

Out of Your Seat and on Your Feet! An adaptable course-based research project in plant ecology for advanced students

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Abstract

University capstone projects can offer science students a rich research experience that illustrates the process of doing scientific research, and can also help students better choose future academic and career pathways. While capstone projects are an effective component of students' learning in the sciences, they are resource and labor intensive for supervising faculty and are not always logistically feasible in understaffed and/or under-resourced departments and colleges. A good compromise is to incorporate a significant research component into upper division classes. This article documents a project I have incorporated into a plant ecology course that I teach every spring. This project gives students a taste of what practicing ecologists do in their professional lives. Students learn how to survey vegetation and environmental factors in the field, apply several statistical analysis techniques, formulate testable hypotheses relevant to a local plant community, analyze a large shared data set, and communicate their findings both in writing and in a public presentation. Over the weeks required for this project, students learn that doing science is quite different from how they typically learn about science. Most say that, while this project is one of the hardest they have completed in their time in university, they appreciate being treated like a fellow scientist rather than as "just a student." Additionally, students' findings often reveal complex and subtle interactions in the plant community sampled, providing further insight to and examples of emergent properties of biological communities.

Learning Goal(s)

- Students will appreciate the time and complexity of performing hypothesis-driven scientific research.
- Students will demonstrate quantitative skills and ability appropriate for an upper-division biology course.
- Students will demonstrate the ability to correctly and succinctly display data and communicate research findings.

Learning Objective(s)

At the end of the activity, students will be able to:

- Articulate testable hypotheses. (Lab 8, final presentation/paper, in-class exercises)
- Analyze data to determine the level of support for articulated hypotheses. (Labs 4-7, final presentation/paper)
- Identify multiple species of plants in the field quickly and accurately. (Labs 2-3, field trip)
- Measure environmental variables and sample vegetation in the field. (Labs 2-3, field trip)
- Analyze soil samples using a variety of low-tech lab techniques. (Open labs after field trip)
- Use multiple statistical techniques to analyze data for patterns. (Labs 4-8, final presentation/paper)
- Interpret statistical analyses to distinguish between strong and weak interactions in a biological system. (Labs 4-7, final presentation/paper)
- Develop and present a conference-style presentation in a public forum. (Lab 8, final presentation/paper)
- Write a publication-ready research paper communicating findings and displaying data. (Lab 8, final presentation/paper)

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Supporting Materials: S1. Plant Ecology Research-Lab 1-greenhouse competition lab pt 1, S2. Plant Ecology Research-Lab 8-greenhouse competition lab pt 2, S3. Plant Ecology Research-Greenhouse activity data template, S4. Plant Ecology Research-Lab 2-plant ID lab, S5. Plant Ecology Research-Lab 3-plant sampling lab, S6. Plant Ecology Research-Lab 4-basic stats lab, S7. Plant Ecology Research-Lab 5-regression lab, S8. Plant Ecology Research-Sample species data, S9. Plant Ecology Research-Sample environmental characteristics, S10. Plant Ecology Research-Lab 6-indirect ordination lab, S11. Plant Ecology Research-Lab 7-direct ordination lab, S12. Plant Ecology Research-Foods, S13. Plant Ecology Research-Foods second matrix, S14. Plant Ecology Research-Field trip logistics, S15. Plant Ecology Research-Red Hills species list, S16. Plant Ecology Research- Red Hills field data sheet, S17. Plant Ecology Research- Red Hills data entry template, S18. Plant Ecology Research-Final presentation scoring rubric and S19. Plant Ecology Research-Final paper scoring rubric.

