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Lesson

When Squirrels Fly: A Networked CURE for Assessing Flight Initiation Distances

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Abstract

Escape behaviors are an important way for animals to avoid threatening situations or stimuli. However, an animal's sensitivity to an approaching threat depends on a variety of factors, including habituation, perceived severity of the threat, and distance to safety. Here, we describe a hands-on, networked activity in which students measure the flight initiation distances (FID) of squirrels by approaching an individual and then recording the distance at which the animal initiates an escape behavior. After completing the measurements in the field, students submit data to an aggregated national database that includes observations from students at multiple institutions as part of Squirrel-Net. Analysis of the national dataset permits students to explore questions of risk tolerance across a broader variety of habitats and species than would be possible at any single institution. This lesson can be implemented as a single laboratory period or adapted into a multi-week course-based undergraduate research experience (CURE), including with student-generated protocol modifications. It can also be scaffolded with other Squirrel-Net CURE modules, such as giving up density (GUD) or the behavioral observations activity, allowing students to investigate questions of risk tolerance using different methods. As part of Squirrel-Net, this activity and our national database focus on squirrels, which are diurnal, charismatic, easily identified, and present in a wide range of habitats (including many college campuses), but the same methods could be broadly used for other terrestrial species, such as birds, reptiles, or other mammals.

Primary Image: Students at University of Portland approach a squirrel to measure flight initiation distance.

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Learning Goals

Students will:

◊ Understand how ecologists and wildlife managers use Flight Initiation Distances (FID) to examine how animals perceive threats and implement setbacks for sensitive species.

◊ Practice science process skills, such as making observations, analyzing data, interpreting results, and communicating results.

From the Ecology Learning Framework:

◊ How do species interact with their habitat?

◊ What impacts do humans have on ecosystems?

◊ What can or do humans do to mitigate negative impacts they have on ecosystems?

From the Science Process Skills Learning Framework:

◊ Pose testable questions and hypotheses to address gaps in knowledge

◊ Plan, evaluate, and implement scientific investigations

◊ Interpret, evaluate, and draw conclusions from data

◊ Share ideas, data, and findings with others clearly and accurately

Learning Objectives

Students will be able to:

◊ Define Flight Initiation Distance (FID) and Alert Distance (AD) and describe the different aspects of ecology and behavior that these measurements represent.

◊ Develop a hypothesis about how FID and/or AD will vary under different experimental conditions and test this hypothesis using data collected in class.

◊ Possible extension: Predict how a species in a different environment might respond to the same "threat" and test this hypothesis by querying a national dataset.

INTRODUCTION

Escape behaviors are a key response among animals to avoid potentially threatening situations (*e.g.,* predation or aggression). Many animals respond to such stimuli by becoming vigilant or alert (stopping current activity to monitor a potential threat at a certain Alert Distance, AD). If the stimulus continues to approach them, animals may then flee (leaving the current location by walking, running, swimming, diving, or flying). Yet, fleeing can also be costly with respect to energy expenditure and lost opportunities related to acquiring food or mates. Thus, animals must balance the degree of risk they perceive against the potential benefits of fleeing danger, and they do this in part based upon the proximity of the threat. The distance at which a behavioral escape response occurs is termed the Flight Initiation Distance (FID; Figure 1). Also sometimes termed "flush distance," "displacement distance," or simply "flight distance," FID can be measured in just about any mobile animal that can detect oncoming approaches and can inform our understanding of how organisms judge and perceive threat.

Many ecological factors affect when an animal chooses to flee. Scientists have demonstrated that some species will have longer FIDs (*i.e.,* they are more sensitive to an approaching threat) when they are farther from a refuge such as a tree, burrow, water body, etc. (1). Although FID is influenced by environmental characteristics, some species regularly show greater FIDs than others across a variety of conditions (2). Likewise, the costs associated with flight (*e.g.,* energetics associated with locomotion and lost opportunity with respect to food resources or mates) can differ by species and situation, and prolonged disturbance by humans can result in ecologically significant shifts in behavior (*e.g.,* changes in habitat use, reduced foraging, compromised parental care, and reproductive failures). For this reason, FID is often used as a tool to help wildlife managers make more informed decisions about lessening potential impacts of human observers on sensitive species of animals. For example, managers can use the average FID of a species to set guidelines for setbacks or buffer zones at viewing areas, to restrict foot traffic to trails or paths, or to develop other management guidelines (3). FID analysis also has interesting applications in the field of human-wildlife conflict; for instance, this technique was used to evaluate whether capture and release can result in aversive conditioning of American alligators. Researchers approached alligators with different capture histories to assess their tendency to flee approaching humans (4). An additional interesting application of this analysis is to understand whether animals are affected by the bright colored clothing in fashion among hikers and outdoor enthusiasts. In fact, a recent study found that lizards tolerated closer approaches by individuals wearing T-shirts that matched their sexually-selected signaling color (5).

