The Power of Place: A Course-Based Undergraduate Research Experience Studying Urban Ecology, Local Apple Trees and Disease Susceptibility

Deidre M. Jaeger†††*, Teresa Bilinski†††, Amy Dunbar-Wallis†††, Irfan Alam†††, and Lisa A. Corwin†††

††taught course, wrote original draft
†††assisted with designing course, coordinating logistics, preparing field and lab materials, developed and administered educational evaluations, wrote and revised manuscript drafts

Abstract

Course-based Undergraduate Research Experiences (CUREs) offered early in an undergraduate student’s career have the potential to include a greater number and diversity of students than one-on-one mentored research. CUREs that use a place-based model to do research relevant to the local community may have even more engagement capacity. However, there are few place-based CURE curricula published and even fewer that include assessments of cognitive and psychosocial outcomes for students. Here, we present a one-semester CURE curriculum where students explore urban ecology concepts and conduct authentic research to investigate apple tree (Malus domestica) resistance to the widespread fire blight bacterial disease (Erwinia amylovora). We hypothesize that a place-based, community-relevant curriculum would increase students’ ecological knowledge, research self-efficacy, and intrinsic motivation. Student responses (N = 11) to pre-post surveys and reflection questions demonstrated that the CURE elements of discovery and relevance contributed to a positive experience, and participation in the course was advantageous to the students’ career goals. Pre and post survey results demonstrated significant increases in ecology knowledge, scientific practices, research self-efficacy, and scientific civic knowledge (knowing how to use science skills to help one’s community). College instructors desiring to engage a whole class in community-relevant urban ecology research may wish to draw units, lessons, activities, and assessments from our semester-long CURE curricula. Preliminary data from this study indicates that modules from this urban ecology CURE could be implemented within existing biology or ecology classes, and assessments could be used for student populations enrolled at multiple types of institutions.

Copyright: © 2024 Jaeger, Bilinski, Dunbar-Wallis, Alam, and Corwin. This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited.

Conflict of Interest and Funding Statement: This work was funded by the National Science Foundation Improving Undergraduate STEM Education Grant # 1836510. None of the authors have a financial, personal, or professional conflict of interest related to this work.

*Correspondence to: Deidre M. Jaeger, 1900 Pleasant Street, 334 UCB, Boulder, CO 80309, deidre.jaeger@colorado.edu

Learning Goals for the Course

Students will:

1. gain understanding of connection between city sustainability goals and urban vegetation.
2. develop understanding of urban microclimate and how the built and natural environment interact.
3. know examples of real-world problems that are too complex to be solved by applying biological approaches alone.
4. apply science process skills to address a research question in a course-based research experience.
5. develop skills in tree sampling and urban ecology field techniques.
6. share ideas, data, and findings with others clearly and accurately.
7. communicate learning concepts and research progress orally and in writing.
8. reflect on learning, performance, and achievements.

Selected Learning Objectives

Justification

We chose to highlight our Week 1 introduction to urban ecology lesson since it uses several active learning techniques, is adaptable for implementation, and gets students out in the field experiencing the power of place.

We chose to feature our Week 8 data collection lesson to provide the field research protocols students used in this place-based CURE project that can be implemented to study apple trees and fire blight in other geographic areas.

Exemplar Learning Objective(s)

After exemplar lesson 1, students will be able to:

◊ characterize several of the definitions of urban ecology.
◊ find and cite primary and secondary scientific literature.
◊ make ecological observations and devise research questions.
Learning Goals for the Course

From the Ecology Learning Framework:

◊ How do species interact with their habitat?
◊ How are living systems interconnected and interacting?
◊ What impacts do humans have on ecosystems?
◊ How do humans depend on ecosystems for their health and well-being?

Selected Learning Objectives

After exemplar lesson 2, students will be able to:

◊ execute protocols and accurately record measurements and observations.

INTRODUCTION

Place-based field learning is done in a local context and incorporates cultural and historical elements to link science concepts and societal issues to an ecological place. Place-based learning results in positive outcomes for undergraduate students such as increased sense of place (1), appreciation of their environment (2), improved knowledge and skills acquisition (3, 4) as well as deeper cognitive and critical thinking skills (5). Connecting science with society also promotes student “ecoliteracy,” an understanding of how generating new knowledge affects real people, and envisioning solutions to unite environmental and social challenges (6). Environmental education programs have developed field-based courses and lessons to connect students to the region of study which have been shown to contribute to cognitive learning gains (2, 7) and students enrolled in a field component had a deeper understanding of ecological issues (8, 9). Field-based courses can also have affective gains resulting in personal attitudinal or emotional shifts from a course experience that may not be explicitly targeted outcomes from the curricula (7). While field courses and place-based courses have been studied separately, there are fewer courses that combine place and field elements and benefits.

Participation in place-based field research that specifically promotes a positive pro-social outcome is likely to boost student persistence in Science, Technology, Engineering, and Mathematics (STEM). Working on a place-based project with community relevance can boost interest and intrinsic motivation in STEM fields (10, 11), particularly in underrepresented minority students (12, 13). For first year undergraduates, place-based learning which emphasizes creativity, intuition, and connections to personal values and a sense of place has been linked to increased persistence in STEM (3). Because engaging students in a Course-based Undergraduate Research Experience (CURE) has also been linked to student persistence in STEM (14–16), CUREs that pose place-based and community-relevant research questions may have even higher potential to engage and retain a diversity of students in the STEM field.

While the number of CURE courses have increased in recent years, there are only a handful of publications describing place-based field CUREs. For example, although the number of CURE courses and lessons published on CourseSource has quadrupled from 2019–2022 compared to 2015–2018 (28 and 7 publications, respectively) (17), only one fifth of them involve field-based instruction components (7 of 53 publications) (17) and none of these explicitly describe pro-social community-relevant goals. Courses with field components are at risk of decline given increases in student enrollment and decreases in qualified staff (18). Other potential deterrents to sustaining or adding field courses include fear of legality in accidents (5), student accessibility and equity concerns of requiring in-person attendance or off-campus make-up labs (19). This potential for decline is unfortunate given that undergraduate research courses containing field research serving a pro-social purpose have high potential to equip students with research skills and increase connections to the local community, which can in turn lead to increased motivation and persistence in STEM. In order to advocate for the inclusion of such courses in departmental curricula, more data about student educational outcomes from participation in place-based CUREs is needed (7, 20). Furthermore, these assessments will be valuable for accurate assessment of the cost and benefit tradeoffs when surmounting barriers.

The work we report on here addresses the current gaps in understanding of outcomes of place-based CURE designs by describing the curriculum and student outcomes for EBIO 1250: Introduction to Ecology and Evolutionary Biology Research with the Boulder Apple Tree Project. In this CURE, the students investigated resistance in local apple trees to fire blight (caused by the bacterium Erwinia amylovora), a devastating bacterial disease that can damage and kill many varieties of fruit trees. This question was co-developed with local apple growers and The Boulder Apple Tree Project (21). The topic is relevant to broader national agricultural communities since apples are the most highly consumed fruit crop in the United States (22). Fire blight bacterial infections are found North America where fruit trees grow (23). The only intervention method available for controlling a fire blight infection is laboriously clipping infected tissue to keep it from spreading in a tree or to others (24). Thus, the question of what types and tree and geographic characteristics resist fire blight is of interest to the agricultural and residential fruit growing communities as the is no widespread “cure” for fire blight.

This semester-long course assumes completion of general high school science courses and does not require previous research experience or college level biology or ecology. Lessons and activities exploring physical, ecological, and social lenses involved visits to local field sites. Place-based field research experiences were designed with the intention of building students’ collective familiarity with, and connections to, the community while engaging with broader societal and environmental challenges in urban agroforestry. The five essential CURE elements (scientific practices, discovery, relevance, collaboration, and iteration) were included in course design since they have been seen to promote student project ownership, self-efficacy, and persistence in the face of problems (16, 25–27). By partnering with our advising office, we recruited transfer students from regional...
community colleges in order to promote persistence of diverse backgrounds in the STEM field.