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INTRODUCTION

Practicing biologists are familiar with the interdisciplinary nature of science and the time it takes to formulate hypotheses, design experiments to test them, analyze data, and communicate results of our findings. Students at the beginning of their academic careers are often eager to undertake research projects, but frequently lack knowledge of the complex logistics of doing research. University capstone projects offer students an opportunity to experience the process of doing scientific research and can also help students better choose among and be more confident about future academic or professional pathways (1), especially for underrepresented minority students (2). It is important to note that collaborative research experiences for K-12 students also help build a scientifically literate populace and help younger students develop scientific skills, which may motivate them to pursue STEM majors in college. (3)

Unfortunately, traditional research internships can be resource and labor intensive for supervising faculty and are not always logistically feasible in understaffed and/or under-resourced departments and colleges; social tensions can also emerge when faculty and undergraduate interact in a research context. (4) Such limitations are especially challenging in institutions such as mine, which focus on excellent teaching with limited focus on research productivity. For example, my department has 800+ declared majors, 17 tenure-track faculty, seven non-tenure track instructors, and one half-time lab technician. All instructors teach three to five courses each semester, in addition to mentoring graduate students, serving on committees, and advising undergraduates prior to registration for courses. Additionally, we have no dedicated research space for faculty; we must either use teaching lab rooms when those rooms are not in use or lab prep rooms. Given the nature of their experimental systems, field biologists are not as constrained for space, but they can be significantly constrained by time. For the field biologists in our department, gaining any significant ground on research projects often happens only between academic semesters in June and July. A good compromise between the desire to offer every student a significant research experience and the logistics of our infrastructure and teaching load is to incorporate a research experience into classes. In this paper, I describe a semester-long research component in an upper division, plant ecology course taught each spring.

Course Logistics

Botany 4600 (Plant Ecology) is offered each spring semester with an enrollment cap of 24 students. It is a four-unit, upper division course that is required for students majoring in agricultural studies and one of four courses that can count as an ecology credit towards a bachelor's degree in biology. Lectures and labs are integrated with three fifty-minute lecture periods and one three-hour lab each week. Prerequisites for the course include a full-year each of general biology and chemistry. I also strongly recommend at least one semester of basic statistics, as we use statistics heavily throughout the course and the research project. In a typical semester, about two-thirds of the students enrolled are junior and senior level biology majors, most of whom identify as pre-health concentrations. The remaining third are majoring in agricultural studies and/or the ecology and sustainability Master's program. Typically, one to four graduate students take the course each spring. Master's students must complete extra

work or projects relevant to their individual research studies. The undergrads seem to enjoy interacting with and looking for leadership from the graduate students.

In lecture sessions, I use a combination of active learning and lecture to explore new concepts, interspersing lecture with in-class exercises, graphs or questions, asking students to work in groups to solve a problem, interpret/generate a graph, articulate testable hypotheses, etc. I endeavor never to talk for more than 15-20 minutes before giving the students time to work with a concept and interact with each other. This decision represents, of course, the age-old compromise that instructors must make between covering what we think is an appropriate amount of content in our specialized disciplines and giving students time to work with the new material. The general arc of lectures over the semester is divided roughly equally to (1) develop an understanding of the concept of biological communities; (2) learn how to measure biological communities and analyze complex data sets; and (3) explore various applications of the community concept in the context of resource management, restoration, and climate change.

Lab sessions are devoted to activities that either reinforce concepts taught in class (e.g. emergent properties of biodiversity) or acquiring skills students will need for the research project and beyond. Labs allow students time to begin learning how to identify plants and sample vegetation, learn several statistical techniques to analyze practice data, do a "dry run" of presentations using data from a greenhouse project, process soil samples and begin entering data after our field trip, work on group projects, and finally present research findings. Except for the final presentation and paper summarizing their Red Hills research, the various lab activities are graded based on completion; this means full credit if submitted on time with 100% of problems honestly attempted. Rather than grade each lab assignment individually, I provide feedback about what they should have seen or produced and ask students who did not achieve the correct answers to see me in office hours for further discussion and troubleshooting of their work.

The Research Project

The research project is a culmination of the many skills and concepts students are asked to learn over the semester. Students gather the data for the project during a day long field trip to the Red Hills Area of Critical Environmental Concern in Tuolumne County, CA. (5) The Red Hills site is distinct from the surrounding Sierra Nevada foothills in that it contains serpentine soils, thus housing a uniquely adapted plant community that differs from surrounding vegetation. Serpentine soils are uplifted seafloor low in calcium, nitrogen, potassium, and phosphorus, and high in nickel and chromium. (6, 7) In general, serpentine soils host endemic and/or highly adapted plant species, and are sparsely covered with plants, compared to nearby nutrient-rich soils.