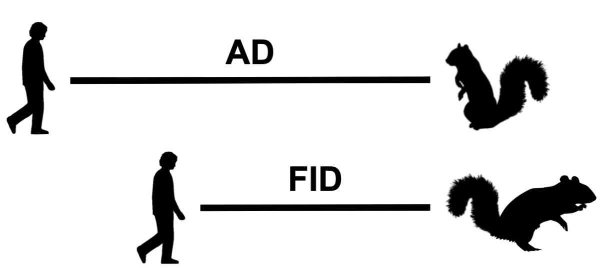

Figure 1. Schematic representation of Alert Distance (AD) and Flight Initiation Distance (FID). All silhouettes are open source from www.phylopic.org.

While FID is a useful tool, it is also dependent on a variety of factors related to the approach, the threatened individual, and the threat. For example, birds often flush at greater distances as starting distances and approach speeds increase, suggesting that animals may pay an additional cost for continuing to monitor a predator approaching from a long way away (2). In addition, experience with humans can also affect FID (3). For example, Uchida *et al*. (6) found that squirrels in rural areas have significantly longer FIDs than squirrels in urban areas when approached by humans. In contrast, Zaman *et al*. (7) found that golden-mantled marmots living closer to human settlements have longer FIDs than marmots in more remote areas when approached by a human. Eye contact from the approaching human can also affect FID (3). These contrasting results suggest that squirrels perceive human approaches differently in different contexts.

While there are many publications using FID methods, few published lessons incorporate this method in the classroom. One example by Darling *et al*. (8) utilizes eastern gray squirrels as a study organism and engages students in field-based research that encourages students to develop their own hypotheses. That lesson is designed to be conducted by small groups of students with intensive input from the instructor at each stage of the project. The statistical rigor of the protocol suggests that it is best suited for small class sections of upper-level biology students. Other FID studies utilize college students in the collection of the data. For example, de Resende *et al*. (9) investigated the FID of saffron finches on a college campus in Brazil, involving college students as participants in the data collection. Likewise, Duggan *et al*. (in prep) modified our protocol so that it could be conducted by students individually during the COVID pandemic. Inspired by a study in which Eurasian tree sparrows decreased their FID when humans were wearing face masks (10), several Squirrel-Net instructors and their students investigated the effect of wearing masks on FID of a variety of animals. That study allowed students at multiple institutions to share data via a central database, promoting a sense of community among students and instructors (11).

Here, we present a lesson in measuring the FID of sciurid rodents (*e.g.,* squirrels), which are generally diurnal, charismatic, easily identified, and available on or near most college campuses. The activity is also easily adaptable for use with other taxa (*e.g.,* birds, lizards, other mammals), depending on the availability/abundance/accessibility of squirrel species. In this activity, students approach an animal and then record the distance at which the animal becomes alert (alert distance; AD) or initiates a behavioral escape (FID). They can then examine predictors of AD and/or FID, such as characteristics of the approaching student (*e.g.,* color of clothing), characteristics of the animal's position in the environment (*e.g.,* distance to cover), or the focal species (*e.g.,* social vs. solitary species). Analyses can be augmented with the use of a national dataset, allowing students to examine hypotheses that transcend any single habitat and/or squirrel species. Assessments and extensions of this activity then guide students to consider the implications of their data for wildlife management.

Rationale and Origin of Lesson

Squirrel-Net is a group of teacher-scholars that share a common goal to promote authentic course-based research experiences, or CUREs, for undergraduate students. We are mammalogists that hold research and teaching positions at higher educational institutions across the United States, which range from R1 universities to primarily undergraduate institutions and colleges serving under-served and/or underrepresented populations. Our goals are to create inquiry-based lesson plans that take students out of the classroom and engage them in research on locally relevant and widely distributed mammals, while also collecting data with standardized protocols to test a wide array of ecological questions across spatial and temporal scales.

This lesson is part of the Squirrel-Net module series (12). All of the Squirrel-Net modules are designed for adaptation to diverse educational contexts, from a single two-hour laboratory period (basic skills acquisition) to a semester-long student-driven research project (open inquiry CURE). In each module, students can submit data to a national dataset that aggregates observations from multiple institutions. Students can therefore access and analyze the freely available national database, which allows them to explore the focal questions of the module across a broader variety of habitats and species than would be possible at a single institution. This lesson adds to the four previously published Squirrel-Net modules (13–16), all of which are designed so that they can be scaffolded into multiple levels in a curriculum, allowing students to return to similar taxa and themes and uniting inquiry across different courses and in different contexts (12, 17). In the current lesson plan, we describe the most basic implementation of this module (*i.e.,* basic skills acquisition in a single, two-hour laboratory period).

Intended Audience

This lesson is intended for undergraduate students at a variety of levels, likely in elective courses in biology, ecology, wildlife management, natural resources, or zoology programs. This lesson has been previously taught in a variety of settings, including the following:

1. This module began as a lab in Behavioral Ecology, an upper-division elective course taken primarily by wildlife ecology and management majors at the University of Wisconsin - Stevens Point (UWSP; *n* = 20 / spring semester). It was modified and used during the pandemic year (2020–2021) in another upper-level wildlife course at UWSP (n = 48), where students contributed data on how face masks affected FID of squirrels, deer, lizards, and corvids to a shared dataset along with students from several other universities, including those listed below (Duggan *et al.*, in prep). UWSP primarily serves rural students from the upper Great Lakes region, many of whom are first-generation students.
2. The module has also been used as a multi-week CURE in Mammalogy and Vertebrate Natural History, which are both upper-division electives taken primarily by biology and environmental science majors at California State University, Monterey Bay (CSUMB; *n* = 23 / semester). In addition to assessing the influence of face masks on FID, students have also examined the impacts of human talking, at both soft and loud volumes, on the FID of squirrels. After conducting simple statistical analyses to test hypotheses, students worked in groups of ~5 to create and present posters disseminating their findings. Students in these courses represent the diverse student population at CSUMB; a majority are first-generation college students and/or come from underrepresented groups. Students vary widely in quantitative and verbal skills; for some students, English is their second language. Students in this course are commonly interested in

pursuing careers as wildlife biologists with government agencies (*e.g.,* California State Parks, U.S. Fish and Wildlife Service) or non-profit organizations (*e.g.,* Monterey Bay Aquarium, Ventana Wildlife Society).

