Ecology in Action: A Niche Modeling CURE

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Abstract

Pedagogical research has demonstrated the effectiveness of authentic, inquiry-based research experiences in a classroom context for improving both cognitive and noncognitive learning outcomes for a broad range of students. Ecology labs are especially suitable for authentic classroom research experiences because they can be designed to integrate a number of important scientific skills. Here we describe a scaffolded, semester-long Course-based Undergraduate Research Experience (CURE) for an introductory ecology lab intended for sophomore-level university students who have completed introductory biology coursework. Learning objectives and skills emphasized by this project cover the gamut of activities involved in implementing a multipart, collaborative scientific project. These include scientific thinking, proper collection and curation of data, analytical skills (e.g., statistical reasoning, using statistical Geographic Information System [GIS] software), and communicating project results in both written and oral format. We emphasize the larger-scale collaborative framework as an approach that students are unlikely to have encountered previously, despite being applied commonly among practicing scientists. We also discuss ways this project could be scaled for different grade levels, access to field sites, and access to computing and other resources.

Key Words: *ecology; field work; niche modeling; CURE.*

○ Introduction

In 2011, the American Association for the Advancement of Science (AAAS) proposed a list of action items that institutions and faculty can implement to improve biology education, one of which is to “ensure that all undergraduates have authentic opportunities to experience the processes, nature, and limits of science” (AAAS, 2011, xv). Authentic experiences are typically learner-centric, mentored, independent or course-based projects, where the learner emulates a scientist (Dolan, 2017; Mraz-Craig et al., 2018). Authentic learning experiences can help students understand how science concepts relate to real-world scenarios, providing a way for students to better understand course material (Kalas & Raisinghani, 2019; Mraz-Craig et al., 2018).

Additionally, the Association of American Colleges and Universities (AAC&U) advocates for the implementation of High-Impact Educational Practices (HIPs) to increase student retention and engagement (AAC&U, n.d.). The Undergraduate Research and Collaborative Assignments HIPs involve students in the scientific process (AAC&U, n.d.). In Course-based Undergraduate Research Experiences (CUREs), a cohort of students collectively undertakes an authentic research experience similar to mentored undergraduate research that occurs one-on-one with a professor (Auchincloss et al., 2014; Corwin et al., 2015; Dolan, 2017). Students are able to develop a better understanding of science content (AAAS, 2011; Blanton, 2008; Hunter, 2007; Frantz et al., 2006; Stein et al., 2004) and gain access to research experiences they may not have had access to through the one-on-one undergraduate research model (Auchincloss et al., 2014; Bangera & Brownell, 2014; Corwin et al., 2015; Dolan, 2017). The one-on-one model limits the number of students who can be reached, and underrepresented minority and non-traditional groups (e.g., students with families, students with full-time jobs, or first-generation college students) often experience barriers (Bangera & Brownell, 2014).

We present a CURE for an undergraduate introductory ecology lab that uses ecological niche modeling (ENM) to investigate factors determining species’ spatial distributions. Ecology labs are ideally suited to CURE experiences, commonly featuring a combination of field, laboratory, and analytical components. Previous studies integrating authentic research into ecology labs have shown successes in both cognitive and noncognitive (e.g., technical skills) student learning outcomes (e.g., Kloser et al., 2013). We followed a scaffolded approach, providing broad outlines of the project while leaving leeway for students to choose their research questions. We sought a middle ground between “cookbook” labs with known results and open-ended inquiry-based labs that may cause frustration for students who have not previously experienced authentic research.

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○ Concept Explanation

Species distribution modeling, or ENM, is a class of statistical methods that predicts species' occurrence based on environmental data from known localities (Elith & Leathwick, 2009; Townsend, Peterson, & Soberón, 2012). ENM is based on the connection between an organism's physiological tolerances for abiotic variables (i.e., temperature, precipitation) and the range of environmental conditions in which it can persist (Elith & Leathwick, 2009). Niche modeling has a spectrum of uses in ecology, such as identifying the environmental variables most crucial in determining a species' ecological niche, predicting species' responses to future climate change, or predicting the behavior of invasive species in a novel environment. Niche models are commonly applied at a broad spatial scale, using locality data taken from across a species' range, but can be applied at smaller scales and can reveal patterns not found in large-scale studies (Muñoz et al., 2016). We were interested in the potential to use the niche modeling framework at a smaller scale as a pedagogical tool to help students think more deeply about the factors determining the distributions of species they might commonly encounter locally.