At the Red Hills site, students work in groups of four to sample vegetation at predetermined permanent sample locations. Each group samples between four and six plots and gathers a small amount of soil from each plot to process back in lab. Students record vegetation and environmental data on pre-made data sheets that they return to me at the end of the day. In the next lab meeting, we process soil samples and begin collating each group's data into a class data set. I add the current year's data to a growing cumulative data set spanning multiple years. As of this writing, we have three years' worth of data to analyze. The resulting data set is comprised of two

matrices: the plant species data and the environmental data for each sampled plot. Students spend the next several weeks working through the data to explore (a) biotic relationships, test hypotheses they formulated prior to sampling vegetation, and develop conference-style presentations and final research papers suitable for submission for publication. As this is a group project, students also assess each group member's contribution to the final project, including self-evaluation of their own contributions. Taken together the final research presentation and paper account for approximately 20% of students' final grade in the course. I also encourage students to present their findings in other public forums such as our annual student research symposium or at regional conferences. Thus far, five student groups have presented their findings to audiences beyond our class, including college and University student research competitions and the national Ecological Society of America in summer 2014.

SCIENTIFIC TEACHING THEMES

How People Learn

This lesson and activities contained herein should appeal to many learning preferences. While data do not support the notion that certain people are "verbal learners" or "social learners" as such, teachers know that, when asked, a learner will express learning preferences that are time and context dependent (e.g., may prefer learning kinesthetically today, but may prefer observational learning in a different activity tomorrow) (8). Elements of this project include writing, displaying quantitative information and designing presentations, data analysis, group work and individual contributions, which should cumulatively appeal to a broad learning audience. Furthermore, this project focuses on a local ecosystem, which inspires some learners to further engage in local and regional environmental issues.

Active learning

In class: small group discussion and/or work, larger group debrief, lab and field activities, data analysis, interpretation and display of quantitative information, evaluation of case studies, experimental design, public speaking, report writing.

Out of class: textbook and primary literature readings, small group work, report preparation and writing, data analysis, background research pertinent to final report presentation.

Assessment

Formative assessments: required lab activities, in-class concept reviews, in-class exercises, in-class discussions, project outline prior to field trip, post-trip project updates.

Summative assessments: second midterm and final exam (all open response questions), final research presentation, final research paper.

Self-reflection: evaluation of each group member's contribution to the research project, including his or her own contribution.

Inclusive teaching

This project fosters inclusive teaching by putting students in charge of their own learning and productivity on the final project. Moreover, the Red Hills is an interesting biological, cultural and historical site easily accessible from our campus and surrounding region. Aside from hosting unique plant and

animal communities due to the nature of its serpentine soils, Red Hills was the site of several Chinese miner camps during the gold rush days of ~1849-1856, and prior to this, the central Sierran Miwok peoples likely utilized the area as a camp for hunting, gathering and processing materials. We go over this historical information before our field trip. Finally, students are contributing to an ever-growing longitudinal data set on serpentine plant communities useful to resource managers and researchers.

I address parity of student contributions to group activities each lab by interacting with each group and asking them how each member is contributing. I monitor group contributions in class and hope students are truthful when they report their contributions to me. I hope that my enthusiasm for the project and constant reinforcement of science as a collaborative endeavor translates to their own perceptions of how much to contribute to the collective group project.

LESSON PLAN

This "lesson" spans an entire 16-week semester; in reality, each lab session could rightly be construed as a lesson on its own. This series of activities is meant to provide a meaningful research opportunity for students in the course in lieu of a faculty-led senior capstone or similar research experience. The entire suite of lessons is modular and adaptable for your class as per your specific system of interest. For example, I have students work in small groups for all labs, but other instructors could opt to have students work individually on the lab activities. Below I describe the general arc of lessons over the semester (see supporting files for specifics of each lab). Table 1 (on page 4 and 5) provides an approximate timeline of labs and brief notes.

