UNDERGRADUATE EDUCATION

Flexible and Inclusive Ecology Projects that Harness Collaboration and NEON-Enabled Science to Enhance Student Learning

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Abstract

The COVID-19 pandemic significantly impacted undergraduate education and fundamentally altered the structure of course delivery in higher education. In field-based biology and ecology courses, where instructors and students typically work collaboratively and in-person to collect data, this has been particularly challenging. In this context, faculty from the Ecological Research as Education Network (EREN) collaborated with the National Ecological Observatory Network (NEON) to design five free-flexible learning projects for use by instructors in varied modalities (e.g., socially distanced in-person, remote, or HyFlex). The five flexible learning projects incorporated the Ecological Society of America's 4DEE framework and included field data collection, data analysis components, and an activity that incorporates existing NEON field protocols or datasets. Each project was designed to provide faculty members with a high degree of flexibility so that they could tailor the implementation of the projects to fit course-specific needs. Collectively, these learning projects were designed to be flexible, inclusive, and facilitate hands-on research while working in alternative classroom settings.

Key words: 4DEE; ecology education; EREN; field research; HyFlex learning; inclusion; NEON; remote learning; undergraduate education.

Introduction

The COVID-19 pandemic significantly disrupted every aspect of academic and human life (Lashley et al. 2020, Turner et al. 2020, Guintella et al. 2021). In undergraduate classrooms, this involved shifting in-person courses online, changing course structure, and fundamentally altering student experiences. In field-based biology and ecology, where many courses have historically been taught in high-contact formats with students working cooperatively to collect ecological data in the field, these changes have been particularly acute and dramatically altered the learning environment (Barton 2020, Lashley et al. 2020, Richter et al. 2021).

To address this pressing challenge, faculty members sought out or designed new activities that facilitated data collection in socially distanced ways in various locations, including campuses, backyards, and public parks (Barton 2020, Lashley et al. 2020, McKinnon 2020). Ideally, these novel activities simulate experiences that students gain from in-person classes, connect to relevant scientific questions and hypotheses, and are followed by robust data analyses that take advantage of the online statistical tools that have emerged in the last decade. However, designing these types of activities is challenging for faculty who, like the rest of society, are dealing with the risk and reality of illness, homeschooling of children, Zoom fatigue, and other demands of rapidly shifting to hybrid and/or fully online teaching (Quezada et al. 2020, Aubry et al. 2021, Lindstrom et al. 2021). Challenges may be especially acute when instructors must switch back-and-forth between delivery modes or deliver a class simultaneously in more than one mode, such as when students are under quarantine.

To meet these challenges, faculty from the Ecological Research as Education Network (EREN) collaborated with the National Ecological Observation Network (NEON) to develop flexible learning projects that could be used by instructors seeking authentic research experiences for their students that combine data from long-term field sites, student-led data collection from local sites, and statistical analysis. NEON offers advantages in this situation, because it provides open access data that can be used in coursework when field-based activities are restricted due to public health measures but also provides access to standardized protocols that can be used to collect complementary local data when possible. Even outside of pandemic conditions, instructors can take advantage of this ability to collect data on a small scale that can be aligned with data collected in the same way across the NEON network, familiarizing students with field methods while also exposing them to continental-scale hypotheses and analyses.

The development of these flexible learning projects was funded through a grant from the Macrosystems Biology and NEON-Enabled Science Program at the National Science Foundation (Award No. DBI-2037827 by Anderson et al.). Four of these projects were developed and ready for implementation by Fall 2020. Our funding also included support for future projects; we released a request for incubator projects that resulted in two additional projects developed in Fall 2020 and implemented first in Spring 2021. In this manuscript, we focus on five of these six projects and discuss how they can be employed in undergraduate and high school classrooms, both for pandemic teaching and in the postpandemic future. The pandemic has revealed extraordinary inequities across all societal dimensions. Greater flexibility and more diverse opportunities for accessing and participating in field-based ecology learning experiences can mitigate inequities by reducing barriers to access.