○ Course Context

This course consisted of a semester-long (15 weeks) collaborative project, beginning with discussions on how hypotheses are formed and ending with oral or poster presentations on the project (Table 1). Working in teams of three, students created ecological niche models for one of five local species—black-tailed jackrabbit (*Lepus californicus*), Utah juniper (*Juniperus osteosperma*), two-needle pinyon pine (*Pinus edulis*), big sagebrush (*Artemisia tridentata*),

Table 1. Semester calendar (15 weeks).

Lab Week	Location	Topic	Activities	Assignment Categories
1	Computer Lab	Introduction to Lab & Research Design	Research Design Brainstorm On Campus GPS Activity	Scientific Thinking
2	Computer Lab	Introduction to GIS	Introduction to GIS Article Summary 1	Scientific Thinking Data Analysis
3	Field	Field Work	Observation Exercise Article Summary 2	Data Collection
4	Field	Field Work	Plant Keying Exercise Data Sheets Article Summary 3	Data Collection
5	Field	Field Work	Data Sheets Article Summary 4	Data Collection
6	Field	Field Work	Data Sheets Article Summary 5	Data Collection
7	Wet Lab	Soil Sampling	Soil Data	Data Collection
8	Computer Lab	Introduction Section	Finding Scientific Papers Dissection of an Introduction Introduction Draft	Scientific Thinking Science Communication
9	Computer Lab	Data Organization and Entry	Data Proofreading Handout	Data Collection
10		Spring Break: NO LAB		
11	Computer Lab	Data Analysis	R Assignment Methods Revisions Assignment	Data Analysis Science Communication
12	Computer Lab	Data Analysis	Results completed by the end of lab	Data Analysis Science Communication
13	Computer Lab	Discussion Drafting	Discussion completed by the end of lab Results Draft Discussion Preparation Handout	Scientific Thinking Science Communication
14	Computer Lab	Project Dissemination	Presentations Discussion Section	Science Communication
15	None	Finals Week: NO LAB	Final Paper Due (Midnight)	

and orange lichen (*Caloplaca* sp.)—relating the likelihood of species occurrence to a number of explanatory variables. We divided assignments up into the following categories to emphasize scientific skills development: Scientific Thinking, Data Collection, Data Analysis, and Science Communication. The course had three primary objectives:

Objective 1—Explain theories related to the interactions, distribution, and abundance of organisms.

Objective 2—Apply facts, principles, and theories to new information through analysis of scientific literature and problem solving.

Objective 3—Begin developing skills necessary for a professional biologist, including designing experiments, collaborating, collecting ecological data in the field, analyzing data, interpreting evidence, and communicating science.

To maintain authentic scientific practices, we included the following skills training: forming hypotheses, finding and reading peer-reviewed papers, collaboratively collecting field data from randomly selected plots, identifying plants and/or animals using taxonomic keys and guides, becoming familiar with technology and important ecological software (e.g., GPS, GIS, R), entering consistently formatted data, interpreting results from graphs and other quantitative data, writing scientific papers, and presenting in a style appropriate for a professional conference (see the Supplemental Material included with the online version of this article).

We provided scaffolded instruction to help students transition from previous lab experiences (i.e., cookbook labs or independent projects with small sample sizes) to the experience of working collaboratively on larger datasets, as is common for practicing scientists. Collaborative data collection is a high-impact practice that is straightforward to implement with the CURE approach (Auchincloss et al., 2014; Brownell et al., 2015; Laungani et al., 2018). Each semester, we had two to five concurrent labs (~24 students per lab). Students collaboratively created, edited, and interpreted large data sets (768 plots cumulative at this time) in a guided environment. This dataset was cumulative, with new data added each semester, so that students collaborated within and among semesters.