Before Field Work

Labs one through nine are critical in helping students build skills required to work with the Red Hills data and to create interesting, effective presentations and reports. Labs one, eight and nine are designed to allow students to assess effects of competition among multiple species in several functional groups. (9, 10) In our very first lab session, we plant seeds of common garden species in pony flats as either monocultures or mixed polycultures (S1). Plants are then allowed to grow in our campus greenhouse for about 7-8 weeks; in lab eight, students count the number of seedlings of each species, harvest all above ground biomass and record mass by species (S2). Students enter data into a template Excel file provided to them (S3) that I then proof and compile into a master data set for the class. My involvement prevents errors of omission, typos, etc. and ensures that the class data set is available to all students within two days. The following week, students present a short summary of their findings related to the effects of competition and biodiversity on plant productivity. This set of lab activities allows students to practice group work, gathering and interpreting data, and communicating results in a public setting. It also allows me the chance to assess which skills students have brought with them to the course and which skills are missing or underdeveloped.

Labs two and three allow students to learn and practice how to identify and sample plants. Since our campus does not have any wild areas with native plants, we make do with having students identify cultivars and sample typical lawn species. In the ID lab (S4) students are asked to describe and name several species each of trees, shrubs, forbs, grasses, lichens

Table 1: Plant Ecology Research-Teaching Timeline

Week	Lab	Notes/Explanation
Unit 1: Learning Plants and Basic Field Practice		
1	Greenhouse: set up competition experiment	Students form groups and plant seeds of common garden plants in mono- and polycultures. Intended to later give students real data and practice in all skills before culmination of Red Hills project.
2	Campus plant walk, ID plants	Students learn to describe plants sufficiently so others can identify them. If nomenclature is not a priority, the morphospecies concept works well. Students must describe/identify three species each of trees, shrubs, perennial herbs, annual herbs, grasses, mosses and lichens. I encourage students to use cell phone cameras to catalogue their species for later reference.
3	Theory and practice of sampling communities	Students gain practice in sampling plant species cover using a quadrat frame both along transects and without transects. Students generate a species-area curve and use rolling average of cover values for a dominant species to determine if they have adequately sampled their “universe”.
Unit 2: Learning and Practicing Statistics		
4	Statistical Methods 1 – The Basics (mean, SD, types of graphs, t-tests, ANOVAs)	Students use practice data sets and guided inquiry questions to learn/practice basic data analysis and generate graphs. Students must use the website VassarStats and one other software such as MS Excel, SPSS, etc. to mine data and generate graphs. Students must report significance values and summarize trends.
5	Statistical Methods 2 – Regression Analysis	
6	Team formation, Statistical Methods 3 – Indirect Ordination	Students use practice data sets and guided inquiry questions to learn/practice indirect ordination and interpret outputs of analysis. Students must use PC-ORD software, although R could also work if users have proficiency. Students must summarize trends.
7	Statistical Methods 4 – Direct Ordination	
8	Process plants/data from competition experiment	Student groups record percent cover and above ground biomass by species for all plantings. Data are collated into a class data set for analysis and reporting. I turn data back over to the class within two days. Presentations are built outside of lab time.
9	Reports from competition experiment, field trip logistics	Student groups give short oral presentations (~10-12 mins) of greenhouse data with Q&A (~3-5 mins) afterward. Hopefully they detect emergent properties of increased biodiversity a’la Darwin and Tilman (3,4). I provide each group feedback and solicit further comment from the rest of the class. Following presentations, each student reflects on their own and other members’ contributions to the presentation, what they did well, what could be improved, etc. Following the greenhouse experiment reports and reflection, we go over field trip logistics, safety concerns, data expectations, etc. I also provide the class with a helpful flora of the Red Hills to aid identification of plants on site. Student groups provide me with a brief outline of their research focus, including hypotheses they might test, how they will modify data (if at all) and what statistics they might use to answer their questions, who will perform what tasks, etc.
Unit 3: Application		
10	Field Trip Prior to this lab Process soil from FT, begin entering/formatting data	Directly upon returning from field trip, I weight soil samples, record mass, and put in ~80° C oven for 48 hrs. Students use this lab session to process soil samples and enter data from field sheets. I then collate data into class data set and fold that into longitudinal data set with prior classes’ data. I have all data ready for students within five days.
11	Work on reports/papers	This week students start wading through data, research primary literature, and otherwise begin working up presentations and reports. Groups typically progress slowly this week. Very quickly I see group dynamics at play (who pretends to help, who will do everything for everyone to get a good grade, how really wants to produce a research project, etc.). I circulate and offer groups feedback on progress, remind them how to use the statistical software, make sure each member is contributing about equally, etc.

