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Essay

An Introduction to the Squirrel-Net Teaching Modules

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Abstract

Although course-based undergraduate research experiences (CUREs) are gaining popularity in biology, most are designed for benchwork-based laboratory courses while few focus on field-based skills. Many barriers to implementing field CUREs exist, including the difficulty in designing authentic research that can be accomplished in a limited lab timeframe, permitting and liability issues, and problems gathering sufficient data to meaningfully analyze. Squirrel-Net (http://squirrel-net.org) is a consortium of mammalogists from eight different institutions who have worked to overcome these limitations through four field-based CUREs focused on sciurid rodents (e.g., squirrels, chipmunks, marmots, prairie dogs). Each module is linked to a national dataset, allowing for broader and more complex hypotheses and analyses than would be possible from a single institution. Modules have been field tested at different institutions and are easily implemented and highly flexible for different courses, levels of inquiry, habitats, and focal species. Beyond the basic lesson plan, each module also provides suggestions for adaptation at different levels of inquiry and scaffolding across a course or an entire curriculum. Moreover, our website provides templates to help lower barriers to CURE implementation (e.g., selecting a field site and writing institutional animal care protocols). Here, we introduce Squirrel-Net and give an overview of the four CURE modules. Additionally, we demonstrate how the modules can be used singly or together to provide authentic research experiences to a diversity of undergraduates.

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INTRODUCTION

Hands-on research experiences are crucial opportunities for students to learn about the nature of inquiry, gain confidence in solving problems, and gain self-identify as scientists (1-4). However, most traditional undergraduate research opportunities only benefit a small number of well-prepared students. In contrast, course-based undergraduate research experiences (CUREs) introduce many more students to authentic research experiences. They can therefore increase inclusivity for students who are financially or time-limited (5) and provide equitable access to research experiences early in a college career (6).

Although many excellent CUREs have been developed for laboratory courses in cellular and molecular biology (see CUREnet for examples; 7), CUREs that engage students in field sciences such as ecology are rare (8-10). Nevertheless, they are critically important for several reasons. First, they help prepare students for the workforce by teaching them hard skills used in wildlife and conservation fields. Secondly, they train students in soft skills that employers highly value, such as problem-solving, teamwork, and written communication (11). Third, they allow students to work on authentic data with unknown results, which improves data literacy (12,13). Lastly, they expose students to ecological and environmental threats, as well as how scientists approach investigating and managing these issues.

In spite of these many benefits of field-based CUREs, instructors can be reluctant to develop them. They can be time consuming to establish and maintain, and do not always fit within the time available for a lab section. Working with vertebrates poses additional challenges because of difficulty obtaining Institutional Animal Care and Use Committee (IACUC) approvals and/or institutional support for liability issues (14).

Furthermore, adequate amounts of ecological data can be time-consuming to collect, resulting in insufficient data to analyze for many classes that attempt to incorporate field studies (15).

Squirrel-Net (http://squirrel-net.org), is a group of mammalogists from eight institutions across the U.S. who wanted to integrate meaningful, field-based CUREs into undergraduate biology education. We have designed a series of inquiry-based lessons that engage students in authentic research by examining the ecology of squirrels, a widely distributed, highly visible, and charismatic group of mammals (16,17; Figure 1). These modules are designed to broaden the availability of field-based CUREs and minimize challenges that often hamper their implementation. First, participating students use the same protocols to collect data, which they submit to a multi-institutional database, alleviating the pressure to collect sufficient data in a single course or at a single institution. By combining data across geographic regions, students can evaluate more variables and therefore test a wider range of hypotheses than would be possible in a single class period. This in turn leads to more creativity and control over a project, with the potential to increase student learning gains in scientific communication, persistence in science, self-confidence and self-efficacy (4). The combined datasets also provide ready-to-analyze data for times when individual classes are unable to collect their own data (e.g., due to inclement weather or lack of animal activity), permit inclusion for students with physical disabilities, and can form the basis for activities that focus on data analysis and management. In addition, Squirrel-Net provides templates for institutional approvals (e.g., IACUC, Animal Use Protocols). Furthermore, we have tested each module at different institutions in different semesters and have found they are easily integrated into a wide range of undergraduate courses and can be combined with other Squirrel-Net modules across a curriculum to provide an integrated set of research activities. We offer suggestions on how each module can be used independently or networked with other modules throughout an entire curriculum.

