2020

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Lesson

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Abstract

All animals need to find and compete for food, shelter, and mates in order to survive and reproduce. They also need to avoid being eaten by predators. Optimal foraging theory provides a framework to examine the trade-offs individuals make while foraging for food, taking into account an animal's body condition, predation pressure, quality of food resources, and food patch availability in the habitat. Here we describe an activity that uses Giving Up Densities (GUDs), which could be used as part of a course-based undergraduate research experience (CURE) or as a stand-alone activity. GUDs provide an experimental approach to quantify the costs and benefits of foraging in a particular patch and is simple to measure in that it is literally the density of food remaining in a patch. However, its interpretation allows students to compare foraging decisions under different environmental conditions, between species, or with different food sources. This activity was designed to study the foraging behavior of squirrels, which are active during the day, forage on seeds, and are found on and around many college campuses, but it can be adapted to nocturnal animals, birds, or other vertebrates. This module is hands-on. Students weigh seeds, sift sand, walk out into the field with bags of sand and trays, and analyze data. The module can be designed at various levels of inquiry to suit the needs of a particular class. Further, students can work individually, in pairs, or in teams. Finally, students and instructors are encouraged to upload their data to a national dataset, which is available to instructors for use in the classroom to broaden the possible hypotheses and analyses students can explore.

Citation: Yahnke CJ, Dizney L, Varner J, Duggan JM, Erb LP, Lanier HC, Flaherty EA, Connors PK, Hanson JD. 2020. Sorry to eat and run: A lesson plan for testing trade-off in squirrel behavior using Giving Up Densities (GUDs). *CourseSource*. https://doi.org/10.24918/cs.2020.30

Editor: Carrie Diaz Eaton, Bates College

Received: 11/21/2019; **Accepted:** 5/22/2020; **Published:** 9/14/2020

Conflict of Interest and Funding Statement: This material is based upon work supported by the National Science Foundation under a collaborative grant (Nos. 2013483, 2013281, 2013308, and 2013320). None of the authors has a financial, personal, or professional conflict of interest related to this work. None of the authors has a financial, personal, or professional conflict of interest related to this work.

Supporting Materials: Supporting Files S1. Sorry to Eat and Run – List of helpful resources in identifying field sites; S2. Sorry to Eat and Run – Giving Up Density (GUD) student datasheet; S3. Sorry to Eat and Run – GUD activity supplies list; S4. Sorry to Eat and Run – Feeding station set up and break down; S5. Sorry to Eat and Run – Squirrel GUD sample data; S6. Sorry to Eat and Run – R Studio Challenge; S7. Sorry to Eat and Run – R script for box plots and Kruskal-Wallis test; and S8. Sorry to Eat and Run – Herbivore foraging project report assignment.

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Learning Goal(s)

Students will:

- understand how animals acquire and allocate energy.
- develop the knowledge and skills used in designing experiments, analyzing and interpreting data, and communicating results.

Learning Objective(s)

Students will be able to:

- design an experiment to test foraging behavior in squirrels.
- analyze and interpret data using statistical methods.
- solve problems encountered during the field experiment.
- summarize the experiment in a formal paper.

INTRODUCTION

A defining feature of animals is that they are heterotrophic — all animals must find and consume food. For this reason, many behavioral ecologists consider foraging behavior to be among the most important behaviors an animal must do to survive. Optimal foraging theory is a framework that behavioral ecologists use to understand an animal's foraging decisions. It posits that natural selection has favored animals that make foraging decisions that maximize food intake within a set of environmental constraints, including but not limited to: an animal's body condition, predation pressure, the quality of the food resource, and food patch availability in the habitat (1,2). Put simply, animals behave in ways that lead to the highest benefit with the least cost for a given situation. For example, animals can maximize their energy intake per food item by minimizing search time and handling time (i.e., the amount of time required to catch and prepare a food item to be eaten) or by maximizing energy intake per food item (i.e., searching for calorie-rich food). The risk of predation can also affect foraging decisions, including patch use and vigilance (3). When foraging in a patch, an optimal forager should remain feeding in the patch as long as the harvest rate in the patch exceeds the sum of the various foraging costs (3).