We designed this urban ecology CURE with the hopes that it would promote three broader outcomes for students:

1. **Increase scientific knowledge** in both general biology concepts and locally connected scientific knowledge through lessons focused on local apple trees (related to learning goals 1, 2, and 4).
2. **Increase scientific self-efficacy** via science skills (ability to perform the scientific method elements), research self-efficacy (beliefs about one’s abilities to execute research), and scientific civic knowledge (knowing how to apply one’s science skills in the community, related to learning goals 3, 4, 5, and 6).
3. **Increase intrinsic motivation** by way of increases in urban ecology subdiscipline interest (related to learning goals 1 and 2), scientific civic value (value of their science skills for the community, related to goals 3 and 6), and science identity (sense of belonging to the field of science, related to goals 4, 5, and 8).

In order to accomplish the above outcomes, we developed two different research tracks for students enrolled in the 2019 in-person CURE: (i) Investigation of the spatial nature of fire blight bacteria incidence and severity across apple trees through a field survey of established trees and (ii) Investigation of how fire blight infection differs among cultivars of apple trees using mechanical inoculation of the disease into leaf tissue of potted tree clones. Both projects required students to draw upon the scientific method (research question design, literature searching, experimental design, data collection, data analysis and interpretation) and present findings at a final poster presentation. In year two (2020), this course was revised for an online format to accommodate safety measures in place for the COVID-19 pandemic. Below we focus on the in-person course offering, but the remote modality version is described in the Alternative Implementations section. Our experience teaching this course at the University of Colorado Boulder (CU) during Fall 2019 allowed us to create a curriculum package that accomplished our goals and can be used in-part or in-full by other instructors.

### Intended Audience

These lessons are intended for first-year undergraduate students majoring in biology, ideally in a region that cultivates some type of fruit trees. The course will be helpful for students further into their degree program that are seeking research experience. The lessons are suitable for instruction at a large research university, a liberal arts college, or a community college. The lab (the focus of this paper) was developed and taught at a large 4-year research university in combination with a 1000-level lecture that the students were required to enroll in for five credit hours, however the lab can also serve as a stand-alone course. The first iteration of the course included 13 students, with two students dropping part way through. Half of the students were in their first year, and the other half included second- and third-year students as well as transfer students from a community college. Transfer students who were no longer in need of lower-division credits could take the course for upper division credit (as independent study with a faculty). These students engaged in additional research tasks of interest to them such as preparing the fire blight inoculum, measuring additional research variables for the apples trees, and writing reflections for our Boulder Apple Tree project website blog.

### Term and Context Description

This laboratory course is designed as a semester-long 15-week in-person course (Supporting File S1). Lab sessions are structured for three hour and 50-minute meetings once per week and involve a combination of lecture, lab work, and field work. The end-of-semester student poster session is part of a public research symposium and is suggested to take place on an evening or weekend to promote public access. We suggest devoting at least one hour to a student poster session. Our symposium included a keynote speaker and other presentations and panels related to apple trees and spanned three hours. We expected students to complete approximately 3 hours of homework per week which included pre-class assignments like filling out questions about a homework reading and post-class assignments such as finishing worksheets and lab notebook entries, entering data, and coordinating with lab group members.

### Prerequisite Student Knowledge

There is no prerequisite knowledge required for students beyond what they are expected to receive in high school biology, however we found it helpful if students have some exposure to making and interpreting graphs, and working in the **R software** programming environment. Prior R experience is not required for this CURE, but students with prior R experience found their background to be helpful during R-based activities in this CURE. First-year students typically did not have any incoming experience with R and were able to navigate the tasks described after receiving one-hour of scaffolded, instructor-led R instruction with an additional 2 hours of individual practice during class time.

### Prerequisite Teacher Knowledge

Instructors should have place-based knowledge of the outdoor student learning environment in which instruction will take place and basic botany field skills to lead the lessons and guide the student research projects. This may include an understanding of general urban ecology themes, local fruit tree varieties, location on public lands, and knowledge of ecological challenges local agriculturists face. To find local fruit trees, a good starting point is searching a public tree inventory for your city. For example, check the website for the municipal forestry organization or agency in your area. Another option is searching fallingfruit.org for crowdsourced tree locations in your area. To gain a sense of priorities for land managers and agriculturists, we recommend trying to reach out to local orchardists or the city’s urban foresters. It is important to note that permission to visit field sites must be obtained in advance of student visits, and special permission for destructive sampling (e.g., removal of leaf samples from trees for fire blight tests) must be explicitly addressed. For sampling of private trees, we recommend reaching out to homeowners via social media boards (i.e., Nextdoor). For public tree access, the municipal forestry department should be able to assist with acquiring a permit. For this plant- and
disease-themed research project, the instructor should be familiar with bacterial culture techniques.

**SCIENTIFIC TEACHING THEMES**

**Course Structure**

Course-based Undergraduate Research Experiences (CUREs) are defined as class-wide investigations of research questions or problems that are of interest to the scientific community and/or have relevance to the broader community (15). The elements of CUREs that contribute to student success are proposed to be similar to elements of Research Experiences for Undergraduates (REUs) and one-on-one faculty mentorship relationships (15). Specifically five essential features have been proposed to contribute to positive student outcomes in CUREs: (i) Use of Scientific Practices, (ii) Discovery of new knowledge or insights, (iii) Broadly Relevant or locally important work, (iv) Collaboration and group work, and (v) Iteration and revision of work (15). Some of these dimensions exist in traditional laboratory courses; however, experts have proposed that it is the intentional integration of these five dimensions that creates a CURE learning experience. Throughout this Urban Ecology CURE, we incorporated all five of these CURE dimensions.

**Scientific Practices**

Because this course is designed for students with no prior research experience, we provided the guiding research questions. How does fire blight disease prevalence differ 1) among apple cultivars and 2) across an urban landscape? These questions were studied with mature, established trees (disease resistance across space) and one-year old potted trees (resistance among cultivars). The scientific practices students focused on were how to search literature, form hypotheses, gather data using field and lab techniques, identify meaningful variation, navigate the messiness of real-world ecological data, develop interpretations, and communicate findings.

**Discovery**

The students investigated the question of how resistance to fire blight bacteria differed among apple trees and across urban gradients (e.g., fire blight incidence at different levels of impervious surface). This Urban Ecology CURE embraced the dimension of discovery because the outcomes of our apple disease research questions were unknown to the students, instructors, and community members who were involved with the project. In addition to the novelty associated with the central research question, method-selection was a point of discovery for the students in 2019. Because some of the methods for the project were not vetted prior to the project or were used in new contexts, the students investigated which methods would work best and also “discovered” new approaches to answering the research questions. For example, even though our research question did not focus on weather, we were not sure how autumn weather extremes may affect our experiment because we could not find any examples of studies that had inoculated apple leaves with disease during the autumn season. Therefore, how to inoculate leaves during fall became a sub-question within our project. We found it useful to explain these inherent challenges and risks associated with authentic research at the beginning of the semester.

**Relevance**

We worked with local orchardists to determine the greatest ecological challenges to their urban agriculture endeavors and how our class research question might be useful for their livelihoods. Apple disease susceptibility is influenced by both the environment and genetics. In Boulder, Colorado, we have located several sites of historic apple trees that contain heirloom varieties named by the United States Department of Agriculture (USDA) as well as trees that do not match a named variety. Understanding disease resistance of apple trees that may be locally adapted to the Colorado Front Range may be useful for future apple tree planting and is of great interest to regional orchardists and local community members. Likewise, understanding how elements of an urban environment influence disease prevalence can inform tree owners and orchardists about potential beneficial changes to tree maintenance and orchard management.

**Collaboration**

Students work in groups of two or three to complete research activities. Group work helps students practice division of labor and role allocation in research tasks ranging from data collection to final poster design. Students are given chances to evaluate the contributions of themselves and their peers several times throughout the semester in order to expose ways to promote increased group function. Collaboration was also present via interactions with the local orchardists which helped to inform the research question and also directly contributed to student learning through field trips and panel discussions. Finally, students collaborated with the researcher-instructors who lead the class to continually evaluate research progress and pivot as needed.