Each flexible learning project was designed to have clear student learning goals and to incorporate the Ecological Society of America's 4DEE framework that guides ecology curricula (http://www.esa.org/4DEE). Each project included components of socially distanced field data collection by students, data analysis in which the data collected at one location could be compared or integrated with datasets from other sites, and an activity that uses either existing NEON datasets or NEON field protocols, or both. All projects contained multiple modules that could be used separately or combined, enabling instructors to tailor for specific class needs. Finally, these flexible learning projects were piloted by faculty and students in the Fall 2020 semester and were then modified after feedback from a semester-long Faculty Mentoring Network (FMN) hosted by EREN members and the Quantitative Undergraduate Biology Education and Synthesis (QUBES) working group.

Here, we provide a basic overview of the approaches (Table 1), learning goals (Table 2), and expected outcomes for five of the EREN-NEON flexible learning projects. These projects are freely available for faculty to implement and address to their specific course learning objectives via the EREN website (https://erenweb.org/eren-neon-flexible-learning-projects/) and QUBES website (https://qubeshub.org/community/groups/erenneonfmn/selected_modules). Adaptation of these materials to develop new class activities or research projects is strongly encouraged.

Flexible Learning Projects

Plants in the human-altered environment

Plant community structure and function varies across landscapes, in part due to anthropogenic landscape alteration shaping plant diversity, vegetation structure, biomass, and ecosystem services (Livesley et al. 2016). The Plants in the Human-Altered Environment (PHAE) project was designed

Table 1. Overview of how lessons can be completed with a classroom where all students and instructor are in-person; are fully remote; or are a blend of each using HyFlex course formats.

Flexible learning project	Course structure		
	Fully in-person	Fully remote	HyFlex
Plants in human-altered environments	Students complete online site characterization and plot selection, field data collection, and data analyses in small in-person groups	Students independently complete online site characterization, plot selection, and collect data at a nearby site. They then work in small groups to analyze data synchronously online	On-campus students lead data collection, while remote students lead data management. Prefield activities and analyses are conducted synchronously online
Backyard Beetles and Pollinators	Students complete observations individually or in small groups as a synchronous class lab, then analyze as class activity in teams	Students conduct fieldwork independently and asynchronously. Another option is that the class can analyze a published open dataset of observations from previous years	Students can conduct observations and analysis either at home and asynchronous or together as class activity; analysis can be solo or in teams and synchronous in class or asynchronous online
Lichens in diverse landscapes	Students complete online and field activities as synchronous in-class activities	Students complete observations near their location - can be done in small urban spaces (e.g., street trees), backyards, or local natural areas. There are short video tutorials for students to watch asynchronously	Students will use data collected in their local environment and online to visualize and evaluate their hypotheses within and across sites
Mosquito surveys along anthropogenic impact gradients	Students conduct field activities either individually or in teams; students analyze class data individually or in teams	Students conduct field activities individually near their residence (e.g., in their yard, on a windowsill of their home); data analysis can be conducted either individually or in teams asynchronously	Students can conduct field activities either during class time or asynchronously off-site. Analysis can be completed synchronously in-person or asynchronously online
Sapsucker tree use across landscapes	Students conduct field activities either individually or in teams; students analyze class data and/or the provided sample dataset individually or in teams	Students independently conduct field activities at a local area with trees and then analyze class data. Alternatively, the class can analyze a provided sample dataset	Students can conduct field observations and data analysis either on their own or together as a class

Note. The EREN-NEON flexible learning projects are designed to be implemented in any teaching modality - or to easily transition across them, depending on student and instructor needs.

Table 2. Overview of how the lessons incorporate the 4DEE framework elements.

Flexible learning project	Core ecological concepts	Ecology practices	Human-environment interactions	Cross-cutting themes	NEON data products and protocols incorporated
Plants in human-altered environments	Individual organisms; species diversity	Fieldwork; working collaboratively; data and computer skills; spatial analysis	Human impacts on landscapes; ecosystem services	Spatial and temporal scales	DP1.10058.001 (Plant presence and percent cover), DP1.10096.001 (Soil chemical properties), DP1.10055.001 (Plant phenology observations), DP1.10017.001 (Digital hemispheric photos of plot vegetation)
Backyard beetles and pollinators	Habitat types; biodiversity; landscapes	Natural history; field identification; data visualization; evaluating claims; working collaboratively	Ecosystem services; urban-rural gradients	Structure and function; spatial scales	DP1.10022.001 (Ground beetles sampled from pitfall traps), DP1.10058.001 (Plant presence and percent cover), DP1.00033.001 (Phenology images)
Lichens in diverse landscapes	Abiotic and biotic features of the environment; individual organisms; biodiversity	Natural history; field identification; spatial analysis; data and computer skills; applying ecology	Urban-rural gradients; human impacts on landscapes	Spatial scales; biogeography	DP1.10058.001 (Plant presence and percent cover), DP1.00013.001 (Wet deposition chemical analysis), DOC.014042 (Plant Diversity Sampling protocol and procedure)