3. In conjunction with two other Squirrel-Net modules (15, 16), this module was used in an Animal Behavior laboratory course (n = 24 students) for junior and senior-level biology majors at Colorado Mesa University (CMU; an undergraduate-focused, four-year, public institution). Students in this course are extremely diverse in terms of their preparation (*i.e.,* courses taken prior to animal behavior) and their quantitative and verbal skills. Many of these students come from rural, western Colorado and are interested in pursuing agency careers in wildlife and/or land management (*e.g.,* through Colorado Parks and Wildlife, US Forest Service, Bureau of Land Management).
4. This module was also used in an upper-division Mammalogy course without a lab (n = 78 students) for junior and senior-level biology students at University of Utah, a large R1 public institution. These students had completed similar prerequisites in introductory biology, ecology, and evolution, but otherwise varied in their preparation. Students largely come from urban and rural counties across the Mountain West, approximately one third are first generation, and they expressed interest in pursuing a diversity of careers related to wildlife conservation and management, veterinary medicine, and human health. In this class, students working in groups of ~4 conducted five trials of FID measurements using the basic protocol described in the lesson plan, followed by five trials with a protocol modification that they hypothesized would affect FID (see *Teaching Discussion* for more context about adapting the module in this way).

Required Learning Time

This lesson was originally designed for a single two-hour laboratory period; however, it can be easily expanded to cover multiple class periods or taught in combination with other Squirrel-Net CURE modules (13–16). See *Teaching Discussion* for more details on expanding the lesson to include structured and open inquiry activities.

Prerequisite Student Knowledge

Students should be acquainted with the basic idea of escape behaviors and threat perception, including the concepts of habituation in urban environments. If not covered earlier in class, Blumstein *et al.* (18) provides a good background. Students will also benefit from a basic familiarity with the scientific method, particularly the processes of asking questions, developing a testable hypothesis/prediction based on prior knowledge and inference, and using a standardized protocol to collect data.

Prerequisite Teacher Knowledge

We recommend that instructors familiarize themselves with how wildlife biologists measure AD/FID and the implications or interpretations of these measures. For example, a group of Swiss avian biologists used the method to compare the behavior of birds in forests with many human visitors versus those with few visitors (19). The authors interpreted the shorter FID found in the forests with many visitors as birds having habituated to human presence. Another study found that FID in Eastern grey squirrels (*Sciurus carolinensis*) decreased as levels of human exposure increased (20), implying that squirrels learn humans are not a threat and therefore decrease their anti-predator response.

Instructors will also need a basic knowledge of the ecology and natural history of the focal species. See Supporting File S1 for instructor resources on selecting a focal species of sciurid. It would also be helpful for instructors to have a basic knowledge of animal behavior, particularly the concepts of vigilance behavior, threat perception, and habituation (18).

In addition, instructors may need approval from the university's Institutional Animal Care and Use Committee (IACUC) for this work, as well as any site access permits for reserves, parks, or universities. Some IACUCs will issue an "Exemption from IACUC Approval for Field Studies" because animals are not being trapped, handled, or housed on campus, whereas others will require a full protocol. To facilitate this process, if necessary, we have provided an example IACUC protocol in Supporting File S2. Example IACUC Protocol. We recommend that instructors contact their university's IACUC as soon as possible to determine whether an IACUC protocol is necessary (Table 1). The process of applying for permits and gaining IACUC approval can sometimes take several months; thus, depending on experience with these activities and the schedule of the university's IACUC, we recommend instructors allow 3–6 months for this pre-class preparation.

SCIENTIFIC TEACHING THEMES

Active Learning

Although the data collection protocols are prescribed (indeed, a key goal of the activity is teaching students how to perform the method), students are central to actively developing questions to ask with the national dataset, including how FID might vary in different environments or for different kinds of species (*e.g.,* urban vs. natural environments, ground vs. tree-dwelling squirrels, social vs. solitary species, etc.), distance to safety (*e.g.,* tree or burrow), or by approacher characteristics (*e.g.,* bright vs. neutral colored clothing, etc.). We also use active learning techniques during the lesson, such as think-pair-share (*i.e.,* ask a question for students to consider first by themselves, then in consultation with their neighbor, and finally in a full-class discussion) or small-group work (*e.g.,* brainstorming or jigsaw activities).

