to others throughout the lesson.

Ask students whether they think languages have changed over time, and what evidence they have for their opinion. In our experience, students will respond affirmatively and provide two major types of evidence: (1) they have read books written in a language that resembles the English they speak but is clearly different (Shakespeare and the Bible are popular examples); and (2) students who are bilingual or who have familiarity with more than one language recognize similar words between languages (e.g., the English word *cat*, which is homologous to *chat* in French and *gato* in Spanish; the Hebrew *shalom* and the Arabic word *salaam*; or even the American English "color" and the British English "colour"; or the fact that most Romance languages use gendered articles while English does not).

The first type of evidence clearly shows that languages were once different than they are now. Although the answer may seem obvious, you may wish to press students to clearly state how they know that modern English is "related to" Shakespeare's English. Students will come to understand that this type of evidence is similar to biologists' use of fossil evidence in evolution.

The second type of evidence – homology – is more subtle and requires that at least some students are familiar with more than one language. If students do not generate this type of evidence on their own, use the information you gathered in the introductory discussion to bring students to some simple homologous words (cognates) or grammatical structures. Ask students why similarity in languages indicates change over time. Students may generate explanations describing the evolution of languages. Another example we have found to be successful is playground rhymes – students who grew

Model 3

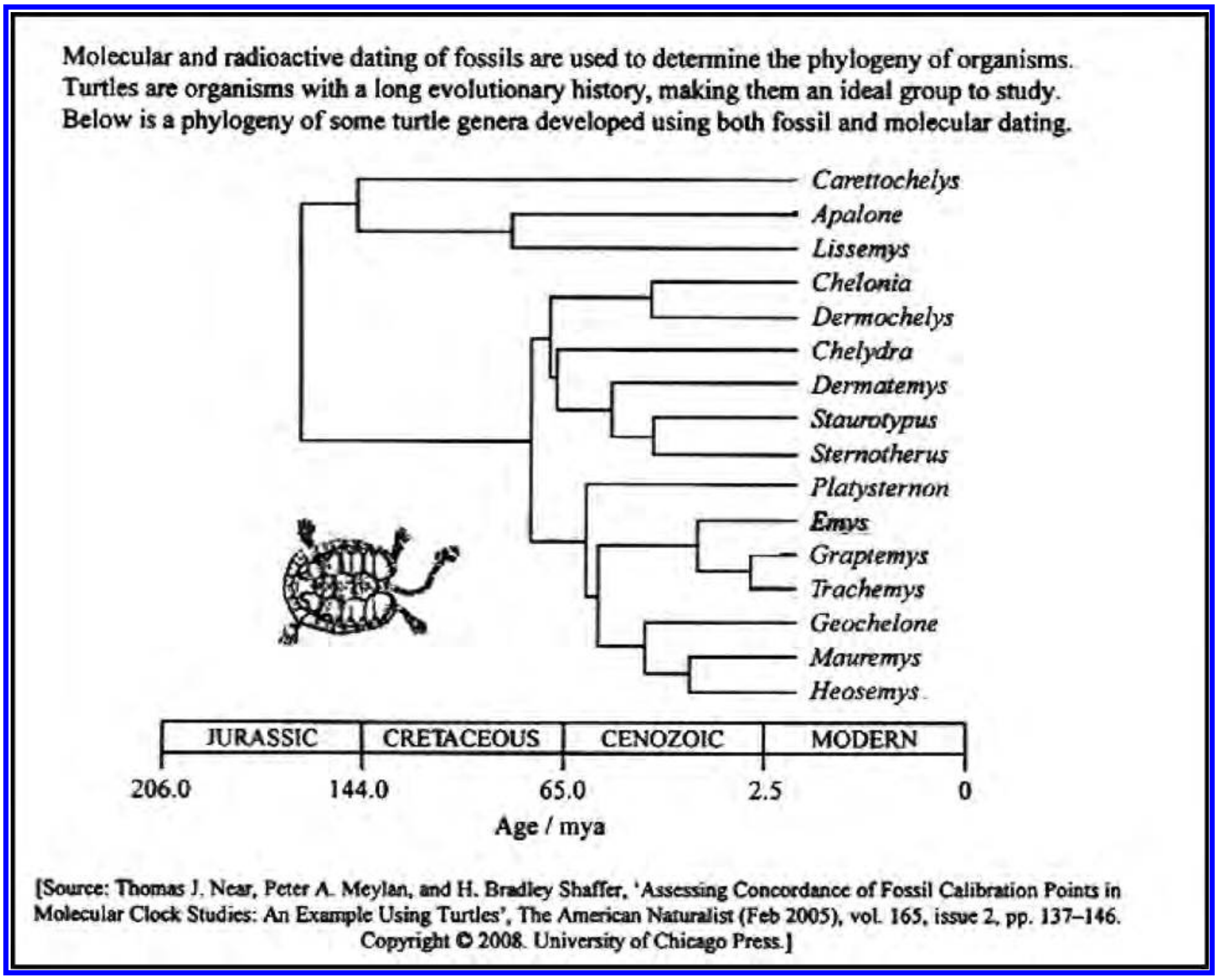


Figure 3. Model 3 (phylogeny of turtle genera).

up in different neighborhoods may know similar, but not identical, versions of the same songs. Ask students to describe how these differences may have come about and encourage them to apply this reasoning to languages.

