Semester-Length Field Investigations in Undergraduate Animal Behavior and Ecology Courses

Making the Laboratory Experience the Linchpin of Science Education

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Undergraduate science laboratory courses often use "cookbook" exercises where expected results are known without the need for thought or experiment The University of Iowa's elective courses Animal Behavior and Ecology provide authentic field study experience for undergraduates using hypothetico-deductive methodology (hypotheses and predictions), experimental design and interpretation, and collaboration, resulting in a scientific paper

Collegiate science education is faced with a dilemma: the skills and experience gained through laboratory science are recognized as a practical necessity for the well-being of individuals and society, yet administrative and budgetary constraints in colleges and universities are undercutting this vital dimension of undergraduate education.

The Commission on Undergraduate Education in the Biological Sciences recommended the adoption of a strong investigative lab component for undergraduate science courses in that body's 1971 report (Thornton 1971). Twenty-six years later, the National Science Foundation (NSF) continues to promote a widely unheeded call for bolstering the laboratory component of undergraduate science for the sake of a future that "... will increasingly require that citizens have a substantial understanding of the methods and content of science and technology—and some understanding of their potential and limitations as well as their interconnectedness" (NSF 1996).

A Rationale for Change

The importance of undergraduate lab science is underscored by findings that identify introductory science courses at the freshman and sophomore years as a crucial link in the chain influencing an undergraduate's decision to major in science (Merriam 1988).

Moreover, the NSF identifies undergraduate science education as "the linchpin of the entire [science education] enterprise—for it is at the undergraduate level that prospective K-12 teachers are educated, that most of the technical workforce is prepared, and that future educators and professional practitioners... learn their fields" (NSF 1996).

In their review of the research on benefits of laboratory investigation, Lazarowitz and Tamir (1994) identified five intellectual gains made by students across studies. Laboratory science provides students the chance to:

- ▲ identify and rectify misconceptions that would likely persist in more didactic science experiences;
- ▲ develop their inquiry and intellectual skills, and appreciate the spirit and nature of science;
- ▲ develop cognitive abilities such as problem solving, analysis, critical

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thinking, synthesis, evaluation, and creativity;

▲ develop attributes such as honesty, readiness to admit failure, critical assessment of results and their limitations, curiosity, risk taking, precision, perseverance, collaboration, and readiness to work toward consensus;

▲ enjoy practical and nontrivial work in the laboratory, which in turn fosters motivation and interest in pursuing study in science (Lazarowitz and Tamir 1994).

Although universal consensus exists for valuing these skills and attributes in every citizen, many science programs are falling short of their realization in undergraduate science coursework. Between 1964 and 1993, the percentage of colleges and universities with an undergraduate natural science requirement that included some form of laboratory work declined from 80 to 30 percent (Moore 1996). From 1970 to 1980 alone, laboratory courses offered and taken by undergraduates in America's colleges dropped by 20 percent (NSF 1996).

This trend led to a scathing 1986 report from the National Science Board that cited laboratory instruction "which has deteriorated to the point where it is often uninspired, tedious, and dull. Too frequently it is conducted in facilities and with instruments that are obsolete and inadequate.... It is also being eliminated from many introductory courses" (National Science Board 1986).

Two pressures have driven this decline (NSF 1996). First, average class size has crept upward at four percent per year from 1979 to 1989. Second, despite an average rise in tuition rates of 25 percent from 1980 to 1992, the cost per student as educational input has risen even faster. The net result—more students and less financial support has stretched budgets for equipment, laboratory facilities, and faculty development. Many institutions, therefore, have made decisions to lower overall costs by reducing the number of lab sections and adding or substituting nonlaboratory courses (NSF 1996).

To reverse this trend, colleges must address budget concerns for lab science, increase student enrollment in lab science, and base laboratory instructional methods on current learning research. More undergraduate laboratory courses are needed that operate on a modest budget, accommodate increasing numbers of students without draining inordinate time and energy from instructors, and that incorporate true scientific inquiry.

A student places monitoring equipment in a pond to measure algal growth as part of a field project on top-down trophic control in ecology.