Table 1: Plant Ecology Research-Teaching Timeline Cont.

Week	Lab	Notes/Explanation
12	Work on reports/papers	Student groups continue working with data, conducting literature searches, writing report drafts and begin making PowerPoints or some other visual to accompany their oral presentation later in the semester. Work progresses faster as groups become more efficient in their work and delegate tasks among group members. I circulate and offer groups feedback on progress, remind them how to use the statistical software, make sure each member is contributing about equally, etc.
13 Spring Break 14	Work on reports/papers	
15	Work on reports/papers or presentations	
16	Presentations	For the sake of equity, if any group is not ready to present, we proceed as in weeks 12-15. If all groups are ready to present, then we proceed as in week 9, with some modification. Student groups give conference-style presentations (~15 mins) of Red Hills research with Q&A (~5 mins) afterward. I solicit further comment from the rest of the class and make extensive comments in writing for groups to see later. Following all presentations, each student reflects on their own and other members' contributions to the project, what they did good, what could be improved, etc. Student groups give conference-style presentations (~15 mins) of Red Hills research with Q&A (~5 mins) afterward. I solicit further comment from the rest of the class and make extensive comments in writing for groups to see later. Following all presentations, each student reflects on their own and other members' contributions to the project, what they did well, what could be improved, etc. If all groups have presented in week 15, then I offer this lab as a review session for the final exam.
17 Finals Week	Final draft of research paper due	Final drafts of written research paper due at start of final exam time, no exceptions! Of course, if a group submits early that is fine.

Fleming, M.P. 2015. Out of Your Seat and on Your Feet! An adaptable course-based research project in plant ecology for advanced students. *CourseSource*.

and mosses. I ask students to use the morphospecies concept and document all specimens with their cell phone cameras. The objective is that anyone reading the students' plant descriptions should be able to find a specimen of that same species in the field. In the sampling lab (S5), students learn basic sampling techniques that they will use at Red Hills. They practice sampling using various sized quadrat frames, both with transects and without. I ask them to sample enough sites to adequately represent the system of interest, to determine how many sites are enough they must generate species area curves (11), and to use a running average of percent cover of a dominant species. To accomplish these goals, it is necessary to graph values as you gather data: when the graphs level off, then an adequate sample of the system has been obtained.

Labs four through seven introduce students to the theory and practice of statistical methods and software. To avoid issues with students' access to Excel, JMP, SPSS, and similar commercial products, we use the excellent website, VassarStats (12), a free, online computational website with a companion e-text that explains various statistical methods and provides examples of each. Labs four and five (S6; S7) ask students to analyze practice data sets related to species and environmental characteristics for various trends and relationships (S8; S9). Students must compute averages and standard deviation for samples, use t-tests and ANOVA to determine if averages among sampled groups are statistically significantly different, and determine positive or negative associations among species and/or environmental factors. Students must also graph their findings. These activities allow me to assess students' statistical and computer capability, their ability to interpret statistical analyses, and ability to graph data correctly. I praise their ability to do these tasks well and offer help where needed.

Labs six and seven (S10; S11) introduce students to ordination techniques using the software PC-ORD (13). Before using the practice data sets introduced in labs four and five, I provide students with data sets on food preferences of various European populations and characteristics of selected European countries (S12; S13) and walk them through an ordination example using PC-ORD (see S10 and S11 for definition and explanation of ordination). While powerful, PC-ORD is not highly intuitive to novice users, so the food example and guided walk through the data allow students to develop some basic competency in both using the software and interpreting outputs. Around this time in the 50-minute class sessions, I take students through a guided orientation to indirect and direct ordination concepts. (For this class, I omit much of the math behind ordination, since it tends only to confuse students.) Note that, as greenhouse material becomes ready for analysis in the competition activity, I may push the ordination labs back until after students have completed analysis of greenhouse material. In the three years I have taught the course, no students have used ordination to analyze greenhouse data. This is surprising because in two of three years students have learned ordination prior to harvesting their greenhouse material. Perhaps I did not help students better transition from the food examples used in class to plant data, or perhaps they did not yet feel comfortable using ordination to analyze data.