**Iteration**

Revision of scientific writing and poster content is where the students have the greatest opportunity to iterate. Students were provided the opportunity to iterate after their instructor reviewed their written poster sections. We also required that students submit their poster to our Ecology department writing center and have a consultation with a science writing expert prior to final poster submission. Depending on weather or time, it may be possible to repeat or revise some aspects of the biological data collection or collect additional data based on the initial results though we found time restrictions and seasonality to restrict this option.

**The 5-E Learning Model**

Class activities and research project lessons typically followed the 5E model (27, 28) and involved significant hands-on learning time. The 5E model is a set of active learning components that invites students to first connect with new content and grapple with their current understanding of how it fits in the world. This model helped students to become more receptive to new ideas when the content was then provided. The five components we used were (i) Engage students to inspire prior experience or interest, (ii) Explore a problem and their current understanding, (iii) Explain new concepts with active participation, (iv) Elaborate by practicing application of ideas or skills, and (v) Evaluate student understanding with assessment (27, 28). This model was well suited to building and retaining knowledge, and easily allowed incorporation of the active learning techniques described above. The 5 E model was primarily used in weeks 1–5 that were instructor directed as students built content.
knowledge and research skills in a classroom and field format. This course used a combination of independent reflection and work, think-pair-share questions, class-wide list generation, instructor-led active lectures, class wide hands-on tutorials and demonstrations, and group work time.

Assessment
Multiple types of assessments were used in the course to promote equity (29). Students were assessed using formative assessments, summative assessment, and self-reflection and evaluation assignments.

Formative Assessments
Formative assessment included reading assignments, post-lesson worksheets, writing assignments, lab notebook checks, and weekly reflection check-ins. These assessments were largely awarded full points for completion and served as a gauge for the instructor to assess students’ progress and understanding. When it was clear that students needed assistance, these assessments helped the instructor to connect with students individually. Weekly instructor feedback encouraged learning with written feedback on points of confusion or misconceptions about content.

Summative Assessments
These assessments included multiple choice midterm exam, an in-field practical, orchard management plan, and final poster submission and presentation. These assignments were graded for correct answers and rubric-based criteria. The skills were practiced through formative assignments and were an opportunity for students to demonstrate learning outcomes.

Self and Group Evaluation
These assessments included reflection and evaluation on the contributions to the research project by oneself and group members at three points during the semester. These assessments gave students a voice to describe group dynamics and provided an opportunity for instructors to facilitate working through group work challenges. The instructor also used these reflections for modifying any group grades for individuals at the end of the semester.

Inclusive Teaching
The course design and learning techniques supported inclusive learning for first year and transfer students. We incorporated inclusive learning through active learning modalities, study of a familiar organism and place, use of open-source software, decision-making capacity about project paths, and remote learning opportunities to make the course inclusive for all students.

We created a summer Bridge program to introduce community college students to the apple tree project research. The Bridge program seeks to help students with the transition from a 2-year college to a 4-year college and equip them with research experience early in their degree program. We worked with student advisors to recruit transfer students for our course that were not a part of the Bridge program as well. Transfer students were invited to enroll at the 4000 level in order to complete the course for upper division elective credit by completing extra research tasks. This helped them to start enhancing their research skills and techniques at the start of the semester and advance more quickly toward graduation.

Increased one-on-one time with these upper-division students created an opportunity for dialogue about the difficulty and challenge of the course. Additional research responsibilities were co-designed between instructor and transfer student to ensure the course activities and progression was maximizing benefits such as skill development for students with more experienced science backgrounds.

We used active learning in the classroom and in the field (Table 1). Active learning and exposure to research are especially important for first-year and transfer students since these students are more at risk for leaving STEM at these times (30, 31). Active learning increases student performance in STEM (32) and can decrease the achievement gap for first-generation and other underrepresented students (33, 34). Thus, this field-based CURE offers many opportunities to incorporate active learning through a variety of individual, group, written, verbal and hands-on learning modalities. While we did not measure retention, the small class size and high proportion of individual time with the instructor through project consultations offered a way for all students to gain mentorship in urban ecology content and research skills.

We selected a familiar and agriculturally relevant organism as the subject of study as a way to engage with students from familial homes in different geographic areas. Place-based learning has been shown to decrease equity gaps in first-year outcomes such as increased sense of place and belonging and improved academic performance (3). Our course focused on apple trees in the Colorado Front Range of the Rocky Mountains. Cultivating connections between academic residences and familial homes is especially important for students living in locales with demographics unlike their familial homes (35–37). Most students did not have prior knowledge of the city’s natural history of apples, but students were familiar with apples in an agricultural sense and often had an experience or story to share about fruits or trees, giving opportunity for students to honor their familial roots and connections. Students were also required to sign-up to attend a community fruit harvest in one of many Boulder neighborhoods to apply the data collection skills they learned in class while at the same time volunteering with a local organization. The partnership with a local non-profit offered a way for first year and transfer students to build self-efficacy as they explain their science project in a casual public setting. Instructors can modify the course by selecting another species of agricultural, ecological, or community significance (see more in Alternative Implementations section).

We used several pieces of open-source software that promote accessibility in student learning by avoiding expensive educational licensing. For field data collection, we used EpilCollect5 for mobile data entry (38). EpilCollect5 is a free and versatile application that can be used on any mobile device as well as accessed online from a web browser. In the lab, we used the open-source and free QGIS and R computing software for our data visualization and analysis. We used Google documents and spreadsheets for course materials and assignments. These programs are free to use and students are able to access them from their own computers.

Finally, we aimed to promote student autonomy and project ownership as students chose their sub-question for the research projects (39). Students could choose between a field-based observational project or a campus-based manipulative project.
These student project decisions supported student project ownership as they were able to select the field work setting.

COURSE LOGISTICS

Course Overview

The fourteen-week timeline of the lab is divided into four sections: (i) Cities as Ecosystems, (ii) Apple Ecology Case Study, (iii) Managing, Analyzing, and Presenting Data, and (iv) Urban Ecological Applications (Figure 1; Supporting File S2). The first five weeks of the course build the foundational theory and skills for the student to be able to conduct group research projects in urban ecology (Table 2). During weeks six through nine, students focus on their apple tree research questions and primarily addressed learning goals 4 and 5 building science process skills (Table 2). Weeks ten through twelve of the course aim to synthesize urban ecology content and research skills with data analysis for the final research poster presentation and primarily address learning goals 4 via data analysis and 6 via graphing skills (Table 2). The final two weeks of the course focus on synthesis and communication of research revisiting learning goal 3 and primarily addressing learning goals 6, 7, and 8 (Table 2). The semester ends with student groups presenting their research findings during a poster session at a public community symposium focused on apples.

Course SCHEDULE

Course Logistics

Our lab course enrolled 14 students per semester in 3-hour and 50 minute sessions that met once per week for 14 weeks. There was one instructor and one undergraduate teaching assistant. We used 3–4 scheduled field trips during the first 5 weeks of the course to explicitly introduce science techniques and concepts via hands-on learning and field-based techniques in the outdoor classroom (Supporting Files S0–S1). We used a 15-passenger van for the field trips, however these lessons could be adapted for use in any outdoor area with trees, such as a college campus (see more in Alternative Implementations section). Canvas, an online course learning management software, was used to organize the weekly course materials for the students. Any online management tools would be suitable to organize and deliver the course content to students, or paper materials could be printed and exchanged in class. The final project was a research poster that was printed for presentation at a public symposium (see Exemplar Lesson 1 for more information on the poster), however the poster could easily be presented digitally on platforms such as Zoom or Padlet.

COURSE SCHEDULE

Course Overview

The fourteen-week timeline of the lab is divided into four sections: (i) Cities as Ecosystems, (ii) Apple Ecology Case Study, (iii) Managing, Analyzing, and Presenting Data, and (iv) Urban Ecological Applications (Figure 1; Supporting File S2). The first five weeks of the course build the foundational theory and skills for the student to be able to conduct group research projects in urban ecology (Table 2). During weeks six through nine, students focus on their apple tree research questions and primarily addressed learning goals 4 and 5 building science process skills (Table 2). Weeks ten through twelve of the course aim to synthesize urban ecology content and research skills with data analysis for the final research poster presentation and primarily address learning goals 4 via data analysis and 6 via graphing skills (Table 2). The final two weeks of the course focus on synthesis and communication of research revisiting learning goal 3 and primarily addressing learning goals 6, 7, and 8 (Table 2). The semester ends with student groups presenting their research findings during a poster session at a public community symposium focused on apples.