The undergraduate elective courses, Animal Behavior and Ecology at the University of Iowa, together fulfill these needs through semester-length field investigations. The independent nature of the work allows more flexibility and less integral involvement on a daily basis for the instructors, and the structure (or intentional lack thereof) of the investigations reflects real science complete with unknown and potentially meaningful outcomes. Finally, the cost is negligible compared to more traditional lab courses.

METHODOLOGY

Animal Behavior and Ecology are both undergraduate elective courses. Each has a large lecture section (80 students) supplemented by multiple lab sections (20 students). Lecture section size should have no negative impact on the field investigations so long as adequate teaching assistant (TA) support exists along with adequate field sites.

No definitive student profile exists for either course; enrollees represent virtually every academic major at every level of study, from freshman to senior to graduate student. The discussion component of the two courses was replaced by the current semester-length field studies developed by one of us (CMR) at the University of Iowa in 1992.

At the first weekly meeting of the lab section, students are introduced to the field studies. Three or four tractable behavioral or ecological questions and hypotheses are presented by the instructor (examples of these topics are listed in Table 1).

The initial discussion presents a) background information on each question, including natural history, ecology, taxonomy, and potential hypotheses, b) logistical considerations unique to each topic (e.g., the locations of local public woodlands or ponds to be used as study sites), and c) goals and expectations for the lab, including deadlines, teaming options, and the format of a final write-up (see below). Students then elect to sign up for one of the investigative topics.

Students are assembled into teams of four to five members by virtue of their choice of study. Teams are then responsible for generating predictions that lead to experimental design. At the mandatory second weekly meeting, teams meet to outline their plan for investigation with close collaboration of the lab instructor.

Teams must delegate tasks and de-

Table 1. *Examples of semester-length research projects in Ecology*

Do effects of predation on herbivores affect algal abundance in aquatic ecosystems?
How do top carnivore scents influence attack rates of smaller predators on their prey?
What is the effect of forest fragmentation on bird nest predation?
How does insect galling influence the fitness of goldenrod?
Do animal population densities as well as population sizes depend on the size of the habitat fragment they inhabit?

vise a schedule. Instructors provide the necessary equipment, as well as varying degrees of design and resource assistance. Most subsequent sessions are devoted to independent research. Instructors continue to be on hand during scheduled lab sessions for teams who may need consultation, but attendance at these sessions is not required.

Typically, one or two of five teams from each section may "drop in" during each session, generally for advice on unforeseen difficulties with an experimental design, for help interpreting emerging findings and with statistical analysis and formatting of the paper, and for assistance on locating relevant literature.

One more mandatory lab is scheduled one-third of the way through the semester, where students present a one-page progress report. This allows the instructor a final check on the quality and tractability of each experimental design. Actual time spent in the field has averaged 25 to over 40 hours per student over the duration of an investigation. Example studies are described in Tables 2 and 3.

To ensure that the research conducted by the students bears on a current question or hypothesis in ecology or animal behavior, students are required to generate a report in the form of a scientific paper formatted for the journals *Ecology* or *Animal Behaviour*. Papers include an introduction where students must place their research question in a context of past work, a detailed description of methods and materials, a report of results with tables and/or graphs and statistical analysis, a discussion that compares their findings to initial hypotheses and the findings of others, and a list of the literature cited in the work (a minimum of five references is required).

Instructors provide the service of data review, experimental critique, and statistical consultation throughout the semester at the optional "drop-in" weekly discussion sessions. This practice diminishes anxiety on the part of students who, in the absence of the detailed lab instructions to which they are accustomed, sometimes wonder if they are "on the right track." The research paper comprises 25 percent of the course grade.

BENEFITS AND LIMITATIONS TO FIELD PROJECTS

Although student evaluations of the field studies have been largely positive (sample comments follow), inevitable trade-offs exist in terms of the implementation and evaluation of this style of laboratory.

Benefits

Field studies are real science. The investigations are of current topics of research and results are unknown in advance. Rather than following a "cookbook" procedure, students are given a general problem and some suggestions, but must develop their own hypotheses and predictions and design and carry out their own experiments and observations. They must define appropriate statistical approaches ahead of time, establish random sampling procedures, and adjust procedures when problems crop up.