Assessment

Like all Squirrel-Net lessons, this activity lends itself to a variety of assessment methods that can be tailored to the appropriate level of implementation. However, we have most frequently assessed this activity by having students prepare a scientific lab report in which they describe their hypothesis and prediction about factors that might influence FID, the methods of data collection, and the results of their inquiry (including both their own data and those data collected by students in the national dataset). Finally, students must also discuss the assumptions and limitations of this method, identify ways in which their experiment could be improved, and defend this choice given the environment and natural history of the focal species. We

Figure 2. Example student unessay project in which two dresses were designed to represent the difference between alert distance (AD) and flight initiation distance (FID). Photos courtesy of Miranda Ring.

have also provided an 'unessay' option as an assessment, where students can use creative approaches to communicate their findings (21, 22). Here, students apply similar development of hypotheses and predictions, analyze their data to evaluate those hypotheses, and then develop an artistic contribution which communicates their findings (*e.g.,* Figure 2).

Inclusive Teaching

The Squirrel-Net modules are designed to provide all students in a class, not just those who are already well-prepared through previous research experiences (23), with the opportunity to engage in authentic research. Participating in a CURE like this Squirrel-Net module 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 (24). One unique element of our CURE is the use of the national network, which 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 (11, 25). In this specific lesson, we also present materials in different modalities (*e.g.,* readings, mini-lectures, discussions), and techniques such as think-pair-share or multiple-hands, multiple-voices provide welcoming opportunities for students to contribute their ideas to classroom conversations (26).

Finally, while experimenter sex is sometimes a cue that can affect the fear response of animals (27), we do not ask students to categorize themselves as binary male/female. In addition, we have not found any evidence that squirrel FID is affected by the sex of the approacher in the literature. Thus, by leaving student sex out of the analysis, we prevent any students who identify as non-binary from feeling singled out or excluded. Instructors should be aware, however, that a student or group of students may hypothesize that sex of the approacher will influence FID in their study. If this is the case, before running the module, instructors should consider whether or not this is a variable they are willing to allow students to analyze, and if so, how they will address gender identity and the complexity of biological sex in a way that does not single out or exclude any students in their course.

LESSON PLAN

Pre-Class Preparation

This activity requires instructors to identify a field site that has a relatively large and broadly distributed population of the focal species that is readily available for approaching (Supporting File S1). Specifically, the population needs to have enough animals for students to approach different animals (see specific ideas below to avoid double-sampling). Instructors should also consider the activity patterns of the focal species and run the lab during a time when the focal species is likely to be active and detectable. For example, if a lab is scheduled during mid-afternoon, but the class is studying a crepuscular, desert-adapted ground squirrel species, consider running the field trip on a weekend morning instead. In this case, instructors will need an option for students to make up the material and the experience, if they cannot attend due to other weekend commitments. Finally, instructors should be sure to follow local regulations (*e.g.,* not approaching wildlife in reserves where off-trail travel is prohibited).

Instructors should take care to avoid a situation where students approach the same animal repeatedly during a class session, especially if the population is small. To avoid this issue, we ask students to spread out over a relatively large area of campus or a reserve, and to take note of whether their selected animal is in sight of any other groups of students. In some cases, we have also sent students off with materials to complete the activity on their own during a period of several weeks, which makes multiple approaches in short succession extremely unlikely. In addition, the student instructions also specify the distance that each focal animal should be from conspecifics, and students record information on the presence of conspecifics in the vicinity (Supporting File S3).

We also recommend that students are familiar with the basic premise of FID measurement before conducting the activity. This can be accomplished through prior readings, assignments, or lectures. We suggest having students read through the lab handout and familiarize themselves with the methodology before coming to lab (Table 1).

Progressing Through the Lesson

1. Lesson introduction and assessing prior knowledge (10 minutes). Upon arrival at the field site, the instructor can spend a few minutes reviewing the foundational learning goals for the lesson: why is escape behavior important for animal species, and what factors might influence FID for the focal species. We try to use inclusive teaching strategies such as multiple hands, multiple voices or whip around (28) to (a) ensure that all students share what they learned from pre-lab materials, and (b) identify any common misconceptions that can be addressed prior to activity implementation. Specifically, we are careful to review the idea that habituated animals are not simply lazy, and that the same "threat" may be perceived differently by different species and/or in different environments.

Instructors then provide some background to the students on the natural history of and behaviors typically exhibited by the focal species. This lesson can easily be adapted for many species of small mammals and birds (Supporting File S1). We provide this information as front-matter in the lab handout, including a photo of the animal and features that will allow students to reliably identify it and distinguish it from other species that may be present in the same area. The instructor then briefly reviews the protocol and datasheet for measuring FID and AD (Supporting File S4).

2. Data collection (30–45 minutes). Students work together to measure FID and AD for the focal species. The instructor may need to break the class into smaller groups (~2–5 students) that search for animals in different parts of the study area. Each group will need a laser range finder, a laser tape measurer, or a measuring tape. Homemade measuring tapes can be made by marking increments on a string held next to either an actual or printable ruler. Alternatively, students could practice distance estimation methods through pacing (*e.g.,* this YouTube video) or other activities (28). If students are working independently, they will need two colorful weighted objects (*e.g.,* beanbags, hacky sacks, or plush toys). Finally, a set of binoculars may also be useful for identifying species from long distances.