Why study squirrels?

Sciurid rodents (i.e. squirrels) provide an excellent opportunity for field-based behavioral studies. North America has 67 species of squirrels and most are diurnal, readily identifiable, and easily observed (16, 17). Squirrels inhabit diverse habitats and are found on or near most college campuses, including those in urban areas (16, 17). The diversity of squirrel species and their habitats allow for a wide range of student-generated questions, such as how sociality, urbanization, or abiotic factors (e.g. temperature and precipitation) affect behavior. Previous research on behavioral ecology of squirrels has yielded fascinating results. For example:

- Prairie dogs use complex language to describe humans by size, color of clothing, and even presence of a gun (18).
- Ground squirrels chew shed skins of rattlesnakes and apply the saliva to their fur to mask their scent from predators (19).
- Tree squirrels that hoard nuts in multiple locations before winter display seasonal growth in brain size, likely to boost the mental mapping of caches (20).

Figure 1. Why study squirrels?

Not only do our modules lower barriers for using field-based CUREs, they also encourage student engagement. Studying animals is intrinsically interesting and compelling for many students. Specifically, observing live animals can foster strong personal connections with science and nature in students from urban settings, who may be less familiar with wildlife (21). Behavioral ecology studies therefore provide unique opportunities to engage students in the scientific process, from generating and testing hypotheses to strengthening quantitative skills and drawing conclusions from data (22). Furthermore, a sense of belonging to a community is a strong predictor of persistence in science, and this may be particularly important for underrepresented groups (23). Our modules provide this sense of community through increasing collaboration with peers, working more closely with teaching assistants and professors, and providing opportunities to be part of a larger scientific network (24).

Below, we briefly summarize each of the four CURE modules and suggest ways that they can be adapted to different levels of inquiry to be used singly or together in a curriculum.

SQUIRREL-NET TEACHING MODULES

Squirreling Around for Science: Observing Sciurid Rodents to Investigate Animal Behavior

The first module in our series engages students in behavioral observations (Figure 2A) to examine how trade-offs influence the time spent in different behaviors (25). In this CURE, students work in pairs to observe a focal squirrel for 5 minutes each, recording its behavior at 20 second intervals. These data are then tallied to determine what proportion of time squirrels spend in various behavior states (e.g., vigilance or foraging). Additional data such as habitat type, weather, and proximity to humans are also collected, allowing students to test hypotheses about how extrinsic factors influence behavior or questions such as how sociality or urbanization affect squirrel foraging decisions. One advantage of this module is that it requires no specialized equipment (although binoculars or video-recording mobile devices may be helpful). Finally, as student observers are not influencing squirrel behavior, most institutional IACUCs do not consider the module as requiring any assurance or approval.

Figure 2. Students enjoy participating in Squirrel-Net research. Students from Colorado Mesa University and California State University Monterey Bay participate in (A) Squirreling Around for Science (25), (B) Sorry to Eat and Run (26), (C) How Many Squirrels Are in the Shrubs (30), and (D) Squirrels in Space (31).

Sorry to Eat and Run: A Lesson Plan for Testing Trade-offs in Squirrel Behavior Using Giving Up Densities (GUDs)

This lesson plan assesses squirrel foraging trade-offs by measuring giving up density (GUD), or the amount of food left when an animal abandons a patch (26). The concept of GUD is based on optimal foraging theory and represents the point at which foraging benefits no longer outweigh foraging costs

(27). Therefore, a lower GUD indicates either a lower cost of foraging (e.g., a safer patch or food that is easier to handle or digest), a higher benefit (e.g., nutrient-rich food), or both. In this module, students place trays filled with a known quantity of seeds and sand at varying distances from safety (Figure 2B), collect them at the end of the day or night, and then reweigh seeds to determine GUD. Students record data on habitat type, proximity to human structures, seed type, and hours the tray was available to animals (diurnal vs. nocturnal). Results can then be interpreted in simple terms of foraging vs. vigilance or in the context of more complex interpretations (e.g., optimal foraging theory or the "landscape of fear" [28,29]). The equipment needed is inexpensive and readily available (trays, play sand, and a food source), and while the module may require IACUC approval, it requires little specialized instructor expertise to facilitate.