Field studies in Animal Behavior and Ecology mirror the real world in that they involve hard work, bad weather, complicated data, and unpredictable events (such as road crews mowing down goldenrod halfway through an experiment). Field studies also foster responsibility in students, who must organize time, delegate responsibility, plan and think ahead, and contribute to a final product.

The strength of teaming enables each member—freshman through graduate student—to bring particular expertise in writing, statistics, and experimental design to the investigation.

Field studies are enjoyable for students. At the close of each semester, students are anonymously queried about the field studies. Of the 65 most recent surveys, 61 were positive with regard to field studies. In answer to the question "How useful and interesting did you find the field project, compared to other biology labs you've taken?" representative comments include:

- ▲ This was so much more useful in comparison to other labs. You learn from other people in the lab, and you get to invent an experiment instead of read about it.
- ▲ The projects were very informational and gave me an idea of things an ecologist does. It is more interesting.
- ▲ I enjoyed the field project because it was different and applicable because we did the entire experiment on our own. Most labs you read a text and follow instructions and get nothing out of them.

Occasional comments attest to the value of authentic investigations in attracting new scientists:

- ▲ It was interesting to do a field lab (my first)—reinforces my interest in the biological sciences.
- ▲ I absolutely loved it. I plan on being a field biologist and this was my first true field experience.

The cost of field studies is favorable compared to a more traditional laboratory format. Average cost per student over the three years of implementation for Animal Behavior and Ecology is seven dollars. The materials necessary to run field investigations are under the creative control of the instructor who can guide experimental design, assuring that needs do not get too elaborate.

Common purchases include bricks, eggs, plastic owl models, thermometers, bird seed, and fishing line. Some existing equipment, such as balances and spectrophotometers, are used in some projects for short periods; these should be available in most biology departments.

Limitations

Fair grading of a group product can be problematic, particularly when differential effort occurs among group members. Two instances have arisen out of over one hundred projects to date in which students registered complaints with the instructor over dissatisfaction with team members. Others have commented in response to the survey question, "Were you happy working in groups on your field project?"

▲ We all had very different personalities and conflicted a lot. Writing styles were different, but most of us just dealt with it

▲ It was nice to work in groups, but as always, there was more cooperation from some members than others

To partially alleviate the problem of group incompatibility, students are given the option to generate an individual paper (based on group-collected data), providing they declare a wish to do so by a predetermined date midway through the semester. Few students have used this option; most seem to prefer to work out any difficulties in their groups.

Field projects require more schedule flexibility on the part of students than would a traditional lab format. Although the minimum time commitment required is only 26 hours, many students choose to spend more time. In addition, field work does not lend itself to set two-hours-per-week scheduling because of the vagaries of weather and because many experiments require more intense work at particular times of the season. Students have commented on the surveys that scheduling presents a challenge.

▲ Trying to organize around people's schedules was difficult, but overall there were no problems

▲ Getting everyone's schedules to coordinate was sometimes difficult

In some cases, independent scheduling of the field lab can be an advan-

Table 2 *An example of a field study in Ecology (single hypothesis and prediction).*

General Context. The top-down trophic cascade model (Hairston, Smith, Slobodkin 1960) holds that herbivore abundance tends to be limited by predators. The model predicts that predator removal should allow herbivores to increase and depress abundance of primary producers.

Tractable ecological question. Do effects of predation on herbivores affect algal abundance in aquatic ecosystems?

Hypothesis/prediction: The presence of aquatic predators on herbivores controls the abundance of algae in a pond. The elimination of predators results in increased algal growth. To test the prediction, students constructed herbivore and predator enclosures in a small eutrophic pond. They compared the growth of producers (algae) with and without the exclusion of herbivores (snails) and predators (fish).

Methods: Microscope slides were mounted on bricks (as a substrate for algal growth). There were three treatments: bricks enclosed in fine wire mesh to exclude snails, bricks in a coarse mesh to exclude fish but not snails, and bricks left open to the surroundings. Three replicates of each treatment were submerged at uniform depths near the north edge of the pond in early fall. Fish and snail censuses were conducted periodically. In early November, slides were retrieved and placed in known volumes of 95% ethanol. One week later the ethanol solutions were analyzed using a spectrometer to determine chlorophyll levels based upon absorbance at 410nm. In order to compare the mean absorbance of each cage to the control, *t*-tests were performed. (With three treatments, a one-way analysis of variance is a more appropriate statistical approach. Because many students have not had a statistics course, we prefer to have them use attainable methods that illustrate the philosophy and methods of statistical analysis, and we do not insist on the use of more advanced techniques.) Fish and snail census data complemented the algal growth results.