Student groups then walk quietly until they detect an animal that is approximately 100 ft (30 m) away and that is not yet alert to their presence (*i.e.,* continuing with whatever it was doing, and doesn't stop and stare at or vocalize at the group). If the animal seems alerted to the group presence, then a new focal animal should be found. Before beginning the approach, students should record information on the observer(s), location, current conditions, and species identification on the datasheet (Supporting File S4).

Next, one student should quietly approach the animal at a constant pace (aim for about 2 steps per second). The "approacher" should keep their eyes focused on the ground to avoid eye contact with the focal animal. Any teammates should remain where they first spotted and identified the animal. When the animal begins to seem alert to the approacher's presence, the approacher should drop a first object (if alone) or quietly notify teammates of the "alert approach location" to mark the alert distance (*e.g.,* by waving behind their back). The approacher should continue quietly walking toward the animal, until it either flees or noticeably changes its speed or travel direction because of the approach. When the animal flees, the approacher should stop walking. If alone, the approacher should drop an object to mark the "flight approach location" (second object). If teammates are present, a person can proceed directly to the spot where the animal initiated its flight (flight location). Finally, students should use a measuring tape or a laser device to measure the distance, in m, between (a) the animal's flight location and the "flight approach location" (*i.e.,* the second object/approacher; this is the FID) and (b) the flight location and "alert location" (*i.e.,* first object; this is the AD).

3. Datasheets and data submission (10–15 minutes). Students should then complete datasheets (Supporting File S4), including the presence of other animals (*e.g.,* squirrels, humans, dogs) within 30 m (100 ft) of the focal animal, the observer's characteristics (*e.g.,* height, clothing colors, etc.), location (*i.e.,* latitude/longitude), current conditions (*i.e.,* cloud cover, precipitation, and wind using qualitative scales), and the FID/AD measurements. A full list of the required data and units can be seen on the datasheet in Supporting File S4. These data should then be submitted to the national dataset. If conducted in the Western Hemisphere (*i.e.,* North or South America), we also recommend that instructors remind students that longitudes will be a negative value. Instructors should follow instructions on the Squirrel-Net website to request access for students to submit data to the national dataset and to download the dataset for class use. Please be sure that only one student per group submits the data for each survey to the national dataset.

4. Class discussion and synthesis (10–15 minutes). For the last few minutes of class, the instructor recaps the activity and discusses the reflection and/or analysis assignment. At the simplest level, we recommend asking students to reflect on the factors they think might be most influential in determining FID in their focal species and which factors might have different effects in different habitats (Supporting File S5). In more advanced courses, we recommend asking students to write a formal lab report in the format of a scientific paper. In our classes, we have asked students to reference the primary literature and to consider these reflection questions in the discussion of their paper (Supporting File S6). In some courses, we have also assigned an 'unessay,' or a creative representation of the material (*e.g.,* Figure 2). This approach may be most appropriate in classes where either a formal lab report is not a skill that aligns with the course's learning objectives (*e.g.,* a nonmajors course), or a course where students have numerous other opportunities to model a scientific paper.

TEACHING DISCUSSION

This lesson has been implemented as both a single 2-hour lab period and as a take-home experiment in which students are provided with materials, protocols, a list of study species (and how to identify them), and a list of potential study sites to visit on their own with known populations of these species. Across implementations, students enjoyed the opportunity to be outside looking for animals and the opportunity to contribute data to nationally networked datasets.

Instructors should be aware that ecological fieldwork, particularly with vertebrate animals, is inherently unpredictable, but we note that these unpredictable events can also be treated as an opportunity for discussion. For example, on one day of this lab, students from Colorado Mesa University had a difficult time finding white-tailed prairie dogs (*Cynomys leucurus*) to approach because nearly all animals were aware (alert) of the human approachers and immediately dove into their burrows before the students saw the animals. Although students were initially frustrated at the lack of animals to approach, they also discovered that this population was frequently culled by area managers seeking to prevent the animals from damaging nearby structures. Thus, they hypothesized that this population may have been sensitized to the presence of humans in a way that other populations with different regulations were not. Indeed, when the activity was conducted with a different population at a popular mountain biking trailhead that was not subject to regular population control, students had no trouble finding animals to approach, and FIDs were much lower.

Likewise, as with most ecological field protocols, this lesson includes many additional opportunities to discuss outside factors that could affect results or their interpretation. These include the potential implications of students using different 'tools' (*e.g.,* measuring methods) or inconsistencies in the protocol (*e.g.,* if students weren't consistent in their speed of approach, eye contact with the animal, etc.). In addition to affecting the interpretation of results, each of these additional factors might bring in some statistical questions related to accuracy, bias, and precision of estimation.

Extensions and Modifications

We initially developed the lesson as a 2-hour laboratory field trip, in which we held group discussions about results in the field; however, depending on conditions and available time, instructors could also ask students to reflect on the activity and their results, and then facilitate discussions in the next class period. As in other more advanced Squirrel-Net modules (13, 14), this kind of implementation would lend itself well to a jigsaw technique (29). Additional class periods could be devoted to conducting the same protocols on a different species and/or environment or to querying the national dataset to test hypotheses about how FID varies among locations, between species, or by characteristics of the approaching student (*e.g.,* whether they were wearing brightly colored clothing).