How Many Squirrels Are in the Shrubs: A Lesson for Comparing Methods for Population Estimation

In this more-advanced module students compare the results of three population estimation techniques and evaluate the underlying assumptions of each (30). Population estimates are essential for many conservation and management techniques, and this module reveals to students that these estimates can differ widely based on assumptions and approach. In this module, students estimate the size of a single squirrel population using strip censuses, scat counts (Figure 2C), and camera traps. In strip censuses, students walk transects and record the distance to any detected squirrel. For scat counts, a number of plots within the area are cleared of scat, then new scat is counted on a return visit. Finally, camera traps are used to capture images of the focal species, and students estimate population size from the number of images. A standardized data sheet walks students through the calculations to estimate population size for each technique. Finally, as in the other modules, students also collect additional meta-data including habitat type, proximity to human structures, weather conditions, and other species observed during the surveys. Students can then compare population size estimates from each technique and consider how the assumptions underlying each technique might bias the outcomes. With the accompanying national database, this lab can also be extended to examine how each technique performs under varying environmental conditions (e.g., habitat type), with different species, or under differing community structures (types and numbers of other species). The only specialized equipment needed for this module are camera traps, although laser range finders can also be useful to measure distances.

Squirrels in Space: Using Radio Telemetry to Explore the Space Use and Movement of Sciurid Rodents

This advanced lesson plan using radio telemetry is aimed at upper division students in wildlife and ecology courses. In this module, students use antennae and receivers (Figure 2D) to locate and track radio-collared squirrels in order to better understand how they move in the landscape (31). They also collect data including habitat, proximity of the squirrel to human structures, and weather conditions. These data can be analyzed to answer questions about home range size, avoidance of roads, and interactions with other squirrels or other wildlife. Students can then interpret their findings through the lens of wildlife management and conservation. The lab requires radio telemetry equipment, which Squirrel-Net hopes to have for loan in the near future (for updates, see http://squirrel-net.org). Instructors must also obtain necessary permits and institutional IACUC approvals to trap, handle, and collar squirrels, making this module the most advanced in terms of both instructor facilitation and student skill development.

IMPLEMENTATION OF MODULES

Levels of Inquiry

Although there is some discussion as to what constitutes a CURE (24, 32), at their core, they are inquiry-based activities where students "do" science within a course framework (24). Through the use of authentic research experiences, they provide undergraduate students with the structured guidance and practice to develop the scientific maturity and skills they will need for a successful career in science. Several authors have articulated the concept of levels of inquiry, where inquiry-based activities can be seen as a continuum moving from highly instructor-led to increasingly more student-led (e.g., 33-35). The progression of each of our inquiry-based lesson plans is based on a four-level model (34,36). Our lesson plans are presented at levels of inquiry that are on the instructor-led end of the continuum (Table 1). However, the standardized collection of data and the use of national databases allow considerable flexibility for each deeper level of inquiry, and suggestions for added complexity are given within each module (25, 26, 30, 31) and Table 1.

Scaffolding

The simplest form of each module (i.e., a single, 2-hour lab activity) is presented in each lesson plan (25, 26, 30, 31). However, one of the strengths of our modules is their adaptability; there are multiple ways to scaffold one or multiple modules into a single course or across the curriculum (Figure 3). Alternatively, a single module could be implemented at multiple levels within a single course or across several courses. For example, the Squirreling Around for Science module (25) could be used several times in an introductory ecology course, building complexity by sequentially considering more explanatory variables, exploring the literature to develop hypotheses, and using the national database to augment data and/or practice data "cleaning". Similarly, a single module could also be used at various levels of inquiry across several courses, allowing students to revisit the same research project several times throughout their coursework at increasing levels of complexity (Figure 3). Whether scaffolding within or across courses, focusing on one module or one taxonomic group (i.e., squirrels) can provide cohesion by reexamining a common theme while moving toward more independent thinking.