Equipment. Nine bricks, 18 glass slides, 4' length of chicken wire, 4' length of window screen, one spool of fishing line, fluorescent flagging tape, waterproof marking pen, access to visible light spectrophotometer for one 2-hour session near the end of semester.

Schedule:

- September 7: Identification of topic, operational hypotheses, experimental strategy
- September 14, 15: build and install experimental apparatus
- September through October: (each week) fish and snail census, monitor apparatus, conduct literature search, meet with instructors as needed
- November: remove apparatus, quantify algal growth, tabulate data, conduct statistics, generate paper (with assistance of instructor)
- December: submit work

Table 3. *An example of a field study in Animal Behavior (multiple hypotheses, multiple predictions).*

General Context: Behavioral pattern: American Crows roost in large flocks in cities during the nonbreeding season (September through March). Crows arrive at roost trees at dusk, and leave to feed up to five miles away in countryside at dawn. Are there benefits that balance assumed energy and predation exposure costs of diurnal migration?

Tractable behavioral question: "What is the cause(s) of diurnal migration in nonbreeding American Crows (*Corvus brachyrhynchos*)?"

Hypotheses/predictions: (1) Predation hypothesis: Urban roosting allows escape from nocturnal predators (e.g., the Great-horned Owl Bubo virginianus); (2) Roost microenvironment hypothesis: Urban roosting reduces metabolic costs if city sites have higher night temperatures and lower winds than country sites. These hypotheses make different sets of predictions that do not overlap. The predation, but not the roost microenvironment hypothesis predicts that predators are more common in the country than in the city. The roost microenvironment hypothesis, but not the predation hypothesis, predicts (a) that windspeed is higher or temperature lower in country than in city, and (b) that crows will choose roost trees with low windspeeds high temperatures, and will avoid high winds at the tops of trees.

Methods: Roost trees are located and temperature, windspeed, and owl abundance are determined in both the city and surrounding countryside Owl abundance is determined via censusing by playing an owl hoot tape in both areas

Equipment: A thermometer, anemometer (can be homemade by students), tape recorder (can be in a privately-owned vehicle), and owl hoot tape.

tage It allows for more flexibility in the scheduling of other courses than would a traditional block of time devoted to lab

Instructors are challenged in novel ways as compared to more traditional lab implementation. For example, with no "recipe book" for the field projects, early stages of development require flexibility, imagination, and creativity as students are guided toward tractable experiments that do not require extensive equipment or exhaustive protocol Thorough familiarity with the topics of investigation is mandatory

Instructor commitment is light in mid-semester, but heavy at the front and ends of the field projects when getting students off to a good start and evaluating final projects, respectively, require significant investment of time. More specifically, total time commitment is no greater and perhaps less overall than more traditional lab or discussion sessions—instructors hold scheduled discussion times and office hours and avail themselves by appointment. There have been no significant problems with excessive numbers of students seeking help simultaneously as a result of the drop-in discussion option.

CONCLUSION

When students are provided the opportunity to conduct relevant and extended field and laboratory work, they gain three durable benefits:

▲ they know they have made a small contribution to the field about how nature works,

▲ they gain an appreciation for the methodology of science (potential and limitations), and

▲ most importantly, they gain personal insights that make them more productive citizens whether or not they pursue the sciences as a career

The attributes promoted through laboratory investigation—problem solving skills, critical analysis, synthesis of divergent information, willingness to take intellectual risk, drive for precision, creativity, and consensus building, to name a few—are far too important to reserve for only the select few in the advanced stages of scientific career preparation

Undergraduate semester-length field projects like those that supplement Animal Behavior and Ecology at The University of Iowa can make major contributions to educators' efforts to build a science and technology-literate society ◻

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