One way to assess foraging decisions is by using Giving Up Densities (GUDs), an experimental approach to quantify the costs and benefits of foraging in a particular patch (3). GUD is very easy to measure experimentally – it is literally the amount of food left when an animal no longer forages in a patch. However, its interpretation is a bit more complex; it integrates the value of a food item (relative to the quality and availability of other food in the environment), the animal's physiological condition (energy demands), and environmental risks (e.g., perceived predation pressure or competition). In other words, GUD helps us understand animal foraging decisions because it indicates the cost-benefit ratio of foraging at that patch; lower GUD indicates a lower net cost and/or a higher benefit of the food item. Since it was first introduced in 1988 (3), GUDs have been used to study foraging behavior in fishes (4), birds (5,6), and a variety of mammals (e.g., 7,8), including larger mammals like ibexes (9).

A few lab activities have been published using GUD to help students understand optimal foraging theory, but these activities focus on analogy rather than experimentation with animals in the field. One activity uses dice, cards, and chips to play a game teaching the roles that competition and predation play in foraging decisions (10). While giving useful background information, this game does not allow students to observe the behaviors in actual, living organisms. Two other published GUD activities involve campus wildlife, but the hypotheses that can be tested using data from a single campus are limited (11,12).

Here, we describe an activity that measures GUDs of squirrels, a common and charismatic mammal found on most college campuses (13). Students fill feeding trays with a known quantity of food and sand and leave them out for a given amount of time. They then measure the amount of food left in them, or GUD, to quantify foraging decisions and costs. With data from their own campus, students can compare foraging behavior of a single species by measuring GUD in trays under varied conditions (e.g., cover vs. out in the open, or near vs. far from humans and their structures). Students can also enter data into a national database comprised of data collected in the same manner from campuses across the United States. With a larger data set and a series of standardized variables collected among classes, students can compare GUDs between multiple species to test differences in foraging behaviors between various habitats, weather conditions, degrees of urbanization, diurnal vs. nocturnal organisms, and bait types. The larger data set allows for a much broader range of potential hypotheses as well as more sophisticated analyses (e.g., multifactorial tests).

Rationale and Origin of Lesson

This module is one of four teaching activities from Squirrel-Net (http://squirrel-net.org). Squirrel-Net is a group of biologists from a wide variety of teaching institutions who came together to create evidence-based instructional practices for mammalogy courses that were flexible enough to be used in other courses. All of the Squirrel-Net modules have therefore been designed to be adaptable to multiple levels, from a single two-hour laboratory period (basic skills acquisition) to a semester-long student-driven research project (open inquiry). In each module, students submit data to a national dataset that aggregates observations from multiple institutions. Students can access and analyze the freely available national database, which allows them to explore their hypotheses across a broader variety of habitats and species than would be possible at a single institution.

In the current lesson plan, we describe the most basic implementation of this GUD module (i.e., basic skills acquisition in two, two- or three-hour laboratory periods with outside work required); however, for more advanced students and/or courses, instructors might consider transferring some of the preparation (e.g., study site selection, use of camera traps, preparation, etc.) to the students themselves. Furthermore, additional class periods can be devoted to conducting the same protocols on a different species and/or habitat or to querying the national dataset to test hypotheses about how different factors affect GUDs. This module is flexible enough to be used on its own, in tandem with one of more of the other modules or expanded into a semester-long Course-based Undergraduate Research Experience (CURE).

Intended Audience

This lesson is intended for introductory core and upper-division elective undergraduate biology and environmental science courses. In the past, it has been taught in a first-year principles in biology course, a sophomore level ecology and evolution course, and upper level mammalogy and natural history courses. It has been implemented for freshman, sophomore, junior and senior-level biology and wildlife ecology majors at five undergraduate-focused, four-year institutions and one R1 institution. Thus, students in these courses are extremely diverse in terms of their preparation and their quantitative and verbal skills. Many of these students come from rural areas of the country and are interested in pursuing agency careers in wildlife and/or land management or professional careers in health care, laboratory sciences, or education that require research skills (14). The lesson has been used in classes ranging from 10-48 students.

Required Learning Time

This lesson was designed for two, two- or three-hour laboratories with work outside of the lab periods to deploy the trays and measure GUDs. It can be easily expanded to cover multiple class periods or semester-long projects or scaffolded with other Squirrel-Net CURE modules (14,15,16,17) within the same course or across the curriculum at an institution. See the Teaching Discussion for more details on reducing the lesson to a single lab period with outside work or expanding the lesson to include structured and open inquiry activities.

Prerequisite Student Knowledge

Students would benefit from a basic understanding of experimental design and hypothesis testing. Specifically, students should review the concepts they learned about scientific inquiry in their introductory biology text (e.g., Chapter 1 in [18]) pertaining to independent versus dependent variables. Students would also benefit from a basic understanding of the constraints and trade-offs for animals foraging and how GUDs are used to understand these trade-offs (e.g., Chapter 51 in [18] on balancing risk and reward, Chapter 8 in [19] on foraging behavior). If these topics have not been covered in pre-requisite courses, then they will need to be covered, at least briefly, in the current course. Alternatively, the instructor can assign a paper to introduce these concepts (e.g. 1,3).