(Continues)

Table 2. (Continued)

Flexible learning project	Core ecological concepts	Ecology practices	Human-environment interactions	Cross-cutting themes	NEON data products and protocols incorporated
Mosquito surveys along anthropogenic impact gradients	Individual organisms; mosquito communities	Fieldwork; working collaboratively; communicating and applying ecology	Humans shape the environment	Spatial and temporal scales; biogeography	DP1.10043.001 (Mosquitoes sampled from CO2 traps), DOC.014049 (Mosquito sampling protocol and procedure), DOC.000910vB (Science design for mosquito abundance, diversity, and phenology)
Sapsucker tree use across landscapes	Landscape gradients; behavioral ecology; keystone species	Natural history, habitat assessment, data analysis, and visualization, working collaboratively	Humans shape the environment; urban-rural gradients	Ecological engineering; biogeography	DP1.10010.001 (Coarse downed wood log survey)

Notes. All the flexible learning projects incorporate NEON protocols and data products, harnessing the power of the large spatial and temporal scale of the NEON macroecology observation network to facilitate flexible student-led research across diverse landscapes.

for students to investigate the relationship between woody plants and anthropogenic impacts from local patches to regional and continental scales within a range of living-learning contexts, whether students, and their research sites, are dispersed across the landscape or only on campus. This project embodies the EREN model by providing a detailed, consistent protocol, guided inquiry-based field research, collection, management, and analysis of both local and regional data in the context of a common yet adaptable research question, and sharing of data to a common database for use by all contributors. The PHAE project also encompasses all four dimensions of the 4DEE framework through exploring fundamental ecological concepts in the field; using real-world field and computational skills, including free software like Google Earth, Google Sheets, and R; identifying and characterizing human-environment interactions; and exploring ecological relationships across seasonal, annual, and geographic scales (Table 2).

Students, working alone or in small groups, measure human impacts locally through the classic proportion of impervious surface area and through a novel metric of proportion of human-influenced viewshed. Following NEON protocols, students identify, characterize, and quantify woody plants in their local patches (Table 1). These data are then analyzed across a range of human-altered landscapes, compared to NEON sites for reference, and thus students explore how ecological relationships are affected by landscape-level anthropogenic impacts. Through this science-through-collaboration model, students gather empirical data at their local scale, share and analyze data at the regional or continental scale, and investigate ecological relationships across time and space, all while contributing valuable data to better understand the influence of humans on woody plants. The PHAE project includes a series of independent modules, with foundational modules for identifying and characterizing research sites and plots and later modules that could be used to address a range of topics such as species diversity, invasive species, aboveground biomass, carbon sequestration, vegetation structure, type and degree of disturbance, and ethnobotany.

Backyard beetles and pollinators

Pollinating insects include a diverse group of taxa, including understudied taxa such as beetles. Concern over insect declines has led to increased attention on the role of urban and managed landscapes and their contributions to food and nesting resources for insect pollinators (Kluser and Peduzzi 2007). This project uses standardized floral observations to measure insect floral visitors on campus, backyards, or nearby natural areas across a rural-urban land-use gradient, and to generate plant-pollinator interaction networks. The goal is to use functional groups to assess network structures and determine whether they vary over rural-urban gradients and ecoregions. Students develop hypotheses about organisms and communities, identify plant and pollinator functional groups, and collect qualitative and quantitative data. Students can then compare their own observations of pollination events and pollinator morphospecies diversity to those measured by their peers in different landscapes with different floral characteristics. They can also examine how their beetle catch compares to NEON terrestrial site abundance and diversity data; how their habitat compares to plant diversity and percent cover data at NEON sites; and how plant-pollinator interaction networks vary across landscape gradients (Table 2). These goals engage all parts of the 4DEE framework, as students learn popular ecology experimental design approaches and techniques through observation of landscape patches, natural history, habitat assessment, and field identification of taxa (Table 2). This project engages students in measuring human dependence on the environment via pollination as an ecosystem service and in considering how land-use and ecological stewardship through plantings (e.g., gardens) can alter organisms and services in a habitat. Finally, this module incorporates cross-cutting themes by teaching students about functional biodiversity, systems thinking across scales, and the role of plants and pollinators in contributing to ecosystem services across space and time.