Make a note of these two types of evidence (and any others that seem valid). Later in the activity, students will compare evidence from fossils and homology in biological evolution to these types of evidence for language evolution.

During this conversation, some students may become suspicious that the class has veered off topic and may need to be reassured that this will all come back to biology in due time. In our experience, though, students generally enjoy this conversation, and we have found that we often get good participation from students who typically do not contribute to class discussions in biology.

Organize Students into Small Groups & Distribute Handouts

Figures 1 and 2 show the "cladograms" used in Models 1 and 2 with accompanying text. Instruct students to answer the questions associated with each model, checking in with you before going on to the second model.

As the students work on the questions, the teacher should float among the groups and, if necessary, ask questions to help guide the students. The teacher should take care to discern whether the whole group is truly stuck. Often this can be assessed by inviting other members of the group to give each other feedback (e.g., "Joe, what do you think about Sarah's question?") – the teacher can quickly tell whether or not Joe and Sarah have already talked about the question. If the whole group is indeed stymied, prompt students with related examples or questions that will help them clarify the concept. If several student groups seem to be stuck on the same question, call a "time-out" and discuss the question as a whole class. Telling the students the answers to the questions without giving them a fair chance to work it out for themselves detracts from the learning experience.

Models 1 and 2 harness students' knowledge with family relationships and language relationships. (In our experience, high school students can very easily describe how "close" various family relationships are; although languages may be less familiar, the class discussion in step 1 helps students consolidate their collective knowledge.) Since students already know the information represented by the diagram, they can fairly easily identify and decode how the diagram

Questions accompanying Model 3

13) Look at the time scale: what is unusual about it?

14) Why do you think the author of this model would choose to represent time in this way?

15) During which geological era did *Emys* and *Trachemys* last share a common ancestor?

16) According to Model 3, which two are most closely related: *Carettochelys, Apalone, Lissemys*? Explain how you know, including the term "common ancestor" in your explanation.

17) According to Model 3, who is more closely related: *Lissemys* and *Chelonia*, or *Lissemys* and *Heosemys*? Explain how you know.

18) Of these three, which two are more closely related: *Trachemys, Emys, Platysternon*? Explain how you know.

19) Model 3 is called a **cladogram**. Define the term cladogram and explain what it is used for.

20) In Model 1, the "branches" represented couples, and the tips of the branches represented individual organisms. How does Model 3 differ from this representation? How is it similar?

21) **Challenge question:** Imagine that a new turtle group has been discovered. The evidence suggests that this group of turtles was more closely related to *Geochelone* than any other known turtle group, but went extinct during the Cenozoic period. Draw a line on the cladogram to indicate where this new group of turtles should be placed on the cladogram.

Figure 4. Questions to accompany Model 3.

represents those relationships. This will be crucial to them when they are asked in Model 3 to discern unfamiliar relationships from the structure of the diagram.

Our questions are also designed to confront students with the problems that are known to arise in cladogram interpretation. For example, Baum et al. (2005), among others, have noticed that "non-specialists are prone to read trees along the tips"; students tend to infer that organisms whose names appear closest to each other on the tree are the most closely related. Our activity directly challenges that notion with questions like "Who is more closely related to Cousin 1, you or your sister?" While most students know that both siblings are equally related to the cousin, they may be momentarily confused by the fact that on the diagram, the word "sister" is closer to the word "cousin" than the word "you" is. This cognitive dissonance is resolved when the student realizes that "tip location" is not an indicator of a close relationship. The student can then apply this principle to unfamiliar sets of relationships, as in Model 3. Watch for our upcoming *ABT* article "Using evolutionary data in developing phylogenetic trees: a scaffolded approach using authentic data" for a description of an activity for which cladogram interpretation is a prerequisite skill.

Distribute Model 3 with Associated Questions

Once all students are comfortable with the concept of common ancestor and the importance of common ancestry in determining evolutionary relationships, distribute Model 3 and the associated questions. Model 3 is a published cladogram of extinct turtle genera whose names will be unfamiliar to high school students. Thus, students will not be able to answer the question on the basis of their prior knowledge or common sense. Instead, they must use the concepts developed in Models 1 and 2 to successfully interpret Model 3. If needed, you can provide support in the manner described in step 2. Figure 3 shows the cladograms used in Model 3, and Figure 4 shows the associated text. Possible target answers for all models and accompanying questions are given in Figure 5.

