

Exploring the Diversity of Life With the
Phylogenetic Collection Lab

● BRIAN T. WHITE

An awareness of the extensive diversity of living organisms is an essential component of a complete biology education. It is important for students to explore the spectacular variety of living things as well as to understand the many solutions to the challenges of living on Earth that have evolved in different organisms. The *National Science Education Standards* (NRC, 1996) require that K-12 students understand that “the great diversity of organisms is the result of more than 3.5 billion years of evolution that has filled every available niche with life forms” and that “organisms are classified into a hierarchy of groups and subgroups based on similarities which reflect their evolutionary relationships” (p. 185). At the college level, Bio 2010 (NRC, 2003) states that biology undergraduates should understand that, “although fundamental molecular and cellular processes are conserved, biological systems and organisms are extraordinarily diverse” (p. 33). Most biology textbooks contain extensive descriptions of the diversity of living things; virtually all general biology courses, at the high school and introductory college level, spend a significant amount of time on this subject.

The data described in this article show that introductory-level biology students at the University of Massachusetts Boston have a very limited awareness of the diversity of living organisms. When most of these students are asked to name different animals and plants, their responses are almost exclusively members of two phyla: chordata and angiospermae. In order to meet the *Standards* described above, it is important that students realize that these two phyla represent only a tiny fraction of the diversity of life on Earth. This article describes a lab exercise, the Phylogenetic Collection Lab, designed to expand students’ knowledge of diversity. In this lab, students collect samples of organisms from 12-16 different phyla that they have chosen from a list of 81 phyla, and discuss their similarities and differences. The data presented here show that this lab exercise significantly increases students’ awareness of plant and animal diversity.

○ **Course Context**

General Biology II (Bio 112) is the second-semester introductory course for biology majors. The course takes place over a 16-week semester; each week consists of three 50-minute lectures given by the author and one three-hour lab led by graduate teaching assistants (TAs). Typically, there are 150-200 students enrolled; most of these are biology majors, some are post-baccalaureate pre-medical students, and a few are majors in other depart-

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ments. In the spring of 2007, when this study was conducted, there were 185 students enrolled in the course.

○ **The Phylogenetic Collection Lab**

The Phylogenetic Collection Lab consists of two parts. The first part takes place over the several weeks before the Phylogenetic Collection Lab session meets; during this time the students collect their specimens. The purpose of this part is to provide a compelling illustration that there is far more to the diversity of life than chordata and angiospermae. The second part takes place in lab where the students present their collections and discuss what they have found. The purpose of this part is to experience the diversity of life: to compare and contrast the different solutions to challenges that all organisms face and to see the similarities and differences that are used to classify living things.

Specimen Collection

The first part takes five to 14 weeks, depending on the constraints of the semester’s schedule. During this time, the students work in groups of one to three to collect specimens of organisms from a specified number of different phyla – in different semesters this has varied between 12 and 16. These specimens must be actual physical samples of the organisms themselves, not photographs, models, or drawings. Students can collect from any phyla of their choosing from a list of 81 phyla provided on the course Web site (<http://intro.bio.umb.edu/111-112/OLLM/112s99/phyla/>). The lab manual instructs the students that, “in order to get credit for a particular phylum, you must bring in something that is clearly recognizable as a member of this phylum to show to your TA. It can be a whole organism or a piece of an organism, but it must be clearly recognizable as a member of that phylum. For example, a dog hair is clearly from a mammal (the only animals with hair) and since all mammals are vertebrates, this is clearly a member of the phylum chordata.” Because the difficulty of finding organisms from unfamiliar phyla is crucial to the experience, I have chosen not to allow students to use photographs of organisms because easy access to the Internet would make the collection process trivial.