Figure 1. Diagram of the general timeline through the 4 units of the Urban Ecology CURE where the focus is (A) introductory material and skills demonstrations (purple), (B) project planning and data collection (orange), (C) data analysis (blue), and (D) communication and applications of the research (green).

EXEMPLARY LESSON PLAN #1

This lesson occurs in week 1 of the semester and is in Unit 1: Cities as Ecosystems as an introduction to the unit. It classroom based with an on-campus field observation activity (Table 3; Supporting Files S3–S4).

Preparation for Class [Optional]

The background readings (Grand challenges in urban ecology and Nature All Around Us: A guide to urban ecology) serves to introduce students to the field of urban ecology, the challenges in this field and the opportunities with an emerging research agenda (Supporting File S5). This reading assignment can also be presented in class or assigned for homework after the first class.

Orientation to the Beginning of the Semester

Since this is the first class of the semester, we include some of the day 1 slides used for peer-to-teacher and peer-to-peer introductions and to orient students to a CURE course learning environment. We also provide a suite of quantitative and open-ended pre-post-assessment questions that can be administered before the start and end of the CURE relating to scientific knowledge, science self-efficacy, and intrinsic motivation.

Lesson Part 1: Characterize Definitions of Urban Ecology

Hand out the Week 1 Worksheet for students to have workspace for their ideas during the following class activities (Supporting File S6).

Engage: Use a think-pair-share activity to engage students in thinking about their connections to elements of the urban landscape in time and space. How do local actions have repercussions at various spatial and temporal scales? Think about local actions that a single person may take in their yard/ house/commute/ workplace and what spatial and temporal effects may occur.

Explore: Use a think-pair-share activity to explore themes of ecology and environmentalism expressed in the introduction section in Nature All Around Us. Ask students to write down an example of an ecological question and an environmental question. Class follow-ups: “Do you think we could have questions that are both ecological and environmental questions? There are people that play both roles, how would someone separate both roles?” Next, develop a class list of differences between “cities” and “natural areas” drawing from Frontiers in Urban Ecology (40). Conclude this section with a final think-pair-share activity from students to consider the questions: “What are the environmental major problems your hometown faces?” If students are unsure, a quick Google search could be helpful.

Explain and Elaborate: Review the definitions of urban ecology with the students and ask them to work in pairs to create a rank of 10 cited definitions from most narrow to broad (Supporting File S7). Request that 2–3 groups of students write their order on a whiteboard, or you could quickly type them into a slide as a student calls out their order. Discuss differences and similarities in how groups interpreted the scope of each definition.

CourseSource | www.coursesource.org

2024 | Volume 11
**Evaluate**: As part of the Week 1 Worksheet part 1, students think about which definition of urban ecology resonates most with them. They can start on this in class or just mention they can return to this for homework.

**Lesson Part 2: Find and Cite Scientific Literature**

**Engage**: Begin this part of the lesson by asking the class about their experience with reading scientific literature. Ask “Who in the class has read scientific literature before? What was it and why did you read it?”

**Explain**: Compare and contrast types of scientific literature with the students, break down strategies for how to read a scientific paper, and demonstrate how to use two common search engines such as Google Scholar and Web of Science.

**Elaborate**: Students practice using the search engines to locate recent scientific articles to use in their final poster project as part 2 of the Week 1 Worksheet. Be prepared to coach students on how to perform more complex searches and develop search terms.

**Lesson Part 3: Make Ecological Observations and Generate Research Questions**

**Explain**: Describe how observations are a cornerstone to generating research questions and the difference between a “survey” question (resulting in a single numeric value or category) and a “testable” question (resulting in relationship between two variables). As example survey and testable questions appear on the slides, students can make silent guesses or raise hands as to the type of question. Explain the three lenses of urban ecology that will be the focus of the next three weeks in class: physical (relating to abiotic environment), ecological (relating the living organisms), and social (relating to humans) aspects of urban ecology. In preparation for the first field activity, describe etiquette for interacting with the public and field safety.

**Explore and Elaborate**: Students embark into the field (local areas on campus) in pairs to make observations relating to the physical, ecological, and social lenses of urban ecology. From their observations, they generate testable research questions and consider how they might test their most interesting one.

**Evaluate**: Class ends with a full group discussion about the students’ experience making observations, their most interesting observations, and how they might test one of their questions.

**Follow-Up**

Assessment questions relating to Lesson part 1, 2, and 3 learning objectives can be found on the online midterm questions 1–4 (Supporting File S8). Finding and citing scientific literature is also assessed in the final poster assignment rubric (Supporting File S9).

**EXEMPLAR LESSON PLAN #2**

This lesson occurs in week 8 of the semester and is in Unit 2: Apple Ecology Case Study of fire blight disease in apple trees as one of the primary data collection days (Table 4).

**Preparation for Potted Tree Project**

At least two weeks before planning an inoculation day, culture fire blight (*Erwinia amylovora*) from existing wild (i.e., naturally occurring) sources (Supporting File S10). Consider asking an orchard owner or arborist for infected tissue if you are not familiar with an infected tree. If fire blight is not naturally occurring in your ecosystem, then this potted tree inoculation project is not recommended to take place outside of a controlled laboratory environment to prevent risk of plant pathogen introductions. Approximately one week is recommended for culturing colonies and one week for isolating a single colony. Once a single colony has been isolated, a glycerol stock can be made to store the bacteria in cold storage (-80 °C) long-term for future use (Supporting File S10).

Approximately three days before inoculation day, use either the cultured colony or a thawed glycerol stock to inoculate a liquid lysogeny broth, a nutrient rich medium for optimally growing bacteria (Supporting File S11). Perform fire blight inoculations on the potted apple tree cultivars in the week preceding the data collection lesson (Supporting File S12). Either students or instructors can perform this step depending on instructor preference. In cooler climates, plan for inoculations two to four weeks before having students complete the data collection lesson. In Supporting File S12, we provide instructions for teachers to guide students safely through their inoculation protocol and collect some initial data on the baseline characteristics of each labeled leaf (Supporting File S13). We used the EpiCollect5 mobile application on students’ smartphones to capture initial tree data, photos and notes however a paper datasheet could be used.

**Preparation for Mature Tree Project**

In order to promote student's field research self-efficacy, we recommend that students familiarize themselves with the apple tree field sampling protocol by practicing the measurements at least one week before going into the field to collect data. You can elect to have them do this in class or independently as homework.

You should also locate apple trees for the mature tree groups to visit in advance of the lab. At least 3 trees per group is a good starting point, and perhaps more trees if they are close in proximity.

**Preparation for Lab (Everyone)**

Due at the start of Week 8 is a worksheet for students to prepare for the introduction section of their final poster product that is graded for completion (Supporting File S14).

**Lesson: Ecological Data Collection**

Students meet in the classroom at the start of the lesson for 20 minutes so instructors can give guidance on the homework, distribute field supplies, and consult with groups who have questions about the data collection plan (Supporting Files S15–S17). Review this week's field notebook entry about the lab’s activities and designate a place for data to be entered for the class dataset (i.e., a Google sheet). In addition, review instructions for students to complete the first draft of their methods for their poster as homework graded for completion.
After the time spent in lab, students will depart for the field to execute research protocols (Supporting Files S18–S19). Ideally, you should first accompany the potted tree group to the on-campus site and then visit the students in the mature tree groups at their sites (if possible). This is the first time that students in the mature tree project will visit sites independently, and it is important that they check-in to confirm they are on-site. This can be done via cell phones (note that if you do not wish to share a personal cell number, Google Voice can be used to generate a temporary number for the semester), and they can call as soon as they arrive at the site. Note that for safety reasons, all field teams should be composed of at least two students. We use safety vests to help students be identified as researchers in the field (Figure 2) and help mitigate some of the potential risks of negative experiences associated with a researcher’s visible identity (41).