Lichens in diverse landscapes

Lichens are an important group of bioindicators, whose presence and abundance are influenced by abiotic (e.g., air quality, impervious surfaces) and biotic drivers (e.g., tree cover, Conti and Cecchetti 2001). Students explore relationships between lichen cover and abundance and land-use variables and other environmental data. This project was designed to follow the 4DEE framework by having students explore how landscape gradients and human activities impact individual organisms and biodiversity through fieldwork and spatial analyses (Table 2). In the first module, students explore NEON data to examine relationships between lichen and environmental variables at coarse spatial scales (Table 2). In the second module, students collect field data on lichen percent cover and other relevant (but optional) variables (e.g., canopy cover, bark pH, aspect) at a finer spatial scale. The intent of the module is that it be versatile enough to be implemented in a more traditional on-campus setting, as well as within remote settings. The project was developed for surveying corticolous lichen; however, faculty can also adapt the project with user-defined protocols for surveys of saxicolous lichen, found on buildings, rocks, and gravestones, to better suit their needs if performed within an urban setting or in pursuit of alternative questions. Students evaluate other relevant geospatial datasets, such as air quality (EPA) and tree cover (Global Forest Watch), which provide additional explanatory variables. Based on their geospatial queries, students generate hypotheses for testing with field-collected or online data sources. These modules are flexible in that they can be implemented in small urban spaces (e.g., street trees), backyards, campus settings, or local natural areas. Students use dichotomous keys and smartphone apps (e.g., iNaturalist, SEEK) as tools to hone species identification skills and crowdsource verification, use homemade sampling grids to assess lichen cover, score air quality using lichens as bioindicators, and gather other field measurements using whatever tools are available (e.g., field compass, smartphone compass app). Students use the data collected locally and online to visualize and evaluate their hypotheses within and across sites. This approach combines multiple disciplines including botany, ecology, environmental science, and geospatial science to create a cross-cutting experience for students and faculty. In addition, this project introduces students to free programs (e.g., Google Sheets, ArcGIS Online, R) to share, visualize, and statistically analyze data.

Mosquito surveys along anthropogenic impact gradients

Container-breeding mosquitoes offer a model system to examine complex ecological and anthropogenic relationships that drive mosquito populations and species distributions across an urban-to-rural land-use gradient. Students develop hypotheses about mosquito species diversity across this land-use gradient, design experiments to test their hypotheses, collect and identify mosquitoes, and record and analyze quantitative data. In some locations in the US (e.g., Florida, Southern Texas), mosquitoes can be sampled year-round and, in other parts, they can be observed firsthand by students seasonally (e.g., Wisconsin, Oregon). Since 2014, NEON has sampled adult mosquito populations across undisturbed, natural, and agricultural sites. Students can use NEON data, as a standalone dataset or along with their own, to analyze how land use and geographic location can impact mosquito diversity, identified taxonomically to either genera or species depending on available tools and course goals. Students can evaluate changes in mosquito species abundance and distributions across space and over time using NEON data. This project incorporates elements from the 4DEE Framework through designing experimental protocols, field sampling and species identification, data analysis, and connecting mosquito diversity to landscapes. (Table 1). There are detailed module-based guides, including introductory material and instructions on mosquito collection, construction of mosquito emergence traps, accessing and utilizing NEON data, and conducting data analyses. Students completing this project gain an increased understanding of population- and community-level mosquito abundance, distribution, and diversity patterns across a rural-urban gradient and how this might influence the prevalence of mosquito-borne diseases.

