students organize complex concepts and visualize the connectedness of hierarchical groups, yet much of the biological sciences depends on ranking, ordering, or grouping of information. Diagnosing disease, converting units, and evolutionary relationships all follow stepwise ranking of groups of information. This article presents a cooperative, low-stakes, inexpensive method for novice students to organize hierarchical information. As an example, students work together placing and rearranging animal cards according to taxonomic and evolutionary relationships along a string using shared characteristics. The cards provided address Next Generation Science Standards pertaining to inheritance/variation (LS3) and unity and diversity (LS4). I provide a detailed description of the activity as well as the tools needed to perform this lesson.

Key Words: hierarchical information; ranking; evolution; diversity; phylogeny; taxonomy; animals.

Introduction

Concepts in biology are often hierarchical and require students to arrange categories based on size, increasing similarities, order within a pathway, or relationships to each other. Converting units of measurement, relating cell or organ types within and between organ systems, diagnosing diseases from symptoms, and scaling levels of biological organization from cells to the biosphere all use hierarchical systems of organization. Here, I introduce an active-learning strategy, similar to a concept map (e.g., Vanides et al., 2005), in which students work as a class to place cue cards on a string to develop a hierarchical system of organization. Although the method can be utilized in numerous other fields, I describe the activity as it pertains to animal taxonomy and evolutionary relationships and provide all the materials needed for this lesson.

““The physical nature of this activity, adding/removing and sliding cards along the string, allows students to literally visualize hierarchical relationships.”

Overview of the Lesson

Objectives

Students will work together to

(a) group organisms based on shared traits;
(b) classify animals using the hierarchical rankings of taxonomy (Phylum, Class, Order, etc.);

Students sometimes struggle to visualize evolutionary relationships among organisms, given the vastness of geological time and the disparity of phenotypes in modern forms (Meir et al., 2007; Jenner, 2014). Students can, however, intuitively recognize evolutionary relatedness among well-known organisms based on their shared traits. For example, students acknowledge that medical studies performed on mice are more relevant to humans than studies using fruit flies, because humans are more closely related to mice than either is to fruit flies. The activity described here utilizes this intuitive grasp of animal relationships to illustrate how organisms are named and classified (taxonomy) as well as how organisms are related to each other and how traits are shared through common ancestry (evolution and systematics).

In this activity, students use cue cards and a string to group easily recognizable taxa according to shared traits. Each card illustrates a unique animal and contains a short description of the animal that does not provide information regarding higher taxonomy, such as “mammal.” By comparing cards containing recognizable animals, the class works cooperatively to arrange them on the string according to their shared traits. They then draw and interpret phylogenetic trees based on the defined relationships of the provided taxa. This activity encourages students to communicate their perceptions about evolutionary relationships, allowing instructors to address the unique alternative conceptions students bring to the classroom.
(c) draw and interpret phylogenies to represent evolutionary relationships of taxa; and
(d) use appropriate terminology, such as synapomorphies, homologies, and convergent evolution, to support hypothetical relationships.

Materials

- String to span the width of a typical classroom (about 6–9 m; Figure 1)
- Tape or adhesive safe for the wall surface (e.g., painter's tape)
- 10 × 10 cm cards with a unique animal and description cut out and laminated (Figure 2; the full set of cards is available with the online version of this article as Supplemental Material Appendix S1), at least one for each student, plus an additional three to introduce the activity (works well with 20–30 students)
- Small binder clips (2 cm wide), ornament hangers, or clothes pins (5 cm long), one for each card (binder clips work best, because small wooden clothes pins break easily and paper clips are difficult to remove from the string)