○ Assignment Categories

Scientific Thinking

Scientific thinking was a theme throughout assignment categories. Portions of each lab day were used to discuss theory, research design, and integration of scientific ideas. During the first class, we explained the CURE model and summarized the semester plan. Next we introduced the basic concepts of niche modeling and its ecological applications. Then students brainstormed potential independent and dependent variables for the project. During the second class, students learned about the research design of field sites, focusing on the importance of unbiased sampling. Specifically, they used ArcGIS, an important GIS program ecologists use for spatial analysis of environmental variables. In this lab, students interpreted satellite imagery, created a circular buffer of a given radius around a point, and sampled random points within the buffer. They also looked at maps of elevation, slope (% steepness of ground), aspect (compass direction of slope), and habitat type across the sampling area, to become familiar with both the type of spatial data that are available in GIS and the environmental context and variability of our specific field site. These class periods covered scientific thinking in course-specific ways.

In subsequent lab periods, students completed activities to learn how to find, interpret, and write scientific papers. We discussed what an academic journal was, how professional scientific societies are involved in their production, and what they looked like in their non-digital formats. We showed them a physical copy of a journal issue, then showed them how the numbers on the spines of the issue related to the numbers found on the pages within the article, then explained how this would be organized in a library that had print copies. We incorporated this after informal conversations revealed students had little context of what a print journal looked like and how they are organized, having only searched for single PDFs of papers online. We also discussed the importance of peer review, journal article types, and the components typically found within the articles. Additionally, we taught scientific writing skills, focusing on paraphrasing, citing sources, and reporting the findings of their project in the context of the literature.

Data Collection

Prior to field work, students engaged in exercises designed to train them to use handheld GPS devices, build general observation skills, and correctly collect field data, including animal sign and plant identification (see Table 1). After training, we collected field data over a four-week period.

At the field site, students worked in teams of three to collect data (Table 2) from 4–5 plots per field day, resulting in 200–500 plots per semester (768 plots cumulative), which we randomly selected previously using the software program ArcGIS. Students used GPS devices to locate these 3-m radius circle plots. After field work, we devoted one lab day to chemical analysis of soil samples using the Luster Leaf 1601 Rapitest Soil Test kits.

Data Analysis

Professional ecologists rely on the free, open-source statistical computing language R (R Core Team, 2020) for many analyses. Students intending to become ecologists benefit from early exposure

Table 2. Dependent and independent variables collected at each plot.

Dependent variables	Presence/absence of focal species: Utah juniper, two-needle pinyon pine, big sagebrush, black-tailed jackrabbit, orange lichen
Independent variables	Presence/absence of other focal species Species richness of plants Plant count Species richness of animals Soil type (e.g., humus, fine dirt, sand) Soil pH, N, K, P % exposed rock % human disturbance

to R, in part because of the steep learning curve of learning a computer language. Additionally, learning to program is a lesson in logic, important for achieving analytical thinking, that benefits all science students regardless of career goals. To make students aware of the utility and logic of R within the limited time frame of a one-semester course, we created a two-lab unit that walked students through R scripts we coded. The first lab walked students through the basics of R: how to download and install, what code looks like, how to run code in R, and basic programming concepts. In the second lab, students ran a script that analyzed data pertaining to their hypothesis from the collaborative data set and produced graphs. Students were trained how to interpret output and organize statistics and graphs into a Results section in the style of a scientific paper.

We used a Classification and Regression Tree (CART) approach to determine which independent abiotic and biotic variables best predict the locations of the focal species, thereby defining which of these variables best describes the species niche (Moisen, 2008). A CART approach identifies predictor variables in multivariate datasets that do not meet the assumptions necessary for parametric analyses such as regression analysis. It is appropriate for analyses with binary dependent variables (such as our presence/absence data to describe focal species' locations). Although CART analyses are advanced multivariate statistics, results can be visualized as a flowchart that students were able to interpret after brief explanation. We used the "rpart" package in R for both analyses and visualizations (Therneau & Atkinson, 2018).

Students also used R to create plot location maps for data collection and boxplots of their results. The plot location maps were used to lay out the spatial distribution of the presence/absence of focal species. They used boxplots to compare the distributions of important variables (e.g., soil potassium values or number of plant species per plot) in plots where the focal species were present versus absent. Using multiple types of visualizations was an important component of building scientific thinking and communication skills (Daniel, 2018).

