Advances in Biology Laboratory Education
Publication of the Association for Biology Laboratory Education
Volume 42, Article 29, 2022

Unlikely Sister Taxa - a Tree Drawing Activity That Facilitates Students' Understanding of Analogous and Homologous Structures

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The misconception that organisms with similar morphology are closely related is common among students. While students may memorize the definitions for analogous and homologous structures, many students find it difficult to understand how these terms relate to convergent and divergent evolution. This activity, which can be implemented into either lab or lecture, gives students an introduction to analogous and homologous structures as well as convergent and divergent evolution. It can also be used as a practice in tree thinking and an introduction to multiple sequence alignment. Students first predict the evolutionary relationship between six organisms by constructing a phylogenetic tree that they think best reflects the evolutionary relationship between them. Thereafter students verify their prediction by comparing DNA sequences using an online software. They then discuss reasons why their original prediction may not be correct. The activity can be expanded upon in several ways, which makes it suitable for introductory as well as upper level courses.

Keywords: evolutionary relationships, analogous and homologous structures, convergent and divergent evolution, phylogeny

Link To Supplemental Materials: https://doi.org/10.37590/able.v42.sup29

Introduction

The misconception that organisms with similar morphology are closely related is common among students. While students may memorize the definitions for analogous and homologous structures, many students find it difficult to understand how these terms relate to convergent and divergent evolution. In this activity, which can be implemented into either lab or lecture, students predict the evolutionary relationship between organisms, verify their prediction by comparing DNA sequences, and discuss reasons why their original prediction may not have been correct. The activity therefore allows students to confront their misconceptions and correct them. After the activity students should be able to: 1) Differentiate between homologous and analogous structures, 2) Explain the relationship between homologous structures and divergent evolution, 3) Explain the relationship between analogous structures and convergent evolution, and 4) Explain why evolutionary relationships often cannot be determined based on morphology or niche. The activity also gives students practice in tree thinking and introduces students to multiple sequence alignment. It is important that students are already familiar with

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drawing phylogenetic trees to present evolutionary relationships among organisms before participating in this activity. They need to understand what a sister taxon is.

The activity can be completed in a 50 min class or lab, but can be expanded and followed up upon in several ways if desired.

Students are first given images (either on the screen or in lab manual) of six mammals: killer whale (*Orcinus orca*), manatee (*Trichechus manatus*), walrus (*Odobenus rosmarus*), moose (*Alces alces*), brown bear (*Ursus arctos*) and African elephant (*Loxodonta africana*). Other organisms can be used as long as some of them share analogous structures while others share homologous structures.

Students, thereafter, work in small groups to construct a phylogenetic tree that they think best reflects the evolutionary relationship between the mammals. After all groups complete their phylogenetic tree (discussion questions 1-4) gather the class for a discussion. Ask students questions such as: Which type of information would you use to build the phylogenetic tree? A. Body shape, i.e. streamlined body or not. B. Habitat, i.e. marine or not. C. Function of forearms, i.e. for swimming or not. D. All of the above. E. None of the above. If clickers are not available, a show of hands will work. While the question may work as an open-ended discussion question, you will likely get more information about the students' misconceptions if you use a multiple choice question. I have found that about 90% of the students answer "All of the above" and about 10% answer "Function of forearms". As a follow up question, I have asked: Which organism do you think forms a sister taxon with the walrus? About 80% of the students usually answer "Manatee", while about 20% answer "Killer whale". This suggests that most (close to 100%) of the students have misconceptions about analogous structures and convergent evolution and will have constructed their phylogenetic tree incorrectly. I don't reveal the answers to any of the discussion questions at this point as the goal of this activity is for students to correct their misconceptions on their own.

Next, students are asked to come up with a method with which they could verify the evolutionary relationship among the six mammals (discussion question 5). After a brief introduction to multiple sequence alignment, students use an online program (https://www.phylogeny.fr) (Dereeper et al. 2008) to compare DNA sequences (Appendix A). The online program calculates the most likely relationships based on the DNA and draws a probable phylogenetic tree based on the results. Students are asked to compare their predicted phylogenetic tree with the calculated tree and discuss reasons why they may differ (discussion questions 6-7). At this point, gather the class for a discussion about analogous and homologous structures and convergent and divergent evolution. This activity helps students correct their misconception that organisms with similar morphology must be evolutionary related. It facilitates students' understanding of analogous structures as they realize that many features of marine mammals (such as the streamlined body and flipper-like forearms) have evolved independently in several lineages through convergent evolution.

Student Outline

Learning outcomes:

1. Differentiate between homologous and analogous structures.
2. Explain the relationship between homologous structures and divergent evolution.
3. Explain the relationship between analogous structures and convergent evolution.
4. Explain why evolutionary relationships often cannot be determined based on morphology.