Procedure

1. Attach a long string at both ends to a whiteboard or wall with surface-safe tape or putty. Additional supports (tape or putty) along the length of the line may be necessary.
2. Give each student one or more cards containing a picture and short description of an easily recognizable animal (see Appendix S1). Place the clips at the front of the room near the string so that students can grab one for each card they attach.
3. The instructor gives a short demonstration showing how to add cards. First, clip two animal cards to the string. For example, clip cards with animals “A” and “B”. They are related to each other equally and the sequence of cards does not matter: [AB] = [BA].
4. Placing the third card (animal “C”) is a bit trickier. This card can be placed next to one of the animal cards already clipped to the string and distanced from the other as in the arrangement [CA…B], which indicates that animal C is more closely related to animal A than either is to animal B. Alternatively, the arrangement [CB…A] indicates that animals B and C are more closely related to each other than either is to A. In the third possibility, animal C is separated from the original cards [C…AB], indicating that the first two animals are more closely related to each other than either is to the third.
5. One by one, each student adds a card to the string, with other students providing suggestions verbally (Figure 1), building a complex series of relationships (e.g., [CD…… EA…G……….B]). Cards can be rearranged on the string at any time, and students are encouraged to ask for help from the class. The instructor is encouraged to remain supportive, but should not intervene until all students have participated.
6. When all cards are attached, discuss how the animals are grouped. Students often arrange some major groups appropriately, following conventional taxonomic names, such as “arthropods” and “mammals.” The relationships of other groups are less well interpreted, leading to a discussion about animal development or preconceptions of which traits are most informative (see further examples below).
7. Use the students’ groupings to practice drawing cladograms depicting the relationships of the animals in the space below the string. Students should be made aware that the organisms’ evolutionary history falls below the line, not along the line. In other words, Taxon A did not evolve into Taxon B, but rather they share a common ancestor, not pictured, somewhere in the past (below the string). Tell students that the cards represent living organisms, not fossils or ancestors of current animals, and label the string “the present” and below the string “the past.” No card should be placed below another. Demonstrate “rotating the nodes” to show that switching does not affect relationships. Add traits, such as “spine,” to the cladogram as they evolved. Practice using the terminology appropriate to the field (e.g., monophyly, sister taxa, convergence, homolog).
8. Finally, the instructor reveals the accepted “correct” relationships by rearranging cards and drawing or sharing the true phylogeny (see Supplemental Material Appendix S2). Alternatively, students could be tasked with researching current knowledge of these relationships on their own.

○ Discussion

Arranging hierarchical information and organizing complex interconnected concepts can be challenging, but this method provides an inexpensive, straightforward, and visual tool to introduce students to topics that require ordering, ranking, or arranging subgroups. It can be expanded to any field with linear or hierarchical organization of information. Here, I have provided the materials to turn students into taxonomists by comparing organisms and arranging them based on shared traits, but the method can introduce students to other concepts, such as unit conversions or the chronology of geological periods. In anatomy and physiology classes, students might place cards with various cell shapes along

Figure 1. Students take turns adding their card to the string depicting the relationship they perceive its animal has with the other animals on the string. Students ask for advice from the rest of the class. The cards can be rearranged by subsequent students.
The activity relies on students’ incoming knowledge, so it can be arranged by students at any level and specifically addresses preconceptions/misconceptions, which are not easily changed in a lecture format (e.g., Alters & Nelson, 2002; Nadelson & Southerland, 2010). Students frequently overlook the diversity of animals by overemphasizing mammals. I deliberately include cards to represent obscure, but major, phyla while also providing taxa often confused with the wrong groups (e.g., dolphins, bats, and penguins) due to convergent phenotypes.

Students routinely place more importance on habitat than do taxonomists, often correctly separating the vertebrates and “wugs” (worms and bugs), but then lumping the others into a category of “aquatic animals,” including sponges (Phylum Porifera), jellies (Phylum Cnidaria), and sea stars (Phylum Echinodermata), but sometimes including crabs (Phylum Arthropoda) and sharks (Phylum Chordata). The placement of dolphins then becomes a hinge point in the lesson: Do they belong in the “aquatic group,” the “fish group,” or the “mammal group?” Which traits are most meaningful? I also liked the trial and error aspect of the activity! So important for students to see what they know, and then build on it!” – M.C.K., elementary education major

**Enumerating Misconceptions & Jargon**

Although similar to other methods designed to teach phylogenetics and systematics (e.g., Russo et al., 2016; Cruz, 2017), this activity uses real biological examples, rather than artificial objects for which evolution does not explain their classification (Nickels & Nelson, 2005; Lehner et al., 2011); for better or worse, there is scientific consensus on the true phylogeny of these organisms for comparison (Appendix S2). It requires no natural specimens to be collected or maintained (Rea & Hugues, 2010; Flinn, 2015) or bulky specialized equipment (Brown, 2016). Everything fits in a small plastic bag and can be carried between classes until needed.

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to address these common misconceptions and others, such as “Do owls lay eggs?,” “Do bats lay eggs?,” “Are penguins birds?,” and “Are insects animals?”

The physical nature of this activity, adding/removing and sliding cards along the string, allows students to literally visualize hierarchical relationships. By grouping a picture of a dolphin with the mammals, students see that dolphins are more closely related to dogs and humans than they are to sharks. The similar features of dolphins and sharks, namely streamlined body and fins, are convergent, and the less obvious traits of mammals, milk production and four-chambered hearts, are homologous. Furthermore, by physically rearranging cards on the string, students can see that when nodes are rotated and taxa switch positions, their relationship does not change. Therefore, sister taxa are connected through most recent common ancestors (drawn below the string) rather than nearness at the top of an evolutionary tree (along the string). The arrangements [AB…C], [BA…C], [C…BA], and [C…AB] are all equivalent. It is especially important to address this misconception because students, as well as textbook figures, often place humans as separate from other animals or at one end of a phylogeny, reinforcing the ideas that either (1) humans are not part of the evolutionary process or (2) evolution leads to a preconceived goal, with humans at the pinnacle.