CONCLUSIONS

Through these innovative modules, Squirrel-Net seeks to lower barriers and increase accessibility to authentic field-based research. The modules are well-suited to this goal because they are easy to implement, often require minimal equipment investment, and have been field-tested with positive outcomes for students and instructors at multiple institutions. Additionally, we provide materials for instructors to work with local, charismatic mammals that are ubiquitous in the United States, including urban areas. Using squirrels as a model system, students can collect data either directly on or near most campuses, reducing barriers for students to access focal species. Finally, our approach is unique because each module connects to a national database, allowing for broader and more complex hypotheses and analyses than data collected from a single institution. The interactions

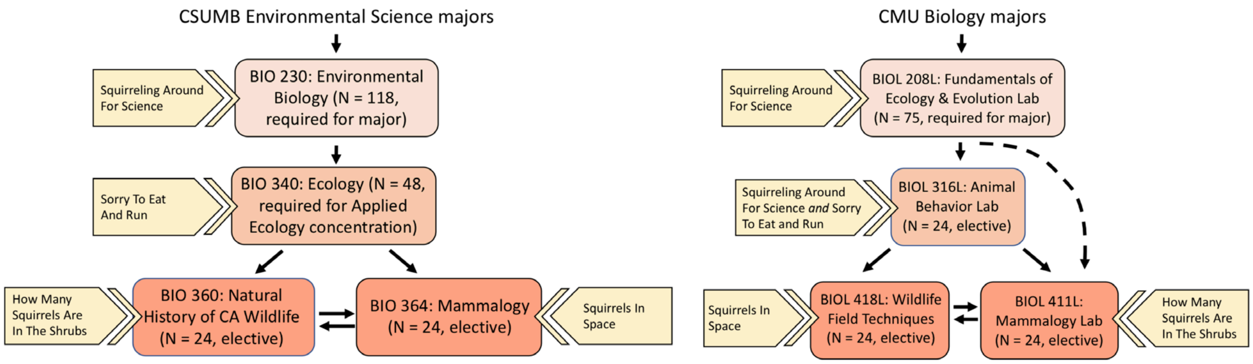

Figure 3. Example of module scaffolding in the undergraduate biology curriculum at California State University, Monterey Bay (CSUMB) and Colorado Mesa University (CMU). Yellow arrows indicate modules which are scaffolded into courses of different sizes (orange boxes); intensity of color increases with levels based on the BioCore Guide (39). In both institutions, students participate in the Behavioral Observation module in an introductory course required by their major. In cases where students repeat the Behavioral Observation module in advanced-level electives, the content and analysis are adapted to higher levels of inquiry (Table 1).

among classes running the same module form the basis for a research network, which helps students develop a sense of belonging to a scientific community and accountability to peers to collect quality data. Each module is highly flexible and can be used at any level of inquiry or adapted to organisms other than squirrels. Lastly, a single module or multiple modules can be scaffolded within a course or more extensively throughout a curriculum, facilitating the intellectual growth of students to become independent and critical thinkers. We believe that this innovative approach to networked, field-ecology focused CUREs permits broad instructor adoption (37) across a wide variety of course levels and institutional types, providing positive student outcomes similar to traditional undergraduate research.

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Table 1. Suggestions for varying the level of inquiry within each Squirrel-Net module. Squirrel-Net modules are designed to be taught at multiple levels of inquiry, ranging from highly structured (i.e., largely instructor-driven) to free inquiry (largely student driven), with an increasing focus on developing data literacy skills (38).