I provide the students with several resources to help them find specimens. As the lab has developed over the years, these have included their textbook (Campbell & Reece, 2005), a list of phyla and descriptions on the course Web site (see above), and a book that has brief descriptions of each of the 96 phyla of life on Earth (Margulis & Schwartz, 1998); the number of phyla differs because different authors use different classification systems. I

Table 1. Typical Phylogenetic Collections

GROUP 1		GROUP 2		GROUP 3	
PHYLUM	SAMPLE	PHYLUM	SAMPLE	PHYLUM	SAMPLE
Chordata	Beef jerky	Chordata	Cat hair	Chordata	Pork
Mollusca	Clam chowder	Mollusca	Conch shell	Mollusca	Clam
Basidiomycota	Canned mushroom	Basidiomycota	Mushroom	Basidiomycota	Mushroom
Angiospermae	Sunflower	Angiospermae	Tomato	Angiospermae	Daisy
Pterophyta	Tree fern	Pterophyta	Lady fern	Pterophyta	Fern
Bryophyta	Moss	Bryophyta	Moss	Bryophyta	Moss
Arthropoda	Shrimp	Arthropoda	Shrimp	Arthropoda	Mealworm
Proteobacteria	Cottage cheese	Coniferophyta	Douglas fir	Coniferophyta	Pine
Chlorophytes	Seaweed	Charophycean	Algae	Chlorophytes	Green algae
Cnidaria	Jellyfish	Cnidaria	Jellyfish	Platyhelminthes	Brown planarian
Ascomycota	Bakers' yeast	Ascomycota	Bakers' yeast	Hepatophyta	Liverwort
Echinodermata	Starfish	Echinodermata	Starfish	Ginkgophyta	Maidenhair tree

encourage students to look for organisms from a variety of sources – these include marshes near campus, ethnic markets, supermarkets, fish stores, their homes, their neighborhoods, bait shops, and Boston Harbor.

The major goal of this part of the lab is to push students to look beyond the plants and animals with which they are familiar – to have them see that their knowledge of diversity is extremely limited. In order to achieve this, it is important to oblige them to find organisms from a large number of phyla. This way, students experience diversity directly: While they have little difficulty finding samples of the first few phyla, it is when they have to find the last few that they come to appreciate the diversity of life. For this reason, the choice of the number of required phyla is crucial to the exercise: too few phyla and they will not move beyond the familiar;

too many phyla and they will find it too frustrating to find representatives from rare or difficult-to-obtain groups. The choice of the number of phyla depends on three factors. First, it is important to give students enough time to complete their collections, so requiring a large number of phyla should be coupled with more time for collecting. Second, if students are allowed to work in groups, they have more resources and should thus be expected to collect from more different phyla than if students work alone. Finally, since different references classify organisms into more phyla than others, the choice of reference influences the number of phyla students can reasonably be expected to collect. For example, an excellent reference on phylogeny (Margulis & Schwartz, 1998) lists three arthropod phyla (chelicerata, mandibulata, and crustacea), while a standard general biology textbook (Campbell & Reece, 2005) considers these as belonging to only one phylum, arthropoda.

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Since members of these groups are commonly available, the choice of one reference over the other has a significant impact on the difficulty of the task.

For most of the eight years that I have used this lab, students have been required to collect organisms from 16 different phyla (using the comparatively large number of phyla listed in Margulis & Schwartz, 1998) and have typically had most of the semester (13 - 15 weeks) to complete their collections. In the spring of 2007, I tried a shorter version of the lab where students had five weeks to collect organisms from 12 phyla using Campbell and Reece (2005) and the Web site listed above, both of which list only 81 phyla. Both formats have been highly successful. Whatever the number of phyla required, it is essential to pick a single classification reference or a consistent set of references to avoid disputes over what counts as a “phylum.”

As the students are assembling their collections, I remind them of typical mistakes that have been made in the past. I encourage them to start collecting long before the due date, as getting the last few phyla takes much longer than getting the first few. Students store their collections at home, preserved dry, frozen, or in 70% isopropanol. I also warn them about the trouble caused by

the imprecision of common names. For example: a loofah “sponge” is not a member of phylum porifera, it is actually a gourd (phylum angiospermae); the kiwi fruit (angiospermae) is different from the a kiwi bird (chordata); and, although there is a “black pepper fungus” (oomycota), the spice “black pepper” is an angiosperm.

When the students bring their collections to lab, it is up to each group to convince its TA that its samples are from the phyla stated and to provide evidence as necessary. Collections are scored based on the total number of phyla represented in the collection, not on the particular phyla collected. I typically use a sliding scale where the last few phyla are worth more points than the first. Typically, student groups have consistently been able to collect representatives from the required number of phyla each semester.