Discussion questions:

1. Predict the evolutionary relationship among the following mammals by drawing a phylogenetic tree: killer whale (*Orcinus orca*), manatee (*Trichechus manatus*), walrus (*Odobenus rosmarus*), moose (*Alces alces*), brown bear (*Ursus arctos*) and African elephant (*Loxodonta africana*).
2. Explain why you predict some of these animals to be more closely related (i.e. to be sister taxa) than others.
3. Which type of information would you use to build the phylogenetic tree?
4. Which organism do you think forms a sister taxon with the walrus? Explain what you base your answer on.
5. How can you confirm your prediction?

Multiple sequence alignment

To analyze the evolutionary relationship among these species, you will compare a certain DNA sequence, the cytochrome oxidase subunit I (COI) gene (mitochondrial DNA). This gene is often used for species identification and in phylogenetic analyses. The fact that the DNA sequence of this gene varies enough among species, but stays the same within a specific species makes it ideal as a "species barcode" (Hebert et al. 2003) and can also be used to analyze evolutionary relationships among species.

To compare the DNA of these six mammals:

1. Download the file called DNA sequences.
2. Open up the phylogenetic analysis website called Phylogeny.fr.
3. Go to the Phylogeny Analysis drop down menu and click on "One Click".
4. Copy the DNA sequences for all six species and paste them together into window and click submit.
5. Compare the phylogenetic tree with your own prediction.

Discussion questions (cont.):

6. Did the sister groups in your predicted tree differ from the sister groups of the tree based on DNA analysis? If so, explain how.

7. Why do you think that species that look similar, i.e. that have similar body shape/function of body parts do not always have a close evolutionary relationship?

Materials

Each student need have access to a computer (or at least one computer per group) as well as an internet connection. Students also need to have access to images of killer whale (*Orcinus orca*), manatee (*Trichechus manatus*), walrus (*Odobenus rosmarus*), moose (*Alces alces*), brown bear (*Ursus arctos*) and African elephant (*Loxodonta africana*) and be able to access an electronic version of Appendix A.

Notes for the Instructor

The most important thing to remember during this activity is to allow students to confront their misconceptions and correct them on their own. Therefore, though it is important to gather the class for a discussion before they compare the DNA sequences of the six mammals, do not reveal the correct phylogenetic tree (Fig. 1) until the students have seen it for themselves first. You can choose to present the learning outcomes to students at the beginning of the activity or use them to conclude the activity at the end. This activity works well as an introduction to homologous and analogous structures as well as divergent and convergent evolution. However, introducing these concepts **ahead** of the activity may actually make it less affective. Rather than confronting their misconceptions, students may return to their misconceptions shortly after completing the activity. Therefore, minimal information about how to analyze evolutionary relationships are given in the student outline.

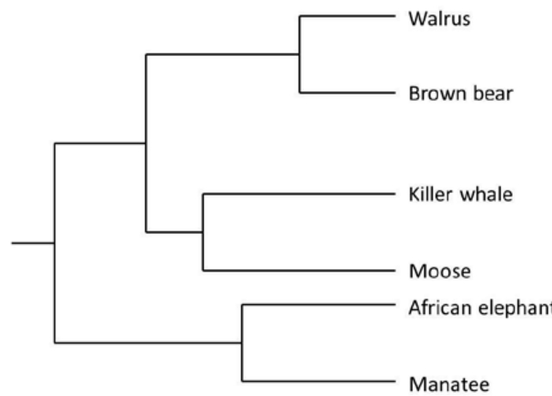

Figure 1. Phylogenetic tree reflecting the most probable evolutionary relationship among killer whale (*Orcinus orca*), manatee (*Trichechus manatus*), walrus (*Odobenus rosmarus*), moose (*Alces alces*), brown bear (*Ursus arctos*) and African elephant (*Loxodonta africana*).

This activity can be expanded upon in several ways. For example, in introductory biology the focus can be on the difference between convergent and divergent evolution, while multiple sequence alignment and species barcoding can be explored further in upper level courses in evolution.

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About the Author

Malin Hansen is an instructor in introductory biology. She has an interest in science education research and is specifically interested in learning how students' mindset affects the way they learn science. She uses active learning to help her students improve their understanding of challenging concepts in biology as well as of how learning works in general.

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Citing This Article

Malin J. Hansen. 2022. Unlikely Sister Taxa - a Tree Drawing Activity That Facilitates Students' Understanding of Analogous and Homologous Structures. Article 29 In: Boone E and Thuecks S, eds. *Advances in biology laboratory education*. Volume 42. Publication of the 42nd Conference of the Association for Biology Laboratory Education (ABLE). https://doi.org/10.37590/able.v42.art29

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