Science Communication

An integral part of any authentic research experience is dissemination, and writing instruction was a core component of the lab. We used writing instruction for two purposes: 1) learning to write and 2) writing to learn (Leist, 2006). For learning to write, students were instructed on the expected content of each section, and provided a rubric to guide drafting. Through a series of scaffolded assignments, they also learned how to read scientific papers, look at those papers as models of writing, extract and cite information, use library databases to find additional papers, and use jargon appropriately. For writing to learn, students first completed pre-writing assignments before drafting the Introduction and Discussion sections, which included prompts to analyze the hypothesis in the context of previously published literature. The aim of these writing to learn assignments was to push students into the deeper understanding needed to interpret and explain their results clearly.

We used multiple assignments (~every other week) and some full lab days to work on writing a scientific research article. All student papers addressed the same general hypothesis: "do abiotic and biotic factors predict the location of a focal species?" Students selected from a list of locally abundant focal species for their individual research paper (see "Course context" above). They wrote Introduction, Results, and Discussion sections separately as drafts during the semester, and revised an instructor-drafted Methods section that included common mistakes (e.g., writing too vaguely or to the wrong audience). Having a small portion of the individual manuscripts due every two weeks rather than at the end of the semester gave time for explicit feedback for each student. We also gave students the option to improve their writing skills via repeated practice by doing revisions to each section. Additionally, they received half credit back if they completed quality revisions for the final draft of the manuscript, thus increasing student buy-in. For example, if a student received an 80% on their first draft and their revision would rate a 90%, they would earn back 5%.

Students also created either a poster or oral presentation of their work. This allowed them to practice styles used in scientific conferences, but more importantly allowed students to discuss the results of the hypotheses tested during the semester. Students reflected on the new knowledge we created, explored alternative explanations for the results, discussed limitations and mistakes, and brainstormed future hypotheses.

○ Scaling the Project

While we have presented the lab course we implemented as a whole, we recognize that replicating it in its entirety may not be feasible. As ecological hypotheses are found across scales, an ecological CURE project can be as small or large as the instructor needs, in spatial extent, number of hypotheses tested, and importance. We previously used this model to test the effects of burn severity on pollinators, plants, and soil after a 72,000-square-acre wildfire affected our area. During the COVID-19 pandemic when students attended class remotely, we tested the hypothesis that urbanization affects the species richness of birds, allowing students to record data in their own yards. In each of these cases the framework and learning goals of scientific thinking, data collection, data analysis, and science communication were applied on different scales or questions. Instructors can take advantage of locally interesting questions (e.g., water conservation, recent large-scale disturbances, biodiversity hotspots) while working within their unique constraints to achieve the same learning goals.

Many of the niche modeling methods we describe can be adapted by instructors with limited access to technology, for example at institutions that do not have a license for the proprietary ArcGIS software.[1] We used ArcGIS primarily to select random plot locations within the study area and to create maps of the study site; many of these functions can be done with the free and open-source R software. Random plot selection can also be done using widely available resources such as Google Maps, Google Earth, or a random direction/number generator. Instructors could also make transects or select plot locations ahead of the lab or as part of the first field lab.

In instances where instructors want to emphasize HIPs in addition to Undergraduate Research, they can include additional writing assignments that focus on improving writing skills, implementing repeated practice with frequent feedback. Instructors could also implement community partnerships, where students work with

[1] ESRI provides free ArcGIS accounts for K-12 instructional use, you can find more information at https://www.esri.com/en-us/industries/k-12-education/schools-software

local groups to apply ecological concepts while reflecting on this work in class (AAC&U, 2008). Students could work with a local branch of a government agency (e.g., National Park Service, The Nature Conservancy) to run a field project, then disseminate the results to a specific local community.

○ Conclusions

CURE experiences are an excellent format to bring multiple aspects of authentic research to a wide array of undergraduate students of varying backgrounds and experiences. The ENM CURE we present provided our students with opportunities to gain skills and knowledge in field methods, data curation, statistical analysis, computer programming, and writing and presenting scientific results. We suggest that niche modeling is a readily accessible, scalable format for a project that can introduce students to ecological concepts and science practices. Additionally, when any data the students collected is published, we suggest adding a line to the acknowledgments section that thanks students who were enrolled in Class ABC during terms 123.

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