## Expanding to Other Taxa

The basic method introduced here is readily expanded or altered to fit other taxa, student levels, or even other subjects. Although it has been used as an icebreaker to introduce tree thinking and taxonomy, it could be used to approach problems after introducing methodology, such as the steps to solving genetics problems. Additional cards could be added after each new concept is introduced and the game played again. Otherwise, students must be sufficiently familiar with the categories within groups. Introductory biology students are not likely to be as familiar with the traits of fungal or plant taxa and cannot as easily compare them as, say, spiders and insects or dogs and birds, even though these kingdoms offer a more linear evolutionary history. More advanced students could work with more specific groups, such as insects. In addition, published genetic sequences could be compared to the students’ morphology-based cladograms using a phylogenetic analysis program like PAUP* (Swofford, 2002). Ideally, the sequences used must be simple enough for students to manipulate, but also provide a manageable number of interpretable trees.

## Supplemental Material

- **Appendix S1.** Animal cards. These cards contain animals representing the nine major phyla in the kingdom. The brief descriptions are to help students recognize the animal but do not indicate relationships among the animals. Cut out along the black box lines and laminate these cards for students to place on the string.

- **Appendix S2.** Current understanding of the evolutionary relationships of the taxa provided in Appendix S1 with distinctive traits of the major groups. The nine major phyla of animals are depicted, as well as members of the major classes of mollusks, arthropods, and chordates: vertebrates.

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## References

Alters, B.J. & Nelson, C.E. (2002). Perspective: teaching evolution in higher education. *Evolution*, 56, 1891.

Berglund, A. (2015). What’s in a word? Concept mapping as a graphical tool to reinforce learning of epidemiological concepts. *Journal of Epidemiology and Community Health*, 69, 1232.

Brown, C.G. (2016). Modeling macroevolution with invented creatures. *American Biology Teacher*, 78, 141.

Cruz, R.A.L. (2017). Here be dragons: using dragons as models for phylogenetic analysis. *American Biology Teacher*, 7, 544.

Flinn, K.M. (2015). Building a twig phylogeny. *American Biology Teacher*, 77, 141.

Hickman, C.P., Jr., Roberts, L.S., Keen, S. L., Larson, A. & Eisenhour, D.J. (2018). *Animal Diversity*, 8th ed. New York, NY: McGraw-Hill Higher Education.

Jenner, R.A. (2014). Macroevolution of animal body plans: is there science after the tree? *BioScience*, 64, 653.

Lehmer, L.M., Ragsdale, B.D., Daniel, J., Hayashi, E. & Kvalstad, R. (2011). Plastic bag clip discovered in partial colectomy accompanying proposal for phylogenetic plastic bag classification. *BMJ* / *Case Reports*, 2011.

Meir, E., Perry, J., Herron, J.C. & Kingsolver, J. (2007). College students’ misconceptions about evolutionary trees. *American Biology Teacher*, 69, 71–76.

Nadelson, L.S. & Southerton, S.A. (2010). Examining the interaction of acceptance and understanding: how does the relationship change with a focus on macroevolution? *Evolution: Education and Outreach*, 1, 82.

Nickels, M.K. & Nelson, C.E. (2005). Beware of nuts & bolts: putting evolution into the teaching of biological classification. *American Biology Teacher*, 67, 283.

Pough, F.H. & Janis, C.M. (2019). *Vertebrate Life*, 10th ed. New York, NY: Oxford University Press.

Rea, R.V. & Massicotte, H.B. (2010). Viewing plant systematics through a lens of plant compensatory growth. *American Biology Teacher*, 72, 541.

Russo, C.A.M., Bárbara, A., Voloch, C.M. & Selvatti, A.P. (2016). When Chinese masks meet phylogenetics. *American Biology Teacher*, 78, 291.

Sommer, R.J. (2008). Homology and the hierarchy of biological systems. *BioEssays*, 7, 653.

Swofford, D.L. (2002). PAUP*: Phylogenetic Analysis Using Parsimony (*and Other Methods). Sunderland, MA: Sinauer Associates.

Vanides, J., Yin, Y. & Tomita, M. (2005). Using concept maps in the science classroom. *Science Scope*, 28(8), 27–31.

Whimsey, A. & Lochhead, J. (1999). *Problem Solving and Comprehension*, 6th ed. Malwah, NJ: Lawrence Erlbaum Associates.

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