Prerequisite Teacher Knowledge

We recommend that instructors are familiar with optimal foraging theory and understand the constraints and trade-offs for animals foraging (1,2), as well as how GUDs can be used to understand these trade-offs (e.g., 3-9). Instructors will also need a basic knowledge of the ecology and natural history of the squirrel species in the region (Supporting File S1. Sorry to Eat and Run – List of helpful resources in identifying field sites, see also 13, particularly Supplementary Data SD1A and SD4). For example, some species of ground squirrels are not active year-round while tree squirrels will be active year-round.

SCIENTIFIC TEACHING THEMES

Active Learning

Although the data collection protocols are prescribed (indeed, a key goal of the activity is teaching students how to solve problems when implementing the methods), students are central to actively formulating hypotheses and predictions. The hypotheses can be based on either the dataset created at their institution or with the national dataset. The students will also actively analyze and interpret the data in terms of the trade-offs and risks animals face when engaging in foraging. Students must also work together to implement the experiment and solve unforeseen problems in the field. We also use small group work during the lesson.

Assessment

Instructors have a variety of options regarding the assessment of this activity. We believe that research is not complete until it is shared, and our assessments reflect this value. Instructors that have implemented this GUD activity have had students write individual formal lab reports, collaborative formal lab reports or prepare poster or oral presentations (individually or as teams). An important part of the reports and presentations is to graphically display the results, as well as offer an interpretation of the GUD findings. We will focus on assessment through individual or collaborative writing.

Inclusive Teaching

Squirrel-Net modules in general are designed to provide all students in a class with the opportunity to engage in authentic research experiences. Participating in CUREs, like Squirrel-Net, has been shown to have significant impacts on students' sense of self-efficacy as a scientist and may promote retention in science, particularly for students from under-represented groups (20). One unique element of this CURE is the use of the national network, which we believe will further help students feel as though they are making important contributions and belong to a broader scientific community beyond their specific classroom or institution (21).

Depending on how the instructor implements this activity, there are numerous opportunities for active learning techniques such as multiple-hands, multiple-voices, think-pair-share, and whip arounds, each of which provide a less-intimidating opportunity for all students to contribute their voice to the discussion (22). We have also used jigsaw to dissect primary literature articles (e.g., 4-9) related to the activity. This can be done separately in a 50-minute lecture period or a shorter version can be incorporated into the first lab instead of the prompt we recommend in the lesson plan. Finelli et al. (23) provide an excellent lesson on how to use a jigsaw with primary literature.

LESSON PLAN

Pre-Class Preparation

Before commencing this activity, students should learn about optimal foraging theory, e.g., through reading a primary literature article or reading an introductory biology or ecology textbook (17,19). In an upper level Mammalogy course, for example, they read the Catania and Remple (2005) paper on star-nosed mole foraging (24). Alternatively, the instructor could have students read a paper (e.g., 3-9) during or before a lecture period and engage in a jigsaw activity (23) before the first lab. With a global pandemic of coronavirus impacting universities nationwide in 2020, students could also read a paper on landscape of fear ecology (25,26). This topic is closely tied to the study of GUDs (26) and may be more relatable for students that experienced anxiety during this pandemic.

This lesson requires students or instructors to identify field sites that have the focal squirrel species of interest (Supporting File S1. Sorry to Eat and Run – List of helpful resources in identifying field sites, 12). Students can work individually, in pairs, or in teams of three or four depending on supplies and class size. Instructors should hand out the GUD datasheet (Supporting File S2. Sorry to Eat and Run – Giving up density (GUD) student datasheet) and review the protocol and data students need to collect. Students should identify a study site where they can deploy seed trays to collect GUD data. These sites can be near their homes, appropriate sites on campus, or parks and nature reserves close to their campus. Instructors should contact groundskeepers, managers, or other personnel for appropriate permissions. Because squirrel behavior is manipulated, an IACUC protocol may be required. This can take time to write and be approved by an IACUC committee. In some cases, students might also put out signs to signify research in progress. Identifying the sites and focal species, contacting the groundskeeper, and making informational signs will take two or three hours depending on familiarity with the campus and surrounding area. Give each site a name (e.g., Student 1 house, Science Building, Oak Trail Reserve), provide a GPS location for the trays (this can be done with a smartphone by going to Google maps and pressing and holding until a pin is dropped or with free apps like GAIA GPS or Handy GPS), and record the habitat type (e.g., urban, desert, deciduous forest, campus, etc.).