The potted tree groups (2–3 students/group) should collect data for each of the leaves that are being studied on inoculated and control trees. Students will collect data on the presence/absence of living tissues, proportion of fire blight, proportion of senescence, total length of the leaf, chlorophyll content estimates, and a photo of the leaf using the EpiCollect 5 mobile application or a paper datasheet (Supporting File S20). Fire blight diagnostics for trees showing signs of fire blight can be performed in the field using from BioReba Agristrips that rapidly test for the presence of fire blight on leaf, stem, or fruit tissues. In a 3-hour field excursion, a group could be expected to survey at least 3 trees or more depending on their proximity to each other.

After both groups of students complete their field measurements, they can elect to either return to lab to work on data entry or their field notebooks or they can choose to depart for the day. Groups from both projects are encouraged to work on their field notebook entries and entering data to an online Google Sheet during lab or as homework due the beginning of the following lab period. Students keep their field equipment after this lab for use in future labs.

**Follow-Up**

At the end of the data collection period (week 9), fire blight diagnostics can be performed on the labeled living or dead leaf tissues from potted trees using BioReba Agristrips. Students in the mature tree group can begin calculations of the degree of impervious surfaces across the urban landscape using a shapefile in QGIS with analysis in R to create a dataset for the trees surveyed (Supporting File S21). Additional landscape level variables (elevation, average air temperature, etc.) can be generated using open-source data available online i.e., Map developers or Weather Underground.

For the summative assessment, ecological data can be analyzed based on student’s choice of using the data collected. Quantitative results can be visualized in R and discussed with implications for society on posters. Groups should present their poster at the department research symposium and include members of the public, if possible (Supporting File S9).

**TEACHING DISCUSSION**

This study was reviewed by the Institutional Review Board (IRB) at the University of Colorado IRB protocol #19-0476 and #18-0410.

We were interested in evaluating were students experienced gains in scientific content knowledge in the fields of urban ecology and apple biology (Goal 1), science skills, research self-efficacy, and scientific civic knowledge (Goal 2), and interest, civic value, and identity (Goal 3; Supporting Files S22–S23). Our data collection about student’s experience included (i) pre- and post-course assessment surveys and (ii) end of semester survey responses provided to the instructor via reflections and anonymous feedback (Supporting File S24). Overall, the eleven students who participated in the Fall 2019 offering of this urban ecology CURE experienced gains related to two of our three main outcomes, including building scientific knowledge and science self-efficacy (Supporting Files S25–S26; Table 5). Below we highlight some of the key the results from our of course effectiveness, student- and instructor-perceived challenges, and potential alternative implementations.

**Evaluation of Course Efficacy**

**Pre-Post Survey Outcomes**

For the eleven students that responded to both pre and post surveys our findings support that students perceived ample
opportunities to collaborate, make relevant discoveries, and iterate in our courses (Supporting Files S25–S26; Table 5). These are comparable to what is seen in other CURE courses (40, 41), and provide evidence that the students were perceiving the class as a CURE experience.

Students made statistically significant gains related to two of our three goals (content knowledge, science skill and research self-efficacy, and motivation). Students’ knowledge of local biology and ecology increased \( (p \text{ all} < 0.01) \), while general apple knowledge was high at the start of the semester and showed no change. Likewise, students reported that their science skills had increased and that they had greater confidence in their ability to do science research tasks and knowledge of how to apply science to their communities \( (p \text{ all} < 0.01) \). Finally, while constructs related to students’ motivation such as students’ urban ecology interest, value for engaging in community endeavors, and science identity did not significantly increase over the course of the semester \( (p > 0.05) \), none of these metrics decreased. This indicates that, at a minimum, the course did not decrease students’ motivation. We feel this is a positive result given that many students leave STEM during their first year or directly after transfer to a new institution often citing loss of interest as a contributing factor \( (42) \). To confirm this, however, we would need to compare these results to other first-year courses’ metrics. Taken together, these results indicate that students make gains in knowledge related to local systems and in confidence to act as scientists and engage with the community. More data is needed, including longitudinal data on student outcomes and comparisons of students to those in other first-year courses, to elucidate whether and how the course is influencing motivation over the long-term.

End-of-Semester Responses

We also collected open-ended responses from the students’ experiences via anonymous feedback to the instructor. Many students noted the place-based connections and community relevance as positive attributes of the course.

This CURE generated place-based connections for nearly half of the students. Students were asked the question “What has been the most rewarding part of this lab experience?” Place-based connection to campus and being able to taste the apples were found as a theme in 5 of 11 student responses collected by the instructor during week 7 (Supporting File S27). One student remarked,

“The most rewarding part was finding some cool [trees] on campus trees and making some interesting observations about them. Especially the quick surveys on similar trees and discovering how all 4 trees had different tasting fruit even though they were only a few feet apart.”

Conducting research in a familiar place, such a college campus, stood out to the students as allowing them to look at these well-traveled places in a new way. Their reflections highlight their increased personal connection to local locations and experiential opportunities such as being able to taste the fruit. The interaction with the local apple trees and fruits stood out as a memorable sensory experience. The instructor observed this sentiment of personal connection to campus trees and the thrill, curiosity, and personal discovery associated with tasting apples among students that worked on both research projects. This adds evidence corroborating recent work that describes how invoking explicit sensory experiences that connect body and mind may have positive outcomes for science students \( (43, 44) \).

Students were also cognizant of their engagement with the real-world problem of apple tree health in the agro-ecology realm and of the issue’s relevance to the community. When asked at the end of the semester on an anonymous assessment “What has been the most rewarding part of this lab experience?” Three of 11 students’ responses were related to community interactions (Supporting File S27). One student said,

“The most rewarding part of this lab was being able to go outside and get involved in a community, and getting hands-on experience.”

The time students spent with orchard owners and community appeared to be an influential part of the course and made it “real.” Students worked alongside community volunteers and our non-profit partner, Community Fruit Rescue, to harvest apples in effort to reduce food waste and redistribute edible resources in an equitable manner. At the same time, they also collected real data about the apple tree health in a very public environment and answered questions from volunteers. The community interaction was also built into the end of the class when they presented their final posters to the community to share results and their experience with interested community members.

Our course design allowed more time to iterate on designing the methods compared to repeating results or analysis. Students in both groups had to adapt due to extreme weather conditions in fall 2019, which is a typical challenge encountered in field courses. One student shared via formative feedback,

“The main thing I learned about experimental design is that no matter how many things you plan for or account for things can always go wrong and you have to be prepared for it. This experience will help me a lot in the future because I’ll know going into projects that things won’t always go exactly as planned.”

We iterated the methods several times in the potted tree group since testing methodology for inoculating the apple trees with bacteria was part of the experimental design. We labeled the leaves on the trees using tape wrapped around the leaf petioles (stems). When it rained the next day and many of the leaves lost their tape label, the students had to troubleshoot what to do: look for the labels and reattach, or create new labels? They did a mix of both and were able to see that troubleshooting is an inherent part of research.

Finally, preparation for students’ future careers and academic goals was a theme found in student’s anonymous end-of-semester responses (Supporting File S28). In their anonymous survey question asking “Did this lab give you research experience that will be valuable for your career?” ten out of 11 students said “yes a little” or “yes very much so” (Supporting File S28). Three of 11 students said this course helped them prepare for future classes or a future job when asked “what was the most rewarding part of this course” (Supporting File S27). One student said,
The instructor explicitly encouraged students to consider how the skills they learned would translate to other classes. We suggest encouraging students to consider application of skills across many subdisciplines as this may be important for students to feel they are getting valuable experience even if their interest is not boosted within the specific subdiscipline of urban ecology.

Teaching Challenges

Next, we discuss three challenges that may be associated with teaching this place-based CURE curriculum as it stands: 1) microbial equipment access, 2) assistance with course preparation, and 3) unpredictable weather.

In order to create inoculum for the potted tree project, access to microbial culturing laboratory supplies and a fire blight source is needed. Routine culture tools such as ethanol (for sterilization), a Bunsen burner, solid or liquid growth media, sterile petri plates, sterile jars or culture tubes, pipettes, hot plates, incubator (fire blight grows best at 28 °C; [45]), and shaker plates are needed for preparing an inoculum of one or multiple bacterial strains. The sterile environment and some equipment could be avoided by culturing using inexpensive premade agar plates (with or without selective media) and pre-packaged sterile toothpicks. A liquid non-selective broth could be used to grow a mixed culture from the collected sample, and then this culture could be screened for the presence of Erwinia amylovora (the causative agent of fire blight) with rapid assay test-strips (e.g., $2.50 per test from BioReba Agristrip) and estimation of relative concentration based on test line color. While fire blight is found across North America, it may be difficult to find the bacterium locally, and a permit is required to order online according to the USDA website. In 2021 it was available in a freeze-dried format for online purchase from microbe products companies (i.e., ATCC 2021), however the inoculations must be done in an indoor controlled environment if the bacteria is ordered.