Sapsucker tree use across landscapes

Sapsuckers are woodpeckers that forage on tree sap, leaving behind rows or grids of small holes in trees (sap wells) that can facilitate food resource access for other species (Daily et al. 1993). The main research question of this project is whether patterns of sap well occurrence and abundance vary across urbanization gradients. Learning goals for participants include (1) gaining an understanding of keystone species, ecosystem engineers, variations across landscape gradients, and foraging ecology; (2) engaging in field observations, habitat assessment, ecological inquiry, data analysis and visualization, and collaboration; and (3) gaining an understanding of the human causes of urban-rural gradients and the consequences of those gradients on sapsucker use of trees for foraging. These goals all fit within the 4DEE framework, by having students explore how landscape gradients impact keystone species, through habitat assessment and collaborative data analysis (Table 2). Participants follow a simple, adaptable protocol centered on observing trees in their locality and recording size, species, and bark characteristics of the trees, along with the occurrence and abundance of sap wells on each tree. Data may be contributed to the project using a smartphone app (iNaturalist) or Google Sheet template. The project's approachable, flexible methodology and relation to multiple ecological concepts make it suitable for a range of different teaching outcomes and contexts, depending on an instructor's course-specific objectives (e.g., tree identification, forestry field techniques, woodpecker foraging behavior, and data analysis). Aside from the primary research question focused on urbanization, data from this project can also be used to explore how sap well occurrence varies with tree species and size, further enhancing our understanding of sap wells as a keystone resource. In addition, NEON and other open access data sources including eBird and iNaturalist provide an opportunity for students to visualize sapsucker distributions across large geographic ranges and to explore their potential relationships to woody vegetation (Table 2).

Considerations

After two semesters of implementing these projects in dozens of classrooms across the country, some common considerations emerged for future instructors in the areas of training, variability in biodiversity across sites, and technological access and failures.

Students and instructors working in various settings, whether in-person, asynchronously, or both, required additional scaffolding to ensure that everyone felt comfortable and prepared for data collection.

This was especially true for activities that required species identification, as students may be collecting data alone and without people to ask for verification. Some solutions involved short video clips that demonstrated the field sampling, data processing, and analysis methods, which allow repeated, asynchronous reviewing, and practice data collection activities with feedback (e.g., identification quiz). In addition, some smartphone apps (e.g., iNaturalist) crowdsource species identification, which aids in verification and student confidence. These tools reduce inconsistencies in methods and identification, as well as help students and instructors, gain confidence in remotely completing the assignment.

Another consideration is the variability of biodiversity, phenology, and landscapes where students are living and learning, if participating remotely and off-campus. For example, students in an area that lacks woody plants would be unable to observe lichens or sap wells on trees. If those situations arise, there are multiple solutions. One option is to record a zero. As many of the flexible learning projects are helping students explore variation in landscapes and gradients, understanding where species are not found is valuable for learning. Another solution is to use NEON data. For example, if students are unable to collect data for the mosquito flexible learning project, those students can use simplified NEON datasets provided by the project lead. A third potential solution is to use data from the flexible learning project collected in previous semesters. For example, if students are in a location where no flowers are in bloom for the backyard pollinators flexible learning project, they can use an available clean observational dataset of floral insect visitors collected during previous class iterations (Stack Whitney et al. 2021). All the flexible learning projects are designed to provide student experiences whether or not they are collecting data firsthand or if the focal taxa are present on-site.

A critical consideration is a technological access and troubleshooting. Multiple students and instructors encountered prohibitively slow upload times due to web applications not working well or due to slow internet speeds at their location. Another challenge was planning for the reality of a wide range of available classroom technologies. For example, some courses have smart boards and resources like computer labs with software licenses available for classes but not all do. Additionally, despite the common assumption, not all students have smartphones. These projects attempt to offer alternative options that accommodate implementation in classes with various constraints. For example, potential solutions include having multiple ways to enter data, such as hard copy/printable data sheets in addition to web interfaces, and starting from the assumption that students participating remotely will not have access to high-speed internet.

Conclusions

While using hybrid and flexible projects requires planning in ways that are different from traditional classroom preparation, they result in unique and engaging experiences for students. Many students who participated in these modules reported being interested in other opportunities for place-based learning. Some had noticed particular elements of the landscape (e.g., sap wells) but had not been aware of their origin and function until participating in the project. Students reported that these projects compelled them to more closely observe and appreciate their local environments, such as the trees they pass every day. Other students expressed appreciation for these lessons helping them to sense their world in a new way, such as understanding the myriad ways that human activities influenced what can survive and co-exist in this shared environment. Faculty reported on feedback surveys that the opportunity to teach through field data collection even in a remote learning context was valuable to them and that they appreciated the modules being available at a time when course content was being rapidly reimagined. Faculty also expressed interest in building on the modules for repeated use as the pandemic continues.

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Data Availability

No data were collected for this study (i.e., theoretical, review, opinion, editorial papers).

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