Instructors should prepare a brief introduction to the natural history of the local or focal squirrel species. The introduction should include information on diet, active times, habitat preferences, native geographic range, primary predators, and photos to help with identification. Gathering this information should take about 30 minutes. Instructors should have the supplies and equipment prepared for the lab. A list of supplies with approximate costs can be found in Supporting File S3. Sorry to Eat and Run – GUD activity supplies list. Decide on the food you will use like shelled sunflower seeds and measure 100 grams into small, labeled resealable bags (i.e., enough for four sampling periods). Instructors should hand out written instructions for students (Supporting File S4. Sorry to Eat and Run – Feeding station set up and break down). Instructors will need to consider the logistics of making these supplies available to students outside of class time. For example, one author has a small table with a scale, buckets of sand, sifting screens, broom and dustpan, etc. outside his office door (Figure 1).

Progressing Through the Lesson

1(a). Lesson introduction and assessing prior knowledge (15-30 minutes).

We began the class with a review of optimal foraging theory and the basic idea that animals will forage in a depletable food patch until it is no longer profitable. Yahnke (2006) suggests discussing with students how they themselves are optimal foragers prior to beginning the GUD exercise (27). We used a think-pair-share activity with the following prompt: "Give examples of how decisions you make regarding foraging and feeding can be explained using optimal foraging theory or the landscape of fear". For example, how could "fast food" be considered an optimal foraging choice?" As another example, Joel Brown used a metaphor of considering how people in differing behavioral states consume a bag of potato chips, which represents a depletable resource (28). Specifically, many people give up foraging in this resource patch once they have consumed all of the large, complete chips; others deplete the patch down to the crumbled pieces of chips or even lick their finger to retrieve the very last crumbs of the resource. Just as in nature, the choice of when to stop foraging in this case depends on many factors, including the forager's personality, hunger state, and environment.

Figure 1. Workstation where students can sift sand, weigh seed, pick up trays and datasheets, and get help when the instructor is in the office.

We next provided a short natural history of focal species in the study area. For example, squirrels come in three general types: ground (e.g. Figure 2A-C), tree (e.g. Figure 2D-F), and flying, which will affect what a squirrel considers "safety" on the data sheet. If you have access to a mammal collection, you can include study skins of the regional squirrels to help students familiarize themselves with species identifications (Figure 2). Our students benefited from participating first in the Squirrel-Net behavior module as a way of learning about the local squirrel species as well as observing foraging and vigilance behaviors (15). This helped them better understand the trade-offs between these two behaviors as they relate to different species characteristics (size, boldness, food preferences, etc.).

Figure 2. Representative tree and ground squirrels from the mammalogy teaching collection at the University of Wisconsin - Stevens Point. Ground squirrels include (A) Eastern chipmunk (*Tamias striatus*), (B) Thirteen-lined ground squirrel (*Ictidomys tridecemlineatus*), and (C) White-tailed prairie dog (*Cynomys leucurus*). Tree squirrels include (D) Eastern gray squirrel (*Sciurus carolinensis*), (E) Eastern fox squirrel (*Sciurus niger*), and (F) Red squirrel (*Tamiasciurus hudsonicus)*. Photo by Christopher Yahnke.

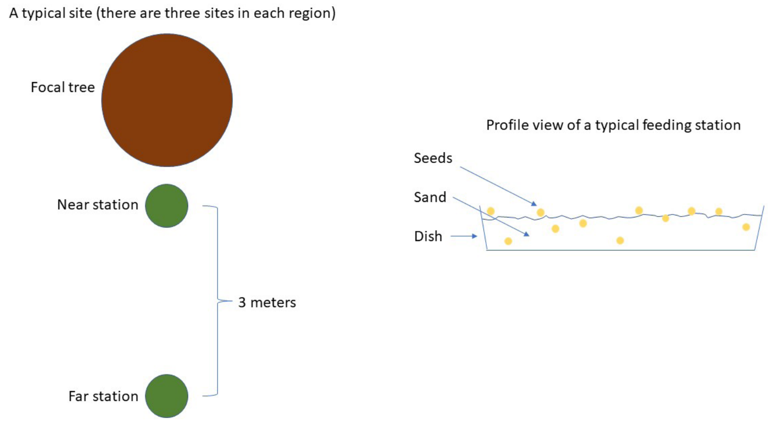

Figure 3. Feeding station diagram showing the general set up of a tray with sand and food, as well as the general placement of the trays at a study site. The experimental design depicted in this figure is for a study of tree squirrel foraging behavior near and far from "safety" (i.e., a tree). This image was modified from Dr. Brian Barringer who implemented the GUD module in a sophomore-level biology course at the University of Wisconsin - Stevens Point (used with permission).