With respect to extensions for this lesson, all Squirrel-Net modules are specifically designed to be implemented by instructors in a variety of classroom contexts (*e.g.,* different class sizes, institutions, etc.; Table 2). In all cases, the most basic level of the assignment (described in this *Lesson Plan*) is structured inquiry, where students are focused on learning data collection skills. Although students are not fully engaging in a CURE experience at this level, they are still gathering data, evaluating results, and submitting these data to the national dataset. At the highest level of inquiry, free inquiry (12), students are only provided the protocols. They then use the literature to generate hypotheses about the most important determinants/predictors of FID and to test these hypotheses using the national dataset (in addition to the data that they themselves generate).

One adaptation that we found particularly successful was to have students conduct five FID measurements with squirrels using the standard protocol described in this lesson plan. We then ask students to think about an experimental manipulation or modification that they think might affect the FID of their focal species and conduct five additional FID measurements using this protocol modification. These manipulations could include a variety of student-generated hypotheses, including: the presence of leashed dogs (additional species), an approacher wearing a costume (change to visual stimulus), an approacher who is playing music from a speaker as they approach (changes to soundscape), application of cologne (changes to scent), or a variety of other protocol changes. It is important that the instructor carefully reviews each student-generated experimental manipulation to ensure it aligns with the guidelines of institutional, state, and/or federal regulatory bodies. Alternatively, students could also hypothesize an outside factor that is already measured on the datasheet and thus does not require experimental manipulation (*e.g.,* proximity of the focal animal to safety, weather conditions, etc.) and then test their hypothesis using the national dataset. Students can then test their hypothesis using their own 10 observations (which control for approacher), and submit their data to the national dataset, while clearly indicating that they modified the protocol.

Additionally, instructors may also wish to adapt this approach to survey the escape responses of other species beyond squirrels. Indeed, although the Squirrel-Net national datasets are typically specific to sciurids, the techniques can be seamlessly adapted to other species of diurnal small mammals (*e.g.,* lagomorphs), larger mammals (*e.g.,* deer), birds, or even lizards. Nocturnal animals are difficult subjects for behavioral studies like FID because the necessary lighting to see the animals inherently alerts them to the presence of an approacher and masks the identity of the approaching threat; however, FID studies with nocturnal species are not impossible for students to conduct outside of class. Of particular interest may be the opportunity for students to study how FID varies between an urban population of a species and a population of the same species living in a more natural area where they may not be habituated to human presence. Such comparisons may also make fruitful extensions for senior-level students and/or those participating in a semester-long CURE.

This activity could also easily be scaffolded with other Squirrel-Net modules that investigate threat perception, including measuring vigilance behaviors (16) and giving up density, or GUD (15). Incorporating multiple, complementary activities in the same course provides students with an opportunity to consider different metrics of risk perception and whether these behaviors are more strongly shaped by species, environment, individual, or context (*e.g.,* distance to safety). Importantly, subsequent CURE modules could also be implemented at different levels of inquiry (12), giving students increasing control over the questions and hypotheses as they progress through each activity.

Finally, if instructors wish to adapt this module to the remote learning environment for online courses, many of the suggestions associated with other Squirrel-Net modules (17) could be adapted for this module. Specifically, students can approach squirrels in their neighborhoods or nearby parks, or if squirrels are not accessible, students can conduct the same study on other species, as described above. Alternatively, if students all live near the same study area, they can be assigned times during which they will visit the study site to avoid approaching the same animal(s) multiple times. If students are not able to work in pairs or small groups, they could instead involve friends, family, or other household members to help mark distances and/or record data. Finally, because of the aggregated, national dataset, not all students need to work with the same squirrel species or even to collect data in the field. Instead, data can be aggregated across different species and environments for analysis, and students can still test hypotheses about how FID might be affected by various covariates without having necessarily collected the data themselves.

SUPPORTING MATERIALS LIST

- S1. When Squirrels Fly – Resources for Identifying Focal Species and Field Sites
- S2. When Squirrels Fly – Example IACUC Protocol
- S3. When Squirrels Fly – Student Handout
- S4. When Squirrels Fly – Student Datasheet
- S5. When Squirrels Fly – Assessment and Reflection Questions
- S6. When Squirrels Fly – Lab Report Instructions

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Table 1. Teaching timeline table.