Students who could successfully interpret Models 1 and 2 may falter when working with Model 3, because of both the unfamiliarity of the organisms and the complexity of the tree itself. If students are struggling to determine which groups of turtles are most closely related, we have found it most helpful to ask students, "Where is the common ancestor of these two? What about these two? OK, so what does that tell you about how closely related they are?" If students have successfully understood that the closeness of an evolutionary relationship is determined by how recently two groups shared a common ancestor, this series of questions should be enough to get them to the right answer. If not, bring them back to questions 10 and 11 in Model 2, which ask students to construct the concept of common ancestry. If the teacher can remain reasonably circumspect, the questions for Model 3 can serve as a formative assessment that evaluates students' ability to interpret complex, unfamiliar cladograms. This ability is a prerequisite skill for the activity described in our upcoming *ABT* article (see above).

○ Group Dynamics

This activity uses many of the principles found in POGIL (Process-Oriented Guided Inquiry Learning) activities (http://www.pogil.com).

Possible target answers to this activity

1.You are more closely related to your sister, because you and your sister have the same parents, while you and your cousin have the same grandparents but different parents.

2. You and your sister are equally related to your cousin; you are both related to her via your grandparents.

3. A. Your parents

B. Your grandparents

C. Your aunt and uncle

4. A line should be drawn parallel to "you" and "your sister" emerging from node A

5. The branching pattern of the lines. You can tell because although your sister is vertically "closer" to your cousin than you are, you and your sister are equally related to your cousin. The branching pattern reflects that idea.

6. All except Latin

7. Latin is a "dead language"; no longer spoken; extinct.

8. Spanish and Italian, because they split from each other most recently.

9. They are equally related, because they both split from French at the same time. This is similar to the cousin in Model 1.

10. It probably shares some traits with both Spanish and Italian, but is not the same as either one.

11. A common ancestor is a thing from the past (a language, in this case) from which two or more current things (languages) have evolved or "come from".

12. The more recently they shared a common ancestor, the more closely they are related.

13. The scale is not constant; equal units of space are used to represent vastly unequal chunks of time.

14. Perhaps the author wanted to show more detail in a particular small section of time (Cenozoic and Modern).

15. The Cenozoic

16. *Apalone* and *Lissemys*, because they share a common ancestor most recently.

17. Both *Chelonia* and *Heosemys* are equally related to *Lissemys*; the most recent common ancestor of *Chelonia* and *Lissemys* is the same as that of *Heosemys* and *Lissemys*.

18. *Trachemys* and *Emys*, because they share a common ancestor most recently.

19. A cladogram is a picture that shows how different things (in this case, groups of organisms) are related to each other through their common ancestors.

20. Model 3 uses "branches" and "tips" to represents groups of organisms, not individuals. However, in a sense, one group of organisms can be a "parent" to other groups, through evolution rather than reproduction.

21. The new turtle group should branch off sometime after the common ancestor of *Mauremys* and *Geochelone*; it should end in an "x"(similar to Latin in Model 2) sometime during the Cenozoic.

Figure 5. Possible target answers for this activity.

In POGILs, students construct concepts and practice their application by collaboratively interpreting models; our activity uses a similar principle. Like many POGILs, our questions begin with simple questions that draw students' attention toward key features of the model, and then ask students to consider more deeply the concept that the model represents. These activities are designed to be completed by students working in small collaborative groups: we have found that groups of three or four work well for beginning high school biology students, whereas pairs are usually appropriate for more sophisticated students. We recommend that you use a collaborative group process that you and your class are comfortable with.

○ Opportunities for Differentiation

- Rather than using it as an in-class activity, you might assign this as independent homework for more advanced students who simply need a refresher on interpreting cladograms before doing more advanced work in studying evolutionary relationships.
- Cladograms can be constructed in a variety of shapes; our activity uses a rectilinear model. More advanced students should be shown the same examples using the diagonal model, which Baum and Offer (2008) found to be "especially confusing."

Acknowledgments

We thank the Knowles Science Teaching Foundation for funding this work.

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KD DAVENPORT is a teacher at Central High School, 1700 West Olney Ave., Philadelphia, PA 19141; e-mail: davenportbiology@gmail.com. KIRSTIN JANE MILKS is a teacher at Bloomington High School South, 1965 South Walnut St., Bloomington, IN 47401; e-mail: kmilks@mccsc.edu. REBECCA VAN TASSELL was most recently a teacher at Horace Greeley High School, Chappaqua, NY 10514; e-mail: rebeccavantassell@gmail.com. All three are Senior Fellows of the Knowles Science Teaching Foundation (http://www.kstf.org).