Level	Structured Inquiry	Controlled Inquiry	Guided Inquiry	Free Inquiry
Description	Instructor provides question and hypothesis. Students collect data in class, input into database. Instructor cleans data. Assessment = interpretive questions and/or descriptive statistics.	Instructor provides question and possible explanatory variables. Students generate a hypothesis and prediction within these constraints. Students collect data in class, input into database. Instructor cleans data. Assessment = descriptive and introductory statistics (e.g., t-test, chi-square).	Instructor provides protocol and a set of possible questions. Students generate hypotheses and predictions. Students collect data in and/or outside of class. Instructor may clean data, but may also leave students to resolve data quality issues. Assessment = communication of scientific process, including statistical analyses appropriate for question; no prescribed format.	Instructor provides protocol. Students use literature to generate questions, hypotheses, and predictions. Students collect data in or outside of class. Instructor does not clean dataset. Assessment = communication of scientific process, including literature references and statistical analyses appropriate for question; formal IMRaD format (e.g., conference-style oral or poster presentation, manuscript-style paper).
[1]Squirreling Around for Science (25)	Instructor provides question (e.g., foraging/vigilance tradeoffs relative to safety) concerning one species at a single field site. Students generate predictions individually or as a class. Behavior observation protocol provided. Students collect data. Instructor provides plotted data for interpretation or discussion.	Instructor identifies a limited number of species (1-2) and field site. Students generate hypotheses and predictions related to the species/site. Behavior protocol provided. Students collect data. Instructor provides cleaned dataset and plotted results. Students calculate summary statistics and interpret results.	Instructor identifies species and field sites. Students generate hypotheses and predictions. Behavior protocol provided. Students collect data at least once in or outside class. Students analyze national dataset (cleaned by instructor or raw) to test their predictions.	Students determine species and are provided potential field sites. Students generate hypotheses and predictions. Behavior protocol provided. Students collect data throughout the semester. National dataset is provided for advanced analyses.
[2]Sorry to Eat and Run (26)	Instructor provides protocol, question, and hypothesis. Students collect GUD data with experimental design focused on a single explanatory variable (e.g., cover, artificial light). Students submit data to national dataset, but may only analyze (cleaned) dataset collected in class.	Instructor provides protocol, question, and possible explanatory variables. Students collect GUD data and submit to national dataset. Instructor cleans dataset, but students choose a predictor variable to analyze (e.g., cover, artificial light) based on available data.	Instructor provides protocol and possible questions. Students generate possible explanatory variables with hypotheses and predictions. Students create experimental design and collect data outside of class.	Instructor provides protocol, but students use full scientific process to examine their own question. Students conduct scientific activities throughout the semester, most outside of class.
[2]How Many Squirrels are in the Shrubs (30)	Instructor sets up lesson ahead of time. Students collect data for 3 population estimators (strip census, scat plots, camera traps) in one habitat for one species. One interpretive assignment asks students to reflect on assumptions of each method and which one might be most appropriate for the focal species in the focal habitat.	Instructor sets up lesson ahead of time. Students collect data for 3 population estimators in one habitat, but also analyze national dataset to look for trends in how estimators perform in other habitat types or for species with different natural histories (e.g., ground vs. tree squirrels, communal vs. solitary species). One interpretive assignment asks students to quantitatively compare estimators across explanatory categories in the national dataset.	Students set up activity themselves outside of class (e.g., placing camera traps, clearing scat plots) and collect data in multiple habitats and/ or with multiple species. Possible questions could be based on species' natural history, habitat structure (e.g., dominant vegetation), or survey conditions (e.g., weather). Students analyze national dataset to test their own hypotheses and predictions.	Students set up activity themselves outside of class and collect data throughout the semester. Students generate their own questions and analyze their own data and the national dataset to test their own hypotheses and predictions about the validity of the different methods under different circumstances.

Level	Structured Inquiry	Controlled Inquiry	Guided Inquiry	Free Inquiry
[2]Squirrels in Space (31)	Students track and collect locations for collared squirrels on campus during class. Students submit data to national dataset and instructor provides plotted data to students for discussion and interpretation. One interpretive assignment outside of class.	Students track and collect locations for collared squirrels on campus in class. Students analyze (cleaned) national dataset to compare mean distance of squirrels to landscape features (e.g., roads, habitat edges) in two populations (e.g., ground vs. tree squirrels, urban vs. natural habitat). Students generate a hypothesis and test a prediction (t-test).	Students track and collect locations for collared squirrels on or near campus outside of class. Students analyze national dataset (cleaned). Possible questions assess individual (e.g., sex), environmental (e.g., habitat), or temporal (e.g., morning) predictors of squirrel space use (e.g., distance to landscape feature). Students choose analysis to test their own hypothesis and prediction.	Students track and collect locations for collared squirrels on or near campus outside of class on multiple occasions. Students choose analysis and clean the (raw) national dataset to test hypotheses and predictions generated from literature.

[1]Squirrel-Net module written at the Controlled Inquiry level but is adaptable to any level
[2]Squirrel-Net module written at the Structured Inquiry level but is adaptable to any level