1(b). Setting up the trays (30 -60 minutes).

The activity requires students to deploy trays at sites they have previously identified, so the first lab period is designed to work through the logistics of the experiment. We start by reviewing the GUD data sheet (Supporting File S2. Sorry to Eat and Run – Giving up density [GUD] student datasheet). Each team should have eight datasheets that correspond to the eight data points they will collect (i.e., two trays x four days). To set up the trays, each team will need the following items: two 14″ (36 cm)-diameter green trays (Supporting File S3. Sorry to Eat and Run – GUD Activity Supplies List), prepared resealable bags of food, and seven data sheets (they should have one started from the pre-class exercise). Students then measure 3 liters of play sand into a container, and using a wire screen, sift the sand into the green tray (Figure 3). Play sand contains small stones that will not fit through the screen mesh. Students should separate the stones from the sand before the first field day; doing so will make it much easier for them to separate the leftover seeds from the sand at the end of the experiment without having to pick through small rocks. Using a digital scale, students then measure 10 grams of seeds (we recommend using shelled sunflower seeds) and spread them evenly through the sand. It is important that the sand is dry so that the seeds do not absorb the moisture in the sand. If the trays will not be deployed within the next day, seeds can be stored separately in a clean resealable bag and added to the sand at the time of deployment. Each team should prepare two trays.

2(a). Experimental design (30-60 minutes).

There are several different experimental design options, providing considerable flexibility to test a variety of hypotheses. The basic model involves each student or team deploying a pair of trays for four days each (Figure 4A). Trays should be placed in pairs to provide individual squirrels with a choice of microhabitats (i.e., near vs. far from cover). Students could also compare different food items for the squirrels in addition to or instead of different microhabitats (Figure 4B). Finally, students could compare two time periods during the semester (e.g., early fall and late fall) or different habitats (Figure 4C). Details about extending the lesson into a semester-long CURE are discussed in the teaching discussion.

2(b). In the field (1-2 weeks).

Regardless of the design, we suggest deploying trays for four days each during either the day or the night, depending on whether the targeted species are diurnal or nocturnal foragers. For many squirrel species, having trays out for 8-12 hours provides enough time for foraging to occur, but not so much time that all of the food has been removed. For nocturnal animals, the trays should be deployed as close as possible to sunset and collected as close as possible to sunrise. At the end of the deployment students collect the sand, sift out the food, and weigh it. The sand can then be re-used with fresh food the next day. Students record the remaining food weight as well as additional data about experimental conditions following a standardized protocol (Supporting File S2. Sorry to Eat and Run – Giving up density [GUD] student datasheet). Students will then submit the data from their datasheets online to the national dataset (visit http://www.squirrel-net.org for instructions on how to request access to the national dataset). Please be sure that only one student per group submits the data for their trials to the national dataset.

2(c). Problem avoidance and problem solving.

The primary problem that we have encountered during this experiment is coordinating field dates without precipitation. If the sand gets wet, or even damp, seeds will absorb the moisture and increase in mass. It is therefore important to ensure that the sand and the seeds remain dry throughout the experiment. If you will be experimenting in a wet climate, you might consider making a cover or tent for the seed trays. Involve the students in the design process as a way to solve local problems related to implementing field studies. One instructor avoided the issue of seed weight gain in wet sand by using whole peanuts instead of chopped peanuts, and simply counted the number of peanuts before and after foraging. We also recommend sifting and weighing the seeds as soon as possible after returning from the field, especially if working in humid conditions. In the case of wet seeds students tried a series of trouble-shooting approaches, such as drying the trays under a fume hood overnight, with limited success. Most students decided to run the trial again if there was any precipitation during the tray deployment. Finally, instructors and students need a way to identify each tray when they carry it back from the field (e.g., labeling trays with painter's tape before placing them out is a low-budget option).