In the spring of 2007, students were asked to collect organisms from 12 different phyla. Table 1 shows sample collections from three different groups of students. This table shows the range of different phyla students were able to collect and the creativity students employed in finding representative samples. Some phyla were found by almost all groups; not surprisingly these include chordata and angiospermae. The shaded rows at the top of Table 1 show these and other commonly-collected phyla. However, in

Table 2. Survey Questions and Sample Answers

Pre-Survey: Completed at Start of Semester					
Q1: In each of the spaces below, enter the name of a different living or extinct animal (common names are OK). Choose your animals so that they are as different from each other as possible.			Q2: In each of the spaces below, enter the name of a different living or extinct plant (common names are OK). Choose your plants so that they are as different from each other as possible.		
Responses	Score		Responses	Score	
1. Dog	<i>Chordata</i>	<i>1 Phylum</i>	1. Fern	<i>Pterophyta</i>	<i>4 Phyla</i>
2. Box Turtle	<i>Chordata</i>		2. Bluegrass	<i>Angiospermae</i>	
3. Rabbit	<i>Chordata</i>		3. Lily	<i>Angiospermae</i>	
4. Parakeet	<i>Chordata</i>		4. Spruce	<i>Gymnospermae</i>	
5. Goldfish	<i>Chordata</i>		5. Moss	<i>Bryophyta</i>	
Post-Survey: Completed after Phylogenetic Collection Lab					
Q1: In each of the spaces below, enter the name of a different living or extinct animal (common names are OK). Choose your animals so that they are as different from each other as possible.			Q2: In each of the spaces below, enter the name of a different living or extinct plant (common names are OK). Choose your plants so that they are as different from each other as possible.		
Responses	Score		Responses	Score	
1. Earthworm	<i>Annelida</i>	<i>5 Phyla</i>	1. Fern	<i>Pterophyta</i>	<i>5 Phyla</i>
2. Snail	<i>Mollusca</i>		2. Cycads	<i>Cycadophyta</i>	
3. Beetle	<i>Arthropoda</i>		3. Oak	<i>Angiospermae</i>	
4. Parakeet	<i>Chordata</i>		4. Ginkgo	<i>Ginkgophyta</i>	
5. Porifera	<i>Porifera</i>		5. Pine	<i>Gymnospermae</i>	

Pre- and post-survey and scores from one student; scores are shown in *italics*.

order to complete their collections, students must seek out samples from more obscure groups; the un-shaded rows at the bottom of Table 1 show some of the phyla that were collected by only some of the groups. In semesters when students were required to collect representatives from 16 phyla, there was substantial diversity in the more uncommon phyla.

Specimen Presentation & Discussion

The second part of the Phylogenetic Collection Lab takes place in lab and begins as the TA checks off the collections students have brought. During this time students go around the room looking at the organisms they and their classmates have collected. This on-the-spot natural history museum, consisting of specimens with which the students are intimately familiar, provides a springboard for a series of class discussions. First, the TA puts up a list of all the phyla brought in and the number of samples that belong to each. The class then discusses why some phyla are more conspicuous and easily-collected and thus represented more frequently than others. The class then compares different phyla and discusses the degree of difference between these groups. Finally, students compare and contrast the organisms within each phylum. Students can then bring their collections home at the end of the lab period.

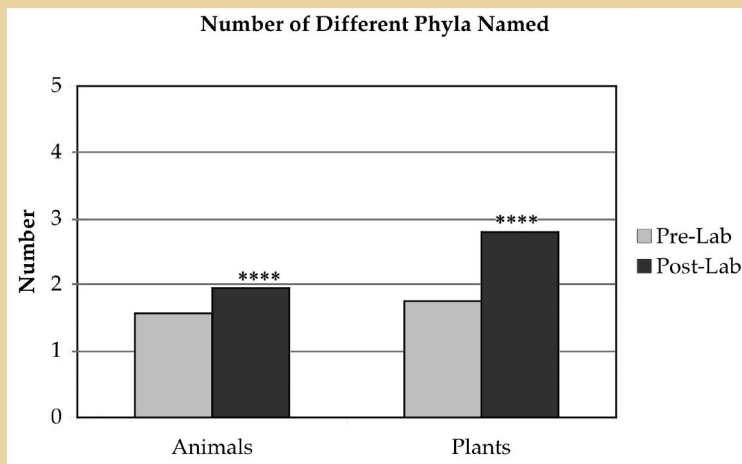
After this lab session, students write a lab report in which each student chooses one phylum that was discussed in class and explores it in detail. First, students choose three organisms from that phylum that were collected by the class. They then describe the common features of these organisms (body plan, habitat, etc.) as well as the differences between them.