Preparing for both the mature tree and potted tree experiments may be difficult to do without assistance to get established in the first year. While grafting apple trees from field-collected scions is the most economical method to acquire tree clones, young apple trees could also be purchased from nurseries to save time with grafting. To prepare the time-sensitive mechanical inoculations for the potted tree project, it is helpful to have assistance from an undergraduate research assistant, or a transfer student taking the course for upper division credit. Of course, the research project can be modified to become an observational study and just focus on field studies of mature trees in order to alleviate the time commitment needed to prepare a bacterial inoculum, safe administration of the inoculum and disposal or sanitization of any contaminated materials. After the first year of preparation, when trees have been located and bacteria can be preserved in a 10% glycerin solution (Supporting File S10), the time to prepare for both research projects is greatly reduced. Students who previously took this course may be good candidates for assisting in future iterations, perhaps as a learning assistant for institutions that have undergraduate teacher training programs, to promote the longevity of longitudinal data collection.

The final challenge we wish to address is the unpredictability of weather conditions. This course was taught from August to December 2019. In October 2019 our city experienced an unexpected and rapid drop in temperature with an early snowstorm. This occurred after the potted trees were inoculated and resulted in some foliage damage in the potted trees and mature trees. Many leaves were freeze dried after a temperature swing from the mid-70s to mid-20 °F within 24 hours. We were able to bring a portion of our trees inside a greenhouse room to protect tissues from damage. While fire blight bacteria can withstand freezing temperatures (46), observation of disease signs was impacted. Instructors wishing to teach this course in a temperate climate may consider using a greenhouse environment to protect against unpredictable weather conditions in both the fall and spring seasons.

Alternative Implementations

There are several ways this curriculum could be adapted. Ideas for alternative implementations include 1) other seasons, 2) other fruit trees and pathogens/pests, 3) lesson or module selection, 4) on-campus learning and research, 5) remote/online learning and research (Supporting File S29).

Other Seasons

If this class was offered in the spring, students could use apples in cold-storage from the previous fall to test fire blight resistance (47), or other apple diseases such as apple scab and powdery mildew.

Other Fruit Trees and Pathogens/Pests

Despite the focus of this lab revolving around apple trees, other hosts or host-pathogen combos could be used. Other fruit and ornamental trees susceptible in the Rosaceae plant family would be suitable to substitute for research study with the fire blight bacteria (63). Another tree with similar fire blight disease susceptibility could be used such as pear (Pyrus sp.), and to a lesser extent, peach (Prunus persica), quince (Cydonia oblonga), and cherry (Prunus serotina) trees may be used in place of apple (48). While apple trees and fire blight are common across much of North America, any fruit trees and other common fruit tree pathogens such as scabs, rusts, rots, or mildew could be the research focus with respect to local agricultural challenges. Conversations with local agriculturalists or land managers are key to revealing what kind of student research may have community relevance and impact.

Teaching Select Units and Lessons

The curriculum presented here need not only be taught in a 14-week semester course in the fall. The lessons within units 1, 3, and 4 cover urban ecology and scientific method content that is widely applicable to many common ecological learning objectives (e.g., urban heat island effects, ecosystem services) and the scientific research process (e.g., experimental design or data analysis). The content and materials from weeks 1–4 in particular could be used on their own as stand-alone lessons about making observations in an urban environment and looking at the physical, ecological, and social lenses of urban ecosystems. Furthermore, this course could be taught in the...
spring or summer semesters, which may be more effective for studying fire blight infection due to warmer temperatures and higher moisture; however, we do not recommend inoculating trees during times when other susceptible Rosaceae plants may be flowering since pollinators may transfer the disease outside of the study area.

Remote and Online Modifications
While we had intended to offer this CURE in the same format for year 2, the second year we designed the course to be nearly entirely remote, due to the COVID19 global pandemic (Supporting File S29). Classes were taught synchronously on the Zoom video platform and students completed variations of most of the lessons using supply kits sent home with students. Since our student enrollment was considerably lower than normal due to the pandemic, we did not present learning outcomes from this iteration of the course, but we are happy to provide information on materials if contacted. While we urge instructors to design a place-based learning course with a strong field component, elements of this alternative implementation may be valuable as a back-up or “rainy day” curriculum, or potentially for increasing the accessibility of the learning objectives for students with differing physical abilities and needs.

Conclusions
We present a model for a place-based urban ecology CURE that effectively engaged students in locally relevant research using apple trees. We found this course to promote positive student outcomes. The civically engaged research projects increased locally-connected content knowledge, science skills, research self-efficacy, and civic knowledge based on analysis of student survey responses. Providing students a shared experience for the first 5 weeks and then allowing them to select their research project supported students in place based connections while also promoting autonomy and ownership in their independent and group work. Students could choose how to engage in their urban ecology research project whether it meant only studying potted trees in the greenhouse or embracing the freedom to explore open space lands. Students grew their scientific skills as they navigated the scientific method, performed field techniques, managed data organization and cleaning, and prepared a final poster in a start-to-finish research project. Despite no gains in outcomes related to intrinsic motivation, student’s science identity started and remained high. Their reflections indicated a high level of pride and satisfaction in what they created in addition to a recognition of the skills gained to help them in future courses or their career.

SUPPORTING MATERIALS

Peer-Reviewed Supporting Files

Course Overview
• S2. Apple CURE – Course Unit Descriptions

Exemplar Lesson 1: Week 1 Introduction to Urban Ecology
• S3. Apple CURE – Week 1 Teaching Outline
• S4. Apple CURE – Week 1 Slides
• S5. Apple CURE – Week 1 Reading Assignments
• S6. Apple CURE – Week 1 Worksheet, Student
• S7. Apple CURE – Week 1 Urban Ecology Definitions

• S8. Apple CURE – Week 6 Online Midterm and Field Practical, Instructor Key
• S9. Apple CURE – Final Poster Assignment

Exemplar Lesson 2: Week 8 Ecological Data Collection
• S10. Apple CURE – Culturing Erwinia amylovora for Use in Inoculation Experiments
• S11. Apple CURE – Preparing Erwinia amylovora Inoculum
• S12. Apple CURE – Inoculating Apple Trees with Erwinia amylovora
• S13. Apple CURE – Week 7 Fire Blight Inoculation Protocol and Datasheet
• S14. Apple CURE – Week 7 Worksheet, Student
• S15. Apple CURE – Week 8 Teaching Outline
• S16. Apple CURE – Week 8 Slides
• S17. Apple CURE – Week 8 Worksheet
• S18. Apple CURE – Week 8 Fire Blight Distribution in Potted Trees, Tree Sampling Protocol
• S20. Apple CURE – Week 8 Data Sheet, Potted and Mature Tree Group
• S21. Apple CURE – Week 8 Impervious Surface Calculation Tutorial

Other Supporting Files

Course Overview
• S0. Apple CURE – Complete Course Contents
• S1. Apple CURE – Course Syllabus

Evaluation of Course Efficacy
• S22. Apple CURE – Table of Educational Goals
• S23. Apple CURE – Description of Research Methods
• S24. Apple CURE – Survey Questions
• S25. Apple CURE – Demographics of Student Population
• S26. Apple CURE – Results and Discussion of Educational Goals and Outcomes
• S27. Apple CURE – Table of Most Challenging and Rewarding Theme Analysis
• S28. Apple CURE – Figure of Future Career Preparation Responses

Virtual Implementation Materials
• S29. Apple CURE – Teaching Schedule and Key Adaptations for Online Semester

