

Evolution Kills: A Web Resource for Instructors of Evolutionary Biology

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Abstract: We have developed a laboratory course that demonstrates how evolution can be taught as a participatory, investigative science at the undergraduate college or advanced secondary high school level. The course emphasizes the applied importance of evolution to areas such as medicine and agriculture. Because many instructors face budgetary or other constraints, we have developed labs that can be run with minimal resources and a wide range of possible materials. To provide access to these materials, we have created a website aimed at instructors of evolutionary biology (<http://www.evolutionkills.org> OR <http://www.faculty.virginia.edu/evolutionlabs>). Included on the website are detailed descriptions of the course materials, a database of other articles describing laboratory and field exercises in evolution, and links to other sources of information pertinent to the teaching of evolution. We believe that this website provides a much needed resource for instructors of evolution and encourages inquiry-based learning approaches to the study of evolutionary biology at the undergraduate level.

Keywords: evolution, laboratory exercises, online exercises

INTRODUCTION

Over the past two decades, evolutionary biology has developed into a vibrant, investigative science with direct relevance to societal issues such as the origins of infectious disease (Antia et al. 2003) and biotechnology (Wilkinson et al. 2003). The emergence of evolutionary biology as a scientific discipline of direct societal relevance is in stark contrast to the continuing efforts to limit the teaching of evolution in high schools, or to question evolutionary ideas as a valid province of science (Antolin and Herbers 2001; Storey 1997). Unfortunately, at many academic institutions, evolution is still largely taught as a theoretical, dialectical discipline that often only discusses broad conceptual landscapes; it is not regularly taught as an experimental, analytical science of applied relevance on par with physiology or molecular biology. This situation often leaves students with the impression that evolutionary biologists are armchair scientists who do not conduct “real” research, rather than with the impression that modern medicine and agriculture, with direct relevance to their lives, are

dependent on an understanding of evolutionary principles. For example, future medical professionals, many of whom major in biology as undergraduate students, need to understand that evolution can kill, as when disease-causing bacteria evolve antibiotic resistance.

To help rectify this situation, we have developed a laboratory course that serves as a model for illustrating how evolution can be taught as an experimental and investigative science at the undergraduate level. In order to encourage the teaching of evolution at a variety of academic institutions, we have developed labs that can be run with minimal resources and a wide range of possible materials. In order to provide access to these materials, we have created a website (<http://www.evolutionkills.org> OR <http://www.faculty.virginia.edu/evolutionlabs>) that includes detailed descriptions of the laboratory and recitation exercises used for this course. In addition, we have built a database of other exercises in evolutionary biology that can be used in undergraduate or advanced

secondary courses. These additional exercises were gathered from an array of sources, including published books, articles and symposia, online tutorials, educational websites, and course websites from other

institutions. In this paper we outline the exercises that were used for the course and the materials that are available on the website (Outline 1).

Outline 1. Information available on the website

- I. Course
 - a. Sample Syllabi
 - i. Recitation (with TA comments)
 - ii. Laboratory
 - b. Multi-week Laboratory Exercises
 - i. Antibiotic Resistance in *E.coli*
 - ii. Speciation
 - 1. *Phytophthora* Isolating Mechanisms
 - 2. *Microbotryum* Isolating Mechanisms
 - iii. Phylogenetics
 - 1. Phylogeny of “fasteners”
 - 2. Phylogeny of biblical passages
 - 3. Molecular Phylogeny / GenBank Class Project
 - 4. Suggestions for independent GenBank Projects
 - c. Stand-alone Laboratory Exercises
 - i. Sexual Selection/Mate Choice
 - ii. Genetic Drift – Beans
 - iii. Genetic Drift – POPULUS
 - iv. Selection Demonstration – Woosleogy/Dawkins
 - v. Group Selection – POPULUS
 - vi. Calculating Heritability – Butterfly Eyespots
 - vii. Wagner Trees – Phylogeny Reconstruction
 - viii. PAUP – Phylogeny Exercise
- II. Additional Laboratory Exercises
 - a. Multi-week labs
 - b. Three-hour labs
 - c. One-hour labs
 - d. Field exercises
 - e. Online resources
- III. Published Labs
 - a. Exercises – sorted by category
 - i. Behavioral/evolutionary ecology
 - ii. Population genetics
 - iii. Phylogenetics
 - iv. Selection
 - b. Exercises – alphabetical by author
 - c. Complete laboratory manuals (with reviews)