Finally, prior to the Red Hills field trip, I provide an overview of field trip logistics and a handy list of the dominant Red Hills vegetation (S14; S15). Student groups provide me with a brief outline of their research focus, including hypotheses they might test, how they will modify data (if at all), what

statistics they might use to answer their questions, who will perform what tasks, etc. Prior to departure, it is necessary for me to arrange transportation to the site, obtain student drivers, preview the site for safety and accessibility, and gather all needed gear and instruments (see S14). As I do not have any TAs for this course, I also recruit a willing graduate student or alumnus of the class to assist in the field with safety and logistics. By this time, students have already been partitioned into small groups. Often the students self-select into groups, but I once used a 10-question survey and PC-ORD to select groups. In the latter case, PC-ORD plotted students as points in an "ordination space" based on their survey answers; clusters of points in the resulting graph were used to determine group composition. The groups practice setting up the nested quadrat plot layout used to sample the Red Hills vegetation.

The morning of the trip, I make an early stop to purchase donuts and coffee for the students, a tradition introduced by one of my graduate school mentors that I am happy to continue. A rough schedule of the day is as follows:

- 6:00 am purchase donuts and coffee; place coffee in thermos or insulated bag to remain hot
- 6:15 - 7:30 travel to site
- 7:30 - 8:00 greet early arrivers in parking lot
- 8:00 - 8:15 reiterate safely and schedule for the day, disperse survey and soil collection gear
- 8:20 begin surveys on first trail by walking to first sample site; orient first group to that location, then continue to next survey site with next group, etc.
- 12:00 pm return to parking lot, eat lunch
- 12:40 continue surveys on new trail
- 3:30 return to parking lot, collect data sheets, survey gear, soil samples, see students off
- 3:45 travel to CSU Stanislaus campus
- 5:00 weigh wet soil samples in camps lab, record initial mass of each, place soil samples in drying oven
- 6:30 return home exhausted.

Field Work

Field work at Red Hills is for one day only, typically for about seven hours. Twenty-four students can obtain a fair amount of data in this time and, when combined with prior years' work, the work creates a large final data set for students to work with. Over the course of the day, each group can survey vegetation and obtain environmental data for approximately six nested plots.

We begin with an orientation to the site, logistics of the day, partitioning gear and data sheets (S16), and learning to identify many of the common species. Of course, this learning happens as students eat donuts and drink coffee. (One should never do field work on an empty stomach!) We finish by stressing a very important motto I learned once while watching a TV show about the Aquarius Underwater Laboratory off Key Largo, FL (14). A group of aquanauts was about to embark on a week long mission to Aquarius and the mission PI told them: "Safety, teamwork, data...in that order!" Each group has data sheets, quadrat frames, measuring tapes, flagging, pins or rebar to mark corners of plots, and soil collection gear (see S14 for gear and equipment list).

My assistant and I then lead student groups to pre-marked permanent plot locations in leapfrog fashion. I lead the first group to it, point out the four corners of the larger area, give them GPS location coordinates from the WGS84 Universal Transverse Mercator (UTM) map projection, elevation, slope and aspect, and they begin surveying. Besides surveying

vegetation, each group gathers a small amount of soil from each large plot area for later analysis in lab. I remain at the front of all groups along trails, while my student assistant brings up the rear. We communicate via walkie-talkie radios, and s/he sends groups up to me as they finish, so I can assign them to another plot. We survey 18 plots on one trail, take a lunch break back at the parking lot, and then survey 18 more plots on a second trail.