Activity	Description	Estimated Time	Notes
Depending on Institution: Securing Appropriate Permission (2–3 months prior to implementing lesson, if required by IACUC)			
IACUC approval	Submit protocol to university IACUC committee. See Supporting File S2 for an example protocol.	A few hours to prepare; review time depends on institution.	• We recommend contacting the university's IACUC as soon as possible to determine whether a protocol is necessary. • Some IACUCs will issue an exemption because animals are not being handled, whereas others will require a full protocol (provided in Supporting File S2). • Full protocol review can take anywhere from a few weeks to a few months, depending on the committee.
Preparation for Class (at least 4–7 days prior to implementing the lesson)			
Field site and focal species identification	See resources in Supporting File S1.	Depends on location of campus and resources available.	• See resources in Supporting File S1. • Field sites should be accessible to students during scheduled class time, and the focal species should be active and detectable during this time.
Student preparation	Ask students to review handouts and familiarize themselves with protocols prior to class.	< 15 minutes	
Class Session: Progressing Through the Activity			
Introduction and assessing prior knowledge	Review learning goals for the lesson and identify any common misconceptions.	~10 minutes	Consider using inclusive teaching strategies, such as multiple-hands multiple-voices or whip around, to ensure all students have an opportunity to share what they learned in their pre-class preparation.
Data collection	Students work together to measure FID.	30–45 minutes	Consider breaking students into smaller groups (3–4 students) in larger classes and spreading out across the study site to ensure that no animal is approached more than once on a given day.
Datasheets and data submission	Students complete datasheets and submit data to national datasets.	10–15 minutes	Be sure students fill out master datasheet (Supporting File S3) in the field.
Class discussion and synthesis	Discuss findings and/or analysis assignments.	10–15 minutes	Tailor analysis and/or reflection to the level of the students.
Post-Class Assessment			
What students prepare	Students prepare a formal lab report or respond to a series of discussion questions.	20 minutes to several hours, depending on depth of assignment.	See Supporting Files S4 and S5 for a list of suggested assessments. In upper division classes, students should access the national dataset and test hypotheses beyond their focal species. See Table 2 and the Squirrel-Net Companion Essay (12) for examples of extensions.

Table 2. Examples of extensions and modifications for this lesson. Levels of inquiry are explained in more detail in the Squirrel-Net companion essay (12).

Level of Inquiry	Example Activities for this Module
Structured Inquiry	Instructor selects focal species and study site. Students collect data in one habitat for one species. One interpretive assignment asks students to reflect on causes of differences between individual FIDs and whether these differences might hold across species or habitats.
Controlled Inquiry	Instructor selects focal species and study site. Students collect data in one habitat for one species, but they also analyze national dataset to look for consistent trends in how FID may vary between habitat types or for species with different natural histories (*e.g.,* ground vs tree squirrels, or communal vs solitary species). One interpretive assignment asks students to quantitatively compare FID across explanatory categories in the national dataset.
Guided Inquiry	Students select focal species and study site(s) outside of class and collect data in multiple habitats and/or with multiple species. Possible questions could be associated with species' natural history, habitat structure (*e.g.,* dominant vegetation type), human population density (*e.g.,* urban vs natural areas), survey conditions (*e.g.,* season or weather), or approaching student (*e.g.,* neutral vs. brightly colored clothing). Students analyze national dataset to test their own hypotheses and predictions.
Free Inquiry	Students select focal species and study site(s) outside of class and collect data in multiple habitats and/or with multiple species throughout the semester. Students generate their own questions and/or protocol modifications and analyze their own data and/or the national dataset to test their own hypotheses and predictions about the factors controlling FID. Students could also conduct intensive re-sampling of one population to generate guidelines for wildlife managers interested in this species (*e.g.,* seasonal setbacks to reduce stress during critical breeding seasons). Students communicate results of inquiry in formal report, paper, or poster.