I have used this lab exercise successfully for the past seven years. As the students struggle to gather their collections, they have the opportunity to apply their creativity as they explore the diversity of life. I have seen samples from grocery stores, sushi restaurants, veterinarians' offices, rocky intertidal zones, health food stores, and backyards. In the classroom, the natural history museum the students produce provides the basis for valuable discussions of the diversity and range of adaptations found in nature.

○ Evaluation

This lab has a variety of educational goals associated with students' understanding of the diversity of living things. In order to measure the extent to which this lab achieved one of these goals – increasing students' awareness of plant and animal diversity – I conducted a study of the 185 students enrolled in Bio 112 in the spring of 2007 using a pre- and post-survey design. Specifically, the survey used two questions to measure students' ability to name animals and plants belonging to a range of different phyla. The first question asked students to name five different living or extinct animals and to choose those animals so that they were as different from each other as possible. The second question was worded identically, except that it asked students to name five different plants. Both questions are shown in Table 2. All of the students filled out the pre-survey at the start of the semester. During the time between the pre- and post-surveys, lectures and labs described evolution; there was little or no mention of specific phyla. The

Figure 1. Number of Different Plant or Animal Phyla Named



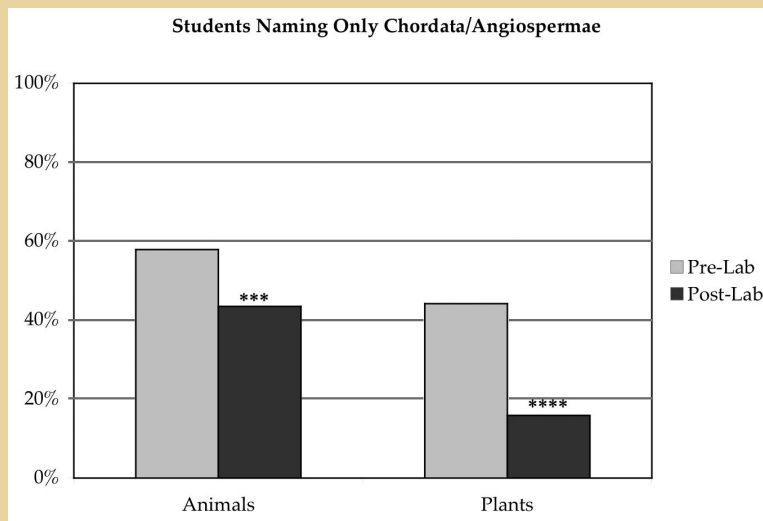
Average number of animal or plant phyla named before or after the Phylogenetic Collection Lab. (**** corresponds to $p < 0.0001$).

post-survey consisted of the same two questions and was administered at two different times. Half of the students completed the post-survey at the start of the Phylogenetic Collection Lab, after assembling their collections but before the discussion; the other half completed the post-survey after the discussion. This design allowed me to separately measure the effects of assembling the collection and the discussion that followed. Students' responses were scored by the phylum to which each animal or plant belonged. All of the surveys were scored by one researcher. As a reliability check, 30% of the surveys were scored by a different researcher; the two researchers' scores showed 96% agreement.

First Analysis

As a first analysis, survey responses were scored for the number of different animal and plant phyla named by each student. For each of the two questions, the scores could vary between one

Figure 2. Students Giving Only Chordata or Angiospermae



Percentage of students whose animals were only chordates or whose plants were only angiosperms. (***) corresponds to $p < 0.001$; (****) corresponds to $p < 0.0001$.

and five. Sample pre- and post-surveys from one student are shown along with their scores (in *italics*) in Table 2. Before the lab, all of the animals named by the student were members of phylum chordata; she was thus scored as having named representatives from only one animal phylum. On the second question, before the lab, she was able to name plants from only four different phyla. After the lab, these increased to the maximum of five phyla for both plants and animals.