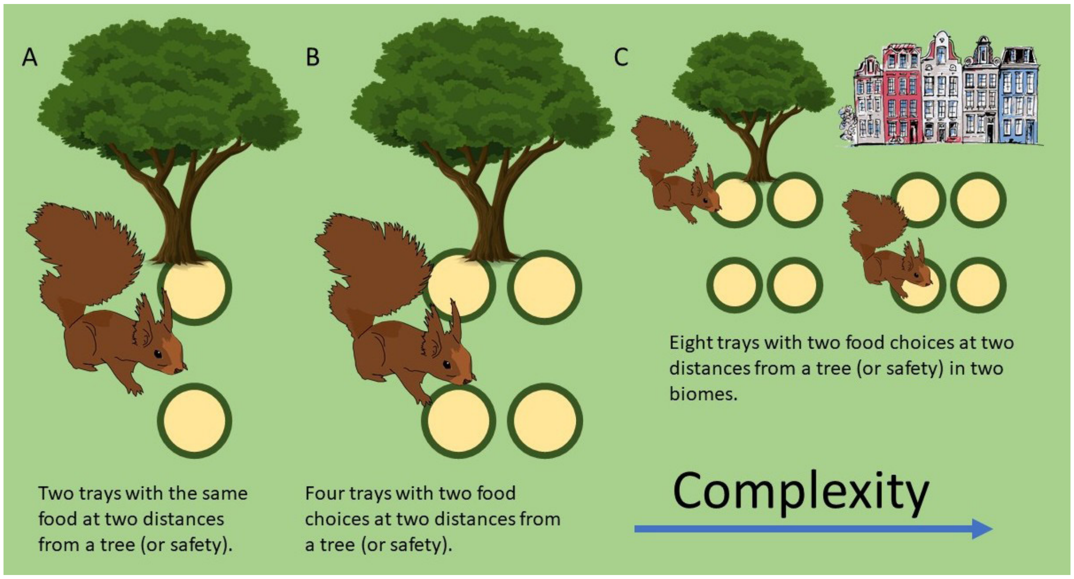

Figure 4. Three examples showing how students, teams, or classes can deploy seed trays with increasing complexity in design. (A) Each student deploys two trays at a site, with one tray close to a tree and another about three meters away from the tree. (B) Each student or team deploys four trays to test two food choices and two microhabitats. (C) Each team deploys eight trays to test two food choices, two microhabitats, and two biomes. Figure by Christopher Yahnke. Vector drawings of squirrel, tree, and city used with permission through open-source licenses: https://pixabay.com/service/license/. Squirrel vector image, https://pixabay.com/vectors/squirrel-animal-cute-rodent-fluffy-41255/; Tree vector image, https://pixabay.com/vectors/tree-forest-trunk-nature-leaves-576848/; Amsterdam vector image, https://pixabay.com/vectors/amsterdam-netherlands-houses-street-4167026/.

3. Analysis of data (45-90 minutes).

The data from each group's datasheets (Supporting File S2. Sorry to Eat and Run – Giving up density [GUD] student datasheet) can either be collated into a class-specific master datasheet (see Supporting File S4. Sorry to Eat and Run – Squirrel GUD sample data for example) that can be analyzed in class, or the instructor can download the national dataset for students to analyze broader patterns of foraging behaviors (request access at our website, http://www.squirrel-net.org). Prior to having our students run analyses, we also have them draw predicted results that would support or fail to support their hypothesis. For example, we might ask them: 'What would your GUD results look like if squirrels were spending more time foraging near the tree?' or 'What data would you expect if squirrels were prioritizing peanuts over sunflower seeds?'

We provide the class with a sample .csv file with actual GUD data (Supporting File S5. Sorry to Eat and Run – Squirrel GUD sample data) that can be imported into a variety of statistical programs. We then used an R Challenge activity (Supporting File S6. Sorry to Eat and Run – R challenge - supplementary activity) to guide students through using R Studio to analyze the sample GUD data as homework. This exercise prepared students to analyze their own class-generated data or the national dataset in lab.

We also incorporated a discussion regarding the choice of statistical analyses used and the assumptions involved. For example, these data are not normally distributed, especially when squirrel activity is low and/or some trays are not discovered by squirrels (i.e., GUD = 10 g). Therefore, the R script includes a few options for plotting the data and evaluating normality, box and whisker plots for visual analysis of GUD in relation to explanatory variables, and nonparametric Kruskal-Wallace tests (Supporting File S7. Sorry to Eat and Run – Script for Kruskal-Wallace test in R).