At the end of the day, we meet back at the parking lot, I collect all gear, soil samples and data sheets, and we debrief. It is at this point when many students complain that plant ecology work is hard! I kid them about being soft pre-meds, and for sure they realize that tromping through scratching shrubs in 90+ degree heat, breathing dust, getting sunburned and bitten by flies and ticks, all while trying to get reliable data is what field biology is all about. Back at campus, I weigh all soil samples, record initial (wet) mass, and place in an ~80C oven for 48 hours.

After Field Work

The first lab after field work is hectic! Students process soil samples as directed in the prior week's lab on logistics (S14) and note percent moisture, pH, texture, color, hue, and chroma. I return data sheets to students so they can enter data into a template on MS Excel (S17). Within five days, I collate each group's data into a class data set and add it to the longitudinal data set; this large data set is available to the class prior to the eleventh lab.

Over the next several labs, students analyze data pertinent to their research questions and prepare their research presentations and papers. At the end of each of these labs, each group must provide a written progress report for the week. For the instructor, these sessions offer a nice opportunity to assess which groups work well together and which do not, offer helpful feedback and constructive criticism, keep students within the parameters of the data and tools at hand, and generally just geek out on plant ecology.

On the final lab of the semester, each group presents their findings in class, in research conference style. There are six groups, each containing four members. Each group gives a 15 minute presentation of their research questions, methods (especially, how they treated/modified data), results, and conclusions. The audience then has five minutes for questions. I take copious notes on a rubric (S18) and later provide this information to groups as feedback on their performance. Final drafts of the research paper must be submitted no later than the date of the final exam, and again I use a rubric to score the paper (S19). Taken together, the final presentation and paper comprise approximately 20% of students' final grade. I also ask questions about skills and/or data relevant to the Red Hills research on the second midterm and final exams. Points on these assessments may comprise ~10% of students' final grades.

TEACHING DISCUSSION

The original goal of this lesson/project was to create both an invitation and an opportunity for upper division ecology students to engage in research, as a practicing plant ecologist would do it. In addition to teaching basic field skills, data management and analysis, and communicating research findings, the project also helps students learn other relevant skills such as group work, time management, and how to research a topic beyond Wikipedia. At the core of the project

is the idea that students get to engage in the process of science over several months. By becoming practicing field ecologists for a semester, engaged in all facets of the research endeavor, students gain appreciation for the time and effort it takes to produce a research project worthy of communicating to a wider audience.

I have articulated three learning goals and nine learning objectives for this course. The learning goals broadly address appreciation of the research process and skills needed by students to develop into practicing scientists. By designing a semester-long suite of activities that culminate in a final research project, students realize that research takes time and involves many steps. The plant ID and sampling labs are designed to help students learn how to identify species, survey vegetation (learning objectives c, d). The greenhouse competition lab and red Hills project are designed to enable students to articulate hypotheses that we can address with vegetation and environmental data (learning objective a). The statistics labs and final project are designed to develop quantitative and analytical skills in students (learning objectives b, f, g), and help students relate environmental factors to plant responses in an ecosystem (learning objective e). Finally, all scientists communicate their research finding in open forums, both written and spoken (learning objectives h, i). On the whole, this course and its various content-specific topics and learning activities helps students come away from the class with not only skills and knowledge specific to plant ecology, but general skills that will help them continue to develop into productive scientists in their disciplines. Not all of these students will go on to become plant ecologists, but in whatever science they do practice, they will have ample opportunity to perform experiments, articulate and test hypotheses, analyze data and communicate their findings. This course is specifically built to foster the development of these skills.

This project, while offered in a plant ecology context in my course, should be readily adaptable for instructors who focus on other systems and organisms, such as streams, birds, reptiles, mammals, etc. All supplemental files included with this article can be modified to suit your needs. Additionally, this project is modular. Perhaps you only want to use the statistical module, or maybe you are a botanist and want to teach your class sampling and ID techniques, but save the research component for another course. This is completely appropriate and encouraged.