This analysis was repeated for all of the students who turned in both a pre- and a post-survey; this amounted to 144 of the 185 (78%) students in the class. These results are shown in Figure 1. They show that the number of animal and plant phyla represented by the organisms named by students increased significantly over the time period that included the Phylogenetic Collection Lab. There was no significant difference between post-surveys completed before or after the discussion, suggesting that the discussion had no additional effect on students' ability to name organisms from different phyla. This is not surprising since most of the students' experience with diversity occurred *before* the lab session as they assembled their collections. Because the two groups of post-surveys were not significantly different, their results were pooled for the remaining analyses.

The data for the class as a whole show that the average number of animal phyla represented increased from 1.57 to 1.95 per student (Repeated measures ANOVA, $p < 0.0001$) with a moderate effect size (partial eta-squared = 0.10); the average number of plant phyla represented increased from 1.75 to 2.8 per student (Repeated measures ANOVA, $p < 0.0001$) with a large effect size (partial eta-squared = 0.46). Although these are substantial increases, there is clearly significant room for improvement.

Second Analysis

As a second analysis, I counted the number of students who could only name organisms from the most common phyla: chordata and angiospermae. The pre-survey in Table 2 was scored as listing only chordata but listing more than angiospermae; the post-survey was scored as naming more than chordata and angiospermae. The results for the class are shown in Figure 2. Consistent with the foregoing results, there was no significant difference between the post-surveys completed before or after the lab discussion; as above, the results were pooled in the following analyses. Before the lab, 58% of the students named only chordates and 44% named only angiosperms. Following the lab, these fractions decreased to 43% and 16% respectively ($p < 0.01$ for both using McNemar's test). This also shows substantial gain with significant room for improvement.

These results suggest that the first part of the Phylogenetic Collection Lab, where students collect organisms from different phyla, has a significant impact on their knowledge of plant and animal diversity. Following the lab, students are able to name organisms from a wider range of phyla than they could before the lab. Interestingly, their ability to name a diverse set of plants increased more than their ability to name a diverse range of animals. Although the students show significant improvement by this measure, their knowledge of diversity is still limited even after the

lab. This finding, along with the fact that most of their learning of diversity occurs before the lab discussion, suggests that the lab discussion could be strengthened to increase student learning.

Expanding the Lab

Based on these, I expanded the lab in the spring of 2008 to include finding the complete classification of as many of the organisms as possible using the NCBI Phylogeny Browser (<http://www.ncbi.nlm.nih.gov/Taxonomy/>) and then using these data to draw a phylogenetic tree. It might also be productive to add more in-depth comparison/contrast of the collected organisms including issues that cut across all living things. These include the following, with sample questions (*in italics*) after each issue:

- Size and Scale. *How do the larger organisms deal with the complications that arise as a result of changes in surface-to-volume ratio?*
- Reproduction. *To what extent does each organism reproduce asexually? Sexually? For sexual reproduction, how does the sperm reach the egg? Are other organisms involved in this process?*
- Gas Exchange. *Which gases must each organism exchange? How have they adapted to do so?*
- Nutrition. *What nutrients does each organism require? Which can it make on its own? How does it obtain the nutrients it requires?*
- Interactions with other species. *How does the organism deal with predators, prey, competitors, and commensals (if applicable)?*
- Habitat. *How do the adaptations you have described above differ between aquatic and terrestrial organisms? Fresh water vs. salt water?*

Using the collection as a concrete basis for the discussion, different instructors can use items from this list or add items of their own so as to reinforce important concepts covered in other parts of their courses.

Conclusion

This article describes a simple and inexpensive lab exercise that increases students' knowledge of plant and animal diversity. The activity provides concrete examples of diversity and an opportunity to discuss phylogeny as well as themes in diversity, both of which are important goals of high school and college biology courses.

Acknowledgments

I would like to thank Andrea Novicki and Jeremy Hatch for their suggestions that led to the creation of this lab. I would also like to thank Bess Thaler, Evelyne Tschibelu, and Lois Luberice for scoring the surveys and Sarah Soule for critical reading of this manuscript. •

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