A COURSE EXAMPLE

We have taught Experimental and Investigative Evolution at the University of Virginia for the last several years. This course is taught as a lecture with an accompanying hour-long weekly discussion section. In

addition, a separate laboratory course is available for roughly 20 students to take concurrently or after they have taken the lecture portion of the course. The course is structured around a central theme of the evolution of disease. By focusing on disease evolution,

the course emphasizes the relevance of evolutionary processes to everyday life, thereby disabusing students of the preconception that the study of evolution is a purely theoretical endeavor.

The laboratory class is divided into four learning units: microevolution, speciation, reconstructing evolutionary history, and analyzing genetic change. Within each unit of the laboratory course, students complete a prescribed group exercise, and then individual students or small groups of students propose and test hypotheses that build on the first exercise.

Each unit concludes with student presentations of these independent projects.

Student response to the laboratory course has been very positive, and the course scores are above department averages. In general, students enjoyed the independent, thought-provoking nature of the research projects. Suggestions for improvement include expanding the scope of the course and making the phylogenetics section more exciting. We have included a summary of course evaluations from a recent semester (see Outline 2).

Outline 2. Course evaluations -- Online course evaluations for Evolutionary Biology Laboratory (Biol 403) at the University of Virginia for the spring semester of 2004 are summarized below. We include student responses to questions regarding the effectiveness and structure of the course. Numeric responses range from 1 (excellent) to 5 (very poor). Average responses for all biology department courses are also listed.

QUESTION	Biol 403 Average	Biology Department Average
In terms of helping me learn the material, the course's organization was	1.67	2.04
The quality of assigned reading for this course was	1.67	2.16
In terms of the amount I learned, this course was	1.33	1.84
My overall evaluation of this course was	1.22	2.03

Responses to open ended questions. We have selected responses that pertain to the course structure. Responses complimenting the teaching assistant and two responses to the second question regarding clarity of expectations for a specific assignment were not included.

1. These are the features of the course that I especially liked:

- a. "I liked the experiments."
- b. "I liked the discussion-based setting and the workshopping time allowed."
- c. "The course was a great combination of thought-provoking [sic] and informative without being overloaded with assignments."
- d. "We got to do the learning. We were provided with the resources we needed and got to motivate ourselves to pursue projects according to our own interest."
- e. "We had a lot of independence in our projects and got to study what we were interested in."
- f. "The course definitely encourages independent thought. This is probably the closest I've gotten to practicing real science here at UVA."

2. These are my recommendations for improving the course:

- a. "Feel like my understanding of evolutionary bio is kind of blotchy . . . I know lots about bacterial resistance, phylogenies and DNA typing, but what else is important to evolutionary bio field? Don't know if this can be practically improved in such a lab course though, because I did like learning things in depth."
- b. "I could have used some more time to organize the phylogenetics..."
- c. "Make phylogenetics portion more excited [sic] or take less time/make less percentage of grade."

Sample syllabi for the laboratory and the recitation portions of the course are available on the “Course” page of the website. These are provided to give instructors an idea of how this class was structured throughout the semester. Additionally, there are sections providing links to “Multi-week Laboratory Exercises” and “Stand-Alone Laboratory Exercises.” The multi-week labs were designed to allow students to investigate a broad evolutionary topic in depth over the course of several weeks. Each of these exercises includes detailed instructions for the lab, suggested readings, background material for students, supplies needed, hints for instructors, and relevant, actual data collected by students at University of Virginia (Laboratory Exercise 1).