4. Class synthesis and discussion of data (60-90 minutes).

After the students have generated results in the form of statistical analyses, figures, and tables, we spend some time discussing the implications of the results. Specifically, we ask students whether there was a difference between two treatments (e.g. trays placed close to a tree versus trays placed further away from a tree). For example, in one study in Wisconsin, students found a difference between early and mid-fall time periods. They suggested the lower GUD in mid fall might be due to increased activity of squirrels and a willingness to take more risks as winter approached. The students also noted GUD decreased significantly from Day 1 to Day 4 and argued squirrels may have become habituated to the trays, particularly on campus. Finally, there are a variety of options available for assessment and analysis of results. For example, some of us had students write individual lab reports (see Supporting File 8: Sorry to Eat and Run- Herbivore foraging project report assignment), others had students prepare oral or poster presentations as individuals or a team.

TEACHING DISCUSSION

In this module, students gain numerous basic skills related to experimental design and execution of an experiment. The experiment is very hands-on, with students sifting sand, weighing seeds, labelling bags and trays to keep track of treatments, and filling out datasheets. The experimental design also teaches students to be accountable to a larger team. For example, one pilot study involved coordinating 48 students in two sections of a sophomore-level ecology and evolution course, each taught by a different instructor, using a relatively sophisticated, multi-factorial experimental design (Figure 4C). The students performed admirably, owned their mistakes and rectified them for the benefit of the entire group, and exceeded expectations on the creativity of their final projects.

We suggest building in opportunities for students to be creative and think outside explanatory factors discussed in class. For example, one team of students suggested comparing giving up densities from day one to day four and found this to be more interesting than comparing two microhabitats. This was not a factor we considered in the pilot study, but the effect of days on GUD has remained significant for multiple semesters and at other campuses. Another team of students decided to test the effects of dog scent on foraging by rubbing pet dogs with pieces of absorbent cloth and placing the cloth samples near half of their foraging trays. One of the benefits of implementing a CURE such as this is that the instructor does not necessarily know the outcome of the experiment, providing space for discussions on how research and science really work and the inherent difficulties with field research.

Students that engaged in this activity were able to translate the learning objectives into interview responses on a mock internship interview (29). Specifically, students used specific examples from this experiment to illustrate competencies like written and oral communication, working on a team, leadership, and quantitative literacy. Further, students were more willing to write collaboratively when they worked together on an experiment that required coordinated team effort. This observation was based on a classroom activity that listed the pros and cons of writing individual reports versus collaborative reports for this project.

Extensions and Modifications

The most basic form of the experiment involves individual students placing trays at a site that they choose, such as close to their homes, and collecting data for four days (Figure 4A). The amount of instructor control can be varied by either organizing the class into teams and scheduling dates and sites for which each team is responsible or allowing students to select their own teams and create their own sampling schedules. While studies examining differences in GUD between microhabitats can be quite simple, complexity can be built into the design by simultaneously comparing multiple factors, such as food preference, microhabitat, and/or biome (Figure 4B and C). With sufficient equipment and cooperative weather conditions, it is possible to collect all of the data in a single week, even for complex studies examining multiple factors. However, our experience has shown that weather does not always cooperate, providing students with opportunities to troubleshoot sampling problems.

Analysis of this GUD module can also be used as part of a thread that runs throughout the semester to teach quantitative literacy, visual literacy, and communication in science through writing and presenting. One extension that gets at this idea involves having students predict and sketch GUD expectations that would support their hypothesis versus those that would not, prior to plotting the data. Another option is to use the R Studio Challenge to introduce somewhat familiar statistical analysis as an assigned homework.

In this case, instructors might consider adapting the module for higher levels of inquiry (Table 2; 30) by transferring much of the preparation and experimental design tasks to the students themselves. Finally, students can also analyze results from the national dataset (request access at http://squirrel-net.org) to test hypotheses beyond the geographic and/or temporal reach of their own experimentation.

Instructors may wish to adapt this lesson plan to other species beyond squirrels. Although our lesson plan was written to examine foraging decisions made by sciurids, the GUD methodology has been used to study foraging in a number of animals often present on college campuses, such as rabbits (12) and robins (6). Indeed, students using our lesson plan have already contributed data to the Squirrel-Net national dataset measuring GUD for nocturnal small mammal communities (i.e., mice, kangaroo rats, woodrats) and oak woodland bird communities (i.e., juncos, towhees, jays). The low cost of equipment and the ease of implementation make this a lesson plan with few limitations beyond student imagination; it is easily adaptable to a wide variety of class needs and student ideas.