There are some caveats with this lesson. The first is trouble with plant identification. Any ecologist knows they must make decisions about whether or not to include particular data in an analysis; being a good taxonomist helps minimize loss of valuable species data. It is possible (likely?) that students fail to accurately identify all of the plants that they encounter in the field. My field guide is incomplete, containing only 34 of the most common Red Hills species. No doubt, students encounter some rarer species that are not included. I trust the students to provide good descriptions/morphospecies accounts/cell phone pictures of unfamiliar plants, but that trust requires me to make some decisions about whether or not to lump species together in the large data set. Even species that I cannot confidently identify are included in the large data set, which likely leads to some duplication of species. For example, maybe *Senecio* was in flower last year when we surveyed, but not this year, so students called it a different species this year. In addition, I do blend some other species; for example, annual grasses and perennial grasses are labeled as such in the data set and I may be losing individual species as a result. Thus, counts of

common species are generally accurate in the data while rare species are likely to be underrepresented.

Another caveat relates to the variable quality of student work. Some groups work very thoroughly in the field while some work so quickly that I question the validity of their work. This observation brings up the question of the “speed for accuracy” trade-off in ecology. Gathering a multi-year data set would prove more reliable with the same field crew over multiple seasons. Each new year brings a new cohort of students who must be trained in all aspects of data collection and analysis. In each cohort, some students will be satisfied to gather field data at a surface level (the “good enough for government work” credo comes to mind), while others seem to be very highly vested in the project and work hard to do a high quality job. Not surprisingly, data obtained from vested groups (as determined through field work, data analysis, oral and written reports) are probably more reliable and so I trust it more. Still, each student contributes to the data set, a critical objective, and I am comfortable with the fact that ecological data are, by nature, messy, regardless of the skill of the observer. Discrepant conclusions among groups and aberrant data points attributable to certain groups provide fodder for in-class and written discussion about observer reliability and objectivity among scientists. While the data may be messy due to the “speed vs. accuracy” trade-off, I find that consideration of this messiness by students as they present and write up their findings offers them an opportunity to become better scientists as they progress through their academic and professional careers. Some selected comments from students on this topic (taken from written anonymous comments on end-of-semester course evaluations) range from “it was a great experience” to “you made me feel like a scientist first, and a student second” to “even though I want to go to med school, I can’t drive down the freeway anymore and see vegetation in the distance and not ask myself questions about why those trees are over there - damn you Fleming!” to thanks from those students who went on to win research competitions or got into graduate school after taking my class.

Finally, at a recent conference of biology educators I was made aware that poster sessions, rather than conference style talks, increase visibility of projects like this. I have used in-class oral presentations to date, and I am inspired to change to a poster “open house” next year and beyond. For the in-class presentations, although I have invited other classes, professors, department chairs and the college Dean, attendance by invitees has been very low. As suggested by an astute reviewer of earlier drafts of this project, I will ask the Dean to give an opening welcome, and other professors to come evaluate presentations with awards for “Best in Show.” A poster open house in the building atrium would offer a significant increase in visibility, and could potentially be partnered with other those of other departments and classes. While several prior students have presented their group’s findings in other public forums, a class poster session doing the same would ensure that all groups’ findings were equally accessible to the University community.

SUPPLEMENTAL MATERIALS

- S1. Plant Ecology Research-Lab 1-greenhouse competition lab pt 1
- S2. Plant Ecology Research-Lab 8-greenhouse competition lab pt 2
- S3. Plant Ecology Research-Greenhouse activity data

template

- S4. Plant Ecology Research-Lab 2-plant ID lab
- S5. Plant Ecology Research-Lab 3-plant sampling lab
- S6. Plant Ecology Research-Lab 4-basic stats lab
- S7. Plant Ecology Research-Lab 5-regression lab
- S8. Plant Ecology Research-Sample speciesv2
- S9. Plant Ecology Research-Sample environmental characteristics
- S10. Plant Ecology Research-Lab 6-indirect ordination lab
- S11. Plant Ecology Research-Lab 7-direct ordination lab
- S12. Plant Ecology Research-Foods
- S13. Plant Ecology Research-Foods second matrix
- S14. Plant Ecology Research-Field trip logistics
- S15. Plant Ecology Research- Red Hills species list
- S16. Plant Ecology Research- Red Hills field data sheet
- S17. Plant Ecology Research- Red Hills data entry template
- S18. Plant Ecology Research-Final presentation scoring rubric
- S19. Plant Ecology Research-Final paper scoring rubric

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