In all three multi-week labs, students first complete an instructor-led exercise, and then design and complete independent or group projects using the materials and/or information acquired in the first portion of the exercise. For example, in the phylogenetics unit, several short exercises are presented, followed by a longer exercise. The students are first instructed on how to construct a phylogenetic tree using pseudo-organisms, in this case “fasteners” such as different types of nails and screws or different models of paperclips, although real organisms could also be used (several are suggested). After identifying pertinent “traits” of the fasteners, the students construct a simple tree. The next exercise involves developing a “phylogeny” of the biblical passage “And God said, ‘Let there be light:’ and there was light.” Students are given different versions of the passage that originate from different versions of the Bible and are asked to construct a tree that they think represents the chronological evolution of the phrase. The biblical phylogeny in particular demonstrates how the tools of evolutionary biology can be used in academic endeavors outside of biology and can lead to discussions about the differences between cultural and biological evolution.

After these two short exercises, the students are introduced to GenBank, a collection of publicly available DNA sequences. Students learn how to find DNA sequences using GenBank and then how to construct trees using PAUP and MacClade computer programs. The specific group exercise involves a medical mystery, in which the students determine whether staff at a French hospital infected a patient with HIV. The students compare the HIV sequences from two nurses with the sequence from the patient and with the HIV sequences in the population at large. After the students complete this portion of the unit, they are ready to use GenBank and their acquired skills to investigate other biological questions.

Students then propose a project using the sequences available on GenBank and complete independent or small group projects. These projects can include topics as diverse as which humans

colonized New Guinea and Australia or whether the phylogeny of parasites such as *Cryptosporidium* spp. follows the phylogenies of their hosts. The unit concludes with presentations of the GenBank projects. These phylogenetic activities demonstrate how easily available materials can be used to construct effective experimental classroom activities for students. The different exercises described could each be taught independently or, as we have done, as part of a larger section on phylogenetics.

STAND-ALONE EXERCISES

Outlines of “Stand-alone Laboratory Exercises” are also provided on the website. These shorter labs are designed to accompany recitation or discussion sections. Like the longer labs, these exercises allow students to test hypotheses and engage in active problem solving. For example, one short exercise focuses on mate choice and sexual selection in humans. Students propose hypotheses about mate choice in humans and then use singles ads or wedding announcements to test their hypotheses. Projects can address topics such as age differences between mates and how this relates to female reproductive potential, or which qualities, physical or economic, men and women emphasize in their ads. Also included in this section are several exercises using the computer program POPULUS by Don Alstad at the University of Minnesota. This program can be used to demonstrate many concepts in evolutionary biology, from the basics like genetic drift, to more complex topics such as interdemographic group selection.

We recognize that cost is one of the limiting factors when instructors are designing courses. All of the exercises described above can be completed with minimal resources; in most cases, the only requirements are computers with Internet access. POPULUS is free for download, and PAUP and MacClade software can be purchased for relatively low cost. If funds are unavailable for software purchase, there are freeware phylogenetic programs, including PHYLIP that can be used instead. Some of the other exercises, such as the *E. coli* antibiotic resistance lab and the speciation labs using *Microbotryum* and *Phytophthora*, require standard culturing tools and incubators, but none require unusual or expensive equipment.

OTHER RESOURCES

There are many well-designed laboratory exercises that encourage students to test hypotheses and design experiments in evolutionary biology. However, there is no single source that has compiled these exercises. Many of the exercises that test evolutionary concepts are located in specialty-journals or general biology education journals that are not specifically focused on evolution. Therefore, in order to facilitate implementation of laboratory-centered evolution courses, we have assembled an extensive online list of published laboratory exercises that focus

Laboratory Exercise 1: Antibiotic resistance in *E. coli* – Sample Results. Class data from the University of Virginia, Spring 2000.