SUPPORTING MATERIALS

- S1. Sorry to Eat and Run – List of helpful resources in identifying field sites
- Supporting File S2. Sorry to Eat and Run – Giving Up Density (GUD) student datasheet
- Supporting File S3. Sorry to Eat and Run – GUD activity supplies list
- Supporting File S4. Sorry to Eat and Run – Feeding station set up and break down
- Supporting File S5. Sorry to Eat and Run – Squirrel GUD sample data. Sample .csv file for use in data analysis activities
- Supporting File S6. Sorry to Eat and Run – R Studio Challenge. For supplementary activity.
- Supporting File S7. Sorry to Eat and Run – R script for box plots and Kruskal-Wallis test
- Supporting File S8. Sorry to Eat and Run – Herbivore foraging project report assignment

ACKNOWLEDGMENTS

CJY was supported by a UW System Teaching Fellows grant. PKC, JMD, and JV were supported by the 2019 CourseSource Writing Studio to develop this article. JMD received support from California State University, Monterey Bay through a Faculty Support Grant and a CURE Fellowship. Support for EAF was provided by the USDA National Institute of Food and Agriculture, Hatch Project 1019737. This material is based upon work supported by the National Science Foundation under a collaborative grant (Nos. 2013483, 2013281, 2013308, and 2013320). Dr. Brian Barringer contributed supplementary materials that he produced during his implementation of the GUD module. We gratefully acknowledge Dr. Joel Brown (University of Chicago and Moffitt Cancer Center) for helpful conversations about adapting his GUD protocols to be suitable for student research and for the value of squirrels as research subjects in general. We would also like to acknowledge all of the students who provided helpful feedback on these modules as we developed and piloted them in our courses.

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Table 1. Sorry to eat and run teaching timeline

Activity	Description	Approximate Time
Prior to class: At least 4-7 days prior to implementing the lesson		

Instructor prep	• Read one of the articles on optimal foraging theory or the landscape of fear in ecology (refs) and skim the others.
	• Examine Supporting file S1: Sorry to Eat and Run: List of helpful resources in identifying field sites.
	• Examine Supporting File S3: Sorry to Eat and Run - GUD activity supplies list
	• Prepare handouts:
	  • Supporting File S2: Sorry to Eat and Run: Giving up density (GUD) student datasheet
	  • Supporting File S4: Sorry to Eat and Run - Feeding station set up and break down
	• Contact groundskeeper
	• Make informational signs
	• Prepare a brief introduction to the natural history of the local squirrel species
		20-30 minutes
		120-180 minutes
		30 minutes

Student prep	• Read assigned paper on optimal foraging theory or landscape of fear in ecology	30 minutes
Class meeting: Progressing through the activity		
Lesson introduction Lab period 1	• Begin with a think-pair-share activity with the following prompt: "Give examples of how decisions you make regarding foraging and feeding can be explained using optimal foraging theory or the landscape of fear" • Provide a short natural history of local squirrels • Review GUD datasheet • Set up seed trays	10-15 minutes 5 minutes 5 minutes 30-60 minutes
Experimental design and data collection	• Explain the experimental design using Figure 4 • Optional: Visit the field locations on or near campus with your students and collect GPS coordinates • Run the field experiment for 4 days (skip days with precipitation)	30 minutes 30-60 minutes 1-2 weeks

Analysis of data
Lab period 2
	• Optional: Complete R Challenge homework
	  • Supporting File S4: Sorry to Eat and Run: Squirrel GUD sample data
	  • Supporting File S6: Sorry to Eat and Run - R challenge - supplementary activity
	• Prior to the second lab, instruct students to enter data from Supporting File S2: Sorry to Eat and Run: Giving up density [GUD] student datasheet to national dataset and give datasheet to the instructor
	• Conduct a Kruskal-Wallace test of the data in R or another statistical package. Create box and whisker plots.
		60-90 minutes
		10 minutes
		45-90 minutes

Class synthesis	• Discuss the implication of the results and how the experiment could be expanded to include other variables. • Discuss written lab report. See Supporting File 8: Sorry to Eat and Run- Herbivore foraging project report assignment	30-45 minutes 30-45 minutes
Post-class assessment		
What students prepare	Students prepare a formal lab report. This can be an individual report or a collaborative report.	

Table 2. Examples of extensions and modifications for this lesson. Levels of inquiry are explained in more detail in the companion essay by Dizney et al. (30).

Level of Inquiry	Structured Inquiry	Controlled Inquiry	Guided Inquiry	Free Inquiry
Example Activities for this Module	Instructor provides protocol, question, and hypothesis. Students collect GUD data with experimental design focused on a single explanatory variable (e.g., cover, scent, or 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 are allowed to choose a predictor variable for analysis (e.g., cover, artificial light, scent, species attributes) 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. Students may analyze aspects of the national dataset in addition to their class-generated data.	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. Students may analyze aspects of the national dataset in addition to their class-generated data.