REFERENCES

1. Dill LM, Houtman R. 1989. The influence of distance to refuge on flight initiation distance in the gray squirrel (*Sciurus carolinensis*). Can J Zool 67:233–235. doi:10.1139/z89-033.
2. Blumstein DT. 2003. Flight-initiation distance in birds is dependent on intruder starting distance. J Wildl Manag 67:852–857. doi:10.2307/3802692.
3. Eason PK, Sherman PT, Rankin O, Coleman B. 2006. Factors affecting flight initiation distance in American Robins. J Wildl Manag 70:1796–1800. doi:10.2193/0022-541X(2006)70[1796:FAFIDI]2.0.CO;2.
4. Kidd-Weaver AD, Rainwater TR, Murphy TM, Bodinof Jachowski CM. 2022. Evaluating the efficacy of capture as aversive conditioning for American alligators in human-dominated landscapes. J Wildl Manag 86:e22259. doi:10.1002/jwmg.22259.
5. Putman BJ, Drury JP, Blumstein DT, Pauly GB. 2017. Fear no colors? Observer clothing color influences lizard escape behavior. PLOS ONE 12:e0182146. doi:10.1371/journal.pone.0182146.
6. Uchida K, Suzuki KK, Shimamoto T, Yanagawa H, Koizumi I. 2019. Decreased vigilance or habituation to humans? Mechanisms on increased boldness in urban animals. Behav Ecol 30:1583–1590. doi:10.1093/beheco/arz117.
7. Zaman M, Tolhurst BA, Zhu M, Jiang G. 2019. Increased Flight Initiation Distance (FID) in Golden marmots (*Marmota caudata aurea*) responding to domestic dogs in a landscape of human disturbance. Animals 9:605. doi:10.3390/ani9090605.
8. Darling RA, Smith A, Mello A. 2021. A field project investigating the influence of urban noise on eastern gray squirrel behavior. Bioscene J Coll Biol Teach 47:10–13.
9. de Resende NC, Teixeira CP, de Azevedo CS. 2024. Flight initiation distance in an urban bird: Influence of the number of people, gaze orientation, and bird behavior. Birds 5:255–264. doi:10.3390/birds5020017.
10. Jiang X, Liu J, Zhang C, Liang W. 2020. Face masks matter: Eurasian tree sparrows show reduced fear responses to people wearing face masks during the COVID-19 pandemic. Glob Ecol Conserv 24:e01277. doi:10.1016/j.gecco.2020.e01277.
11. Connors PK, Lanier HC, Erb LP, Varner J, Dizney L, Flaherty EA, Duggan JM, Yahnke CJ, Hanson JD. 2021. Connected while distant: Networking CUREs across classrooms to create community and empower students. Integr Comp Biol 61:934–943. doi:10.1093/icb/icab146.
12. Dizney L, Connors PK, Varner J, Duggan JM, Lanier HC, Erb LP, Flaherty EA, Yahnke CJ, Hanson JD. 2020. An introduction to the Squirrel-Net teaching modules. CourseSource 7. doi:10.24918/cs.2020.26.
13. Duggan JM, Varner J, Lanier HC, Flaherty EA, Dizney L, Yahnke CJ, Connors PK, Erb LP, Hanson JD. 2020. Squirrels in space: Using radio telemetry to explore the space use and movement of sciurid rodents. CourseSource 7. doi:10.24918/cs.2020.25.
14. Varner J, Lanier HC, Duggan JM, Dizney L, Flaherty EA, Connors PK, Erb LP, Yahnke CJ, Hanson JD. 2020. How many squirrels are in the shrubs? A lesson plan for comparing methods for population estimation. CourseSource 7. doi:10.24918/cs.2020.6.
15. Yahnke CJ, Dizney L, Varner J, Duggan JM, Lanier HC, Erb LP, Flaherty EA, Connors PK, Hanson JD. 2020. Sorry to eat and run: A lesson plan for testing trade-offs in squirrel behavior using Giving Up Densities (GUDs). CourseSource 7. doi:10.24918/cs.2020.30.
16. Connors PK, Varner J, Erb LP, Dizney L, Lanier HC, Hanson JD, Yahnke CJ, Duggan JM, Flaherty EA. 2020. Squirreling around for science: Observing sciurid rodents to investigate animal behavior. CourseSource 7. doi:10.24918/cs.2020.7.
17. Dizney L, Varner J, Duggan JM, Lanier HC, Connors PK, Erb LP, Flaherty EA, Yahnke CJ, Hanson JD. 2021. Squirreling from afar: Adapting Squirrel-Net Modules for remote teaching and learning. CourseSource 8. doi:10.24918/cs.2021.2.
18. Blumstein DT, Samia DSM, Stankowich T, Cooper WE Jr. 2015. Best practice for the study of escape behavior, p 407–419. *In* Cooper WE Jr, Blumstein DT (ed), Escaping from predators: An integrative view of escape decisions. Cambridge University Press, Cambridge, United Kingdom.
19. Bötsch Y, Gugelmann S, Tablado Z, Jenni L. 2018. Effect of human recreation on bird anti-predatory response. PeerJ 6:e5093. doi:10.7717/peerj.5093
20. Engelhardt SC, Weladji RB. 2011. Effects of levels of human exposure on flight initiation distance and distance to refuge in foraging eastern gray squirrels (*Sciurus carolinensis*). Can J Zool 89:823–830. doi:10.1139/z11-054.
21. Jakopak RP, Monteith KL, Merkle BG. 2019. Writing science: Improving understanding and communication skills with the “unessay.” Bull Ecol Soc Am 100:1–5. doi:10.1002/bes2.1610.
22. Sullivan P. 2015. The unessay: Making room for creativity in the composition classroom. Coll Compos Commun 67:6–34. doi:10.58680/ccc201527441.
23. Kim YK, Sax LJ. 2009. Student–faculty interaction in research universities: Differences by student gender, race, social class, and first-generation status. Res High Educ 50:437–457. doi:10.1007/s11162-009-9127-x.
24. Rainey K, Dancy M, Mickelson R, Stearns E, Moller S. 2018. Race and gender differences in how sense of belonging influences decisions to major in STEM. Int J STEM Educ 5:10. doi:10.1186/s40594-018-0115-6.
25. Dewsbury B, Brame CJ. 2019. Inclusive teaching. CBE Life Sci Educ 18:fe2. doi:10.1187/cbe.19-01-0021.
26. Tanner KD. 2013. Structure matters: Twenty-one teaching strategies to promote student engagement and cultivate classroom equity. CBE Life Sci Educ 12:322–331. doi:10.1187/cbe.13-06-0115.
27. Sorge RE, Martin LJ, Isbester KA, Sotocinal SG, Rosen S, Tuttle AH, Wieskopf JS, Acland EL, Dokova A, Kadoura B, Leger P, Mapplebeck JCS, McPhail M, Delaney A, Wigerblad G, Schumann AP, Quinn T, Frasnelli J, Svensson CI, Sternberg WF, Mogil JS. 2014. Olfactory exposure to males, including men, causes stress and related analgesia in rodents. Nat Methods 11:629–632. doi:10.1038/nmeth.2935.
28. Huang H-ME. 2015. Elementary school teachers’ instruction of measurement: Cases of classroom teaching of spatial measurement in Taiwan. Chin Teach Math 149–184. doi:10.1142/9789814415828_0005.
29. Karacop A. 2017. The effects of using jigsaw method based on cooperative learning model in the undergraduate science laboratory practices. Univers J Educ Res 5:420–434. doi:10.13189/ujer.2017.050314.