ACKNOWLEDGMENTS

We would like to thank the EBIO department and the National Science Foundation Improving Undergraduate STEM Education Grant # 1836510 for providing financial support for the course development. Thank you to Drs. Carol Wessman and Katharine Suding for their support and guidance with implementing the curricula. We thank undergraduate students Brandon Sandoval and Darcy Traynor (Front Range Community College) and Vanessa Arnold and Kailee Haith from the University of Colorado Boulder for their assistance in developing the laboratory methods in summer 2019. We thank Chris Smith, Vanessa Arnold, Matt Arnold, and Bret Pilkington (University of Colorado Boulder) for their assistance in watering and maintaining the potted trees in 2019. We thank Ryan Graedon, Eric Johnson, Sharon Perdue,
and Vince Aquino for consulting on the disease biology and management of fire blight in apple trees and for providing sources of infected material. Thanks to Dr. Noah Fierer, Jessica Henley, Hannah Holland-Moritz for use of their microbiology lab materials, equipment, and for expert guidance. We thank Philip White for his development of the QGIS tutorial and assistance with Lab 10. We thank our community partners for assistance in locating trees for study: Therese Glowacki (Boulder County Open Space), Hannah Tyrell-Wysocki (Community Fruit Rescue), Lauren Kelso (Growing Gardens), Yvonne DiStefano (University of Colorado Boulder). Thank you to Molly Callaway, Sandhya Krishnan, Sam Ahler, and Dr. Jennifer Knight for their editorial suggestions. This study was reviewed by the Institutional Review Board (IRB) at the University of Colorado IRB protocol #19-0476 and #18-0410.
The Power of Place: A Course-Based Undergraduate Research Experience Studying Urban Ecology, Local Apple Trees and Disease Susceptibility

Table 1. Learning techniques used in the course with description and breakdown of average time spent on each type of activity in lab period. Note that because several lab periods were fully in the field for data collection (weeks 6–9), these estimates relate to lab periods that involved some degree of class time.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Estimated Proportion of Each Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent reflection</td>
<td>Students encouraged to contemplate prompt(s) and after given time to think before being asked to share a written or verbal response</td>
<td>10%</td>
</tr>
<tr>
<td>Class-wide list generation</td>
<td>Students encouraged to share a response and the instructor adds response to a list that the whole class can see (i.e., on a projected slide or whiteboard)</td>
<td>10%</td>
</tr>
<tr>
<td>Think-pair-share</td>
<td>Students encouraged to think about prompt(s) for 1–5 minutes, then talk about their ideas with a partner or small group, then share out a summary to the entire class</td>
<td>10%</td>
</tr>
<tr>
<td>Instructor-led active lecture</td>
<td>Students listened to audio/visual content delivered by the instructor with regular opportunities for questions</td>
<td>20%</td>
</tr>
<tr>
<td>Class-wide hands on tutorials/ demonstrations</td>
<td>Students completed an activity or procedural step at the same time or immediately after demonstrated by the instructor</td>
<td>20%</td>
</tr>
<tr>
<td>Group work time</td>
<td>Students worked with 1–2 other people to complete assignments or research tasks such as data collection, analysis, and final poster production</td>
<td>30%</td>
</tr>
</tbody>
</table>
Table 2. Course timeline table showing the main learning goals, key activities, and weeks of instruction for each of the four units.

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Main Learning Goals</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit 1: Cities as Ecosystems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1 - Gain understanding of connection between city sustainability goals and urban vegetation</td>
<td>Introduction to urban ecology. Practice observations of both the physical, biological, and social aspects of urban ecology.</td>
</tr>
<tr>
<td>2</td>
<td>2 - Develop understanding of urban microclimate and how the built and natural environment interact</td>
<td>Measure temperature across an urban gradient.</td>
</tr>
<tr>
<td>3</td>
<td>5 - Develop skills in tree sampling and urban ecology field techniques</td>
<td>Learn plant identification and practice the mature tree field sampling protocol.</td>
</tr>
<tr>
<td>4</td>
<td>3 - Know examples of real-world problems that are too complex to be solved by applying biological approaches alone</td>
<td>Visit an orchard and practice identifying fire blight bacteria and running rapid diagnostic tests.</td>
</tr>
<tr>
<td>5</td>
<td>8 - Reflect on your own learning, performance, and achievements</td>
<td>Midterm and Field Practical. Preparations for field experiment.</td>
</tr>
<tr>
<td><strong>Unit 2: Apple Ecology Case Study of Fire Blight Disease in Apple Trees</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 6–9 | 4 - Apply science process skills to address a research question in a course-based research experience  
5 - Develop skills in tree sampling and urban ecology field techniques | Students engage in field research to answer the question “What is the prevalence of fire blight among different cultivars and across the urban landscape?” Options for engagement: observational project on mature trees in the urban matrix OR experimental project with potted trees on campus. |
| **Unit 3: Managing, Analyzing, and Presenting Data** | | |
| 10–12 | 4 - Apply science process skills to address a research question in a course-based research experience  
6 - Share ideas, data, and findings with others clearly and accurately | Explore and analyze data in R, create graphs using R and maps using QGIS. Create final visualizations for their poster and write interpretations of their results. |
| **Unit 4: Urban Ecological Applications** | | |
| 13–14 | 3 - Know examples of real-world problems that are too complex to be solved by applying biological approaches alone  
7 - Communicate learning concepts and research progress orally and in writing  
8 - Reflect on your own learning, performance, and achievements | Implementing a new orchard on campus problem solving activity and report generation. Panel discussion considering aspects of orchard design. Practice presentations of research and receive peer feedback. Final presentations at symposium (out of class time). |
Table 3. Teaching timeline table for exemplar lesson 1 (week 1 introduction to urban ecology) shows the order of in-class activities, a description of each activity, the estimated time, and notes indicating associated supporting materials for the activity. Pre-class preparation and post-class follow-ups are also included.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Estimated Time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preparation for Class</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Background reading (optional)</td>
<td>Teachers assign background reading and 2 reflection questions on the frontiers of urban ecology and introduction to urban ecology</td>
<td>30–60 min</td>
<td>Supporting File S5</td>
</tr>
<tr>
<td><strong>Orientation to Beginning of Semester</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slides 1–9 (optional)</td>
<td>Introductions, course logistics</td>
<td>20 min</td>
<td>Supporting Files S3 and S4</td>
</tr>
<tr>
<td>Slide 10 (optional)</td>
<td>Pre-assessment</td>
<td>20 min</td>
<td>Supporting File S24</td>
</tr>
<tr>
<td><strong>Lesson Part 1: Characterize Definitions of Urban Ecology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slide 11</td>
<td>Engage students in thinking about personal connections to urban ecology with think-pair-share</td>
<td>15 min</td>
<td>Supporting Files S3, S4, and S6</td>
</tr>
<tr>
<td>Slides 12–13</td>
<td>Explore the overlap between ecology and environmentalism in an urban landscape with think-pair-share</td>
<td>15 min</td>
<td>Supporting File S6</td>
</tr>
<tr>
<td>Slides 14–19</td>
<td>Explain and elaborate to characterize several definitions of urban ecology and challenges in this landscape. Students rank definitions of urban ecology from narrow to broad.</td>
<td>25 min</td>
<td>Supporting File S7</td>
</tr>
<tr>
<td>Slide 20</td>
<td>Evaluate which definition of urban ecology resonates most and why</td>
<td>5 min</td>
<td>Supporting File S6</td>
</tr>
<tr>
<td><strong>Lesson Part 2: Find and Cite Scientific Literature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slide 21</td>
<td>Engage students in discussion about previous experience with scientific literature</td>
<td>5 min</td>
<td>Supporting File S3</td>
</tr>
<tr>
<td>Slides 22–26</td>
<td>Explain the types of scientific literature</td>
<td>4 min</td>
<td>Teacher-led lecture and demo of Google Scholar and Web of Science</td>
</tr>
<tr>
<td>Slide 27</td>
<td>Elaborate as students search for articles related to their semester research project</td>
<td>12 min</td>
<td>Supporting File S6</td>
</tr>
<tr>
<td><strong>Lesson Part 3: Make Ecological Observations and Generate Research Questions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slide 28</td>
<td>Explain making observations, research questions and the 3 lenses of urban ecology</td>
<td>15 min</td>
<td>Supporting File S3</td>
</tr>
<tr>
<td>Slides 29–32</td>
<td>Explore and elaborate: visit outdoor urban ecosystems to make observations and testable questions</td>
<td>60–75 min</td>
<td>Supporting File S6</td>
</tr>
<tr>
<td>Slide 33</td>
<td>Evaluate: class discussion about their most interesting observations and experiment ideas</td>
<td>25 min</td>
<td>Supporting File S6</td>
</tr>
<tr>
<td><strong>Follow-Up</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summative assessment</td>
<td>Questions 1–4 on the midterm assess this lesson’s learning objectives</td>
<td></td>
<td>Supporting File S8</td>
</tr>
<tr>
<td>Summative assessment</td>
<td>Use of scientific literature in final poster project</td>
<td></td>
<td>Supporting File S9</td>
</tr>
</tbody>
</table>
The Power of Place: A Course-Based Undergraduate Research Experience Studying Urban Ecology, Local Apple Trees and Disease Susceptibility