In this lab exercise, students collected *E. coli* from swabs of themselves and then tested the cultured strains for antibiotic resistance. Figures 1 and 2 show *E. coli* colonies that were grown on eosin-methylene blue agar plates in the classroom. The results show that a quarter of the class harbored antibiotic resistant *E. coli*. This exercise can be used to launch a discussion of how disease-causing organisms can evolve resistance to common antibiotics. Students can then propose independent projects that use the cultured strains to test specific hypotheses about resistance. For example, experiments that investigate competition between resistant and non-resistant strains can be conducted to determine whether there is a cost to antibiotic resistance. Complete instructions for the lab are available on the website (http://www.faculty.virginia.edu/evolutionlabs/Antibiotic_Lab_Web_Page.html)



Figure 1 *E. coli* colonies grown on eosin-methylene blue (EMB) agar



Figure 2. Growing *E. coli* on eosin-methylene blue (EMB) agar in the classroom

ANTIBIOTICS TESTED

1. Ampicillin (Amp)
2. Chloramphenicol (Chl)
3. Kanamycin (Kan)
4. Rifampicin (Rif)
5. Streptomycin (Strep)
6. Tetracycline (Tet)

Class size of 15

Total number of lines grown = 262

12 people with no resistance to any antibiotics (total 216 lines with no resistance)

3 people with resistance

person A

17 lines resistant to Amp, Strep, and Kan

1 line resistant to Kan only

person B

1 line resistant to Amp, Chl, Kan, and Strep

16 lines resistant to Amp and Strep

person C

11 lines resistant to Tet

on evolutionary biology (http://www.faculty.virginia.edu/evolutionlabs/published_exercises.html). These articles were gathered from general biology

education journals such as *American Biology Teacher* and *Bioscene*, from specialty education journals such as *The Plant Health Instructor* and *Journal of Natural*

Resources and Life Sciences Education, and from workshops presented at symposia, such as the Wilson Society and Ecological Society of America. Lab exercises that are part of course websites from other academic institutions are also listed. An additional database of online resources is presented; these resources include professional educational websites, professional organizations focused on evolution and/or biological education, tutorials in evolutionary topics, and modeling software for evolution.

Published activities have been categorized according to broad evolutionary topics, including: behavioral/evolutionary ecology, population genetics, phylogenetics, and speciation. Many of the labs would fit into multiple categories, but all have evolutionary questions at the center of their investigations. At present, we list thirty-nine separate articles describing laboratory exercises. When possible, links to PDF files or to online access of articles are provided. Roughly 75% of articles listed have such links, which provide instant access to these resources. We have provided the bibliographic information for nine complete laboratory manuals that have broadly defined evolutionary themes. Unfortunately, many of these manuals are out of print, and others are difficult to find. When possible, informal reviews by one of the authors (JRV) are listed. The reviews attempt to identify which activities in the manuals are likely to be useful for designing evolution lab exercises, although we have not specifically tested the activities in the manuals.

Finally, in the "Additional Labs" section of our course website, we have included links to other, less formal, laboratory exercises, the majority of which are located on course websites for evolution classes at other universities. Because these course links change frequently, when possible, and with permission from the course instructors, we have provided a permanent link to the information on our website. Frequently, however, we were unable to contact the author of the course material. In these cases, we have simply provided a link to the original source of the material, which may or may not be permanent.

These additional labs are divided into sections according to length/type of exercise (Multi-week labs, three-hour labs, one-hour labs, and field exercises). Within each sub-heading, activities are listed according to what type of materials the lab uses: labs using

organisms, labs using models, and labs using data that are provided. Finally, some of the published articles describing exercises that fit into these categories are also listed. Hence, there is some redundancy between the Additional Labs section and the Published Labs section, but this redundancy is intended to aid instructors by providing more information about the scope of activities available.

Also included on this web page is a section listing "Online Resources." The online resources are provided to give instructors ideas of other of places to look for teaching suggestions and background information. The online resources are divided into the categories of educational websites, models/simulations, online tutorials/activities, and pages of links.

We have also included comments from teaching assistants that taught the recitation/short exercise portion of the course. These comments, with minimal editorializing, are posted alongside the recitation syllabus and should be helpful to instructors planning to use the activities.

CONCLUSION

Evolution needs to be taught as an investigative discipline that forms the essential core of biology education. Biology students at all levels should learn the basic tools of evolutionary biology. We have created a course and accompanying website to encourage this broad educational goal. Because of the number and variety of exercises listed, this website should be a valuable resource for instructors of evolutionary biology at all institutions regardless of the scope of their specific courses or their budgets.

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