Table 4. Teaching timeline table for exemplar lesson 2 (week 8 ecological data collection) shows the order of in-class activities, a description of each activity, the estimated time, and notes indicating associated supporting materials for the activity. Pre-class preparation and post-class follow-ups are also included.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Estimated Time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preparation for Potted Tree Project</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-lesson microbiology prep (at least 4 weeks before week 8 lesson)</td>
<td>Teacher cultures Erwinia amylovora to have an active petri culture or glycerol stock prepared</td>
<td>1 week of culturing colonies, 1 week of isolating and cultivating a single colony per strain (est. 10 hours lab bench time for teacher experienced with microbial cultures)</td>
<td>Supporting File S10</td>
</tr>
<tr>
<td>Pre-lesson microbiology prep (2 weeks and 3 days before week 8 lesson)</td>
<td>Teacher uses active petri culture or glycerol stock to generate liquid inoculum for Erwinia amylovora</td>
<td>3 days culturing liquid inoculum (est. 5 hours lab bench time experienced with microbial cultures)</td>
<td>Supporting File S11</td>
</tr>
<tr>
<td>Pre-lesson microbiology prep (1 week before lesson)</td>
<td>Teacher guides students through inoculating leaves of potted apple trees</td>
<td>3–4 hr</td>
<td>Supporting Files S12 and S13</td>
</tr>
<tr>
<td><strong>Preparation for Mature Tree Project</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practice the apple tree field measurements</td>
<td>Teacher guides students through collecting apple tree ecological data</td>
<td>30–60 min</td>
<td>Supporting File S19</td>
</tr>
<tr>
<td><strong>Pre-Class Homework</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-class homework</td>
<td>Students work on a draft of the introduction section of their final poster assignment</td>
<td>30 min</td>
<td>Supporting File S14</td>
</tr>
<tr>
<td><strong>Lesson: Ecological Data Collection</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slides 1–5</td>
<td>Instructor goes over poster introduction and methods homework, distributes supplies, and answers any questions about the data collection protocols</td>
<td>15 min</td>
<td>Supporting Files S15–S17</td>
</tr>
<tr>
<td>Potted group (1 week after inoculation): Execute protocols and accurately record measurements and observations for potted trees</td>
<td>Students collect ecological data on potted trees, record observations in field notebook</td>
<td>3–4 hr</td>
<td>Supporting Files S17, S18, and S20</td>
</tr>
<tr>
<td>Mature Tree group: Execute protocols and accurately record measurements and observations for mature trees</td>
<td>Students collect ecological data on mature trees, record observations in field notebook. Instructor locates potential apple trees for groups to visit</td>
<td>3–4 hr</td>
<td>Supporting Files S19 and S20</td>
</tr>
<tr>
<td><strong>Follow-Up</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire blight diagnostic testing</td>
<td>Students use rapid assays to test for fire blight prevalence across the potted apple tree cultivars</td>
<td>During weeks 9 or 10</td>
<td>BioReba Agristrip</td>
</tr>
<tr>
<td>Landscape level variable compilation</td>
<td>Students use external data sources to create a dataset of their landscape level variable of interest (i.e., impervious surfaces, precipitation, elevation)</td>
<td>During weeks 9 and 10</td>
<td>Supporting File S21</td>
</tr>
<tr>
<td>Summative assessment</td>
<td>Visualization, analysis and interpretation of data on final poster project</td>
<td>During weeks 10–12</td>
<td>Supporting File S9</td>
</tr>
</tbody>
</table>
Table 5. Student outcomes for perceiving the CURE essential elements (Collaboration, Relevant discovery, and Iteration) the goals related to student's science knowledge, research self-efficacy, and intrinsic motivation in science, see Supporting File S26 for more detailed results and discussion.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Scale</th>
<th>Pre-Survey Mean and Standard Error</th>
<th>Post-Survey Mean and Standard Error</th>
<th>Paired t Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effectively Perceive CURE Elements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collaboration</td>
<td>1-never, 2-one or two times, 3-monthly, 4-every other week, 5-weekly</td>
<td>N/A</td>
<td>Weekly, 4.6 (+/- 0.7)</td>
<td>N/A</td>
</tr>
<tr>
<td>Relevant discovery</td>
<td>1-strongly disagree to 6-strongly agree</td>
<td>N/A</td>
<td>Agree, 5.2 (+/- 0.1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Iteration</td>
<td>1-strongly disagree to 6-strongly agree</td>
<td>N/A</td>
<td>Somewhat agree, 4.3 (+/- 0.2)</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Goal 1: Science Content Knowledge Gains</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General biology</td>
<td>0-incorrect and 1-correct</td>
<td>0.82 (+/- 0.04)</td>
<td>0.85 (+/- 0.04)</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>Local biology</td>
<td>0-incorrect and 1-correct</td>
<td>0.74 (+/- 0.05)</td>
<td>0.95 (+/- 0.03)</td>
<td>t(54) = 3.3, p = 0.002</td>
</tr>
<tr>
<td>Local ecology</td>
<td>1-strongly disagree to 5-strongly agree</td>
<td>Disagree, 2.6 (+/- 0.1)</td>
<td>Neither disagree or agree, 3.9 (+/- 0.1)</td>
<td>t(75) = 7.0, p &lt; 0.001</td>
</tr>
<tr>
<td><strong>Goal 2: Science Research Self-Efficacy Gains</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science skills</td>
<td>1-strongly disagree to 5-strongly agree</td>
<td>Neither disagree or agree, 3.9 (+/- 0.1)</td>
<td>Agree, 4.3 (+/- 0.08)</td>
<td>t(87) = 4, p &lt; 0.001</td>
</tr>
<tr>
<td>Research self- efficacy</td>
<td>1-strongly disagree to 5-strongly agree</td>
<td>Neither disagree or agree, 3.6 (+/- 0.1)</td>
<td>Agree, 4.3 (+/- 0.08)</td>
<td>t(59) = 6.0, p &lt; 0.001</td>
</tr>
<tr>
<td>Scientific civic knowledge</td>
<td>1-strongly disagree to 6-strongly agree</td>
<td>Somewhat disagree, 3.9 (+/- 0.2)</td>
<td>Somewhat agree, 4.7 (+/- 0.2)</td>
<td>t(67) = 3.0, p = 0.005</td>
</tr>
<tr>
<td><strong>Goal 3: Intrinsic Motivation in Science</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban ecology interest</td>
<td>0-strongly disagree to 5-strongly agree</td>
<td>Neither disagree or agree, 3.4 (+/- 0.2)</td>
<td>Neither disagree or agree, 3.1 (+/- 0.1)</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>Science civic value</td>
<td>1-strongly disagree to 6-strongly agree</td>
<td>Somewhat agree, 4.3 (+/- 0.2)</td>
<td>Somewhat agree, 4.1 (+/- 0.2)</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>Science identity</td>
<td>1-strongly disagree to 5-strongly agree</td>
<td>Agree, 4.0 (+/- 0.1)</td>
<td>Agree, 4.1 (+/- 0.1)</td>
<td>p &gt; 0.05</td>
</tr>
</tbody>
</table>
The Power of Place: A Course-Based Undergraduate Research Experience Studying Urban Ecology, Local Apple Trees and Disease Susceptibility

REFERENCES


