Eco 101

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Adapting Your Research into Inquiry-Based Lessons for Public Outreach in High School Classrooms: an Answer to the Calls to Action

A number of authors have encouraged ecologists to connect with the public through outreach and community engagement activities (e.g., Brewer et al. 1992, Brewer 2001, Nadkarni 2004, 2006, Morgan et al. 2008, Lowman and Randle 2009, Messinger et al. 2009, Salguero-Gomez et al. 2009). Ecological outreach activities are valuable both to participating citizens and to scientists. Outreach presents scientists with professional development opportunities, such as networking and improving public communication skills (Messinger et al. 2009, Salguero-Gomez et al. 2009). It also provides an important public service, builds connections to local communities (Messinger et al. 2009), and increases public appreciation for ecological issues, the scientific process (e.g., Nadkarni 2006), and one's institution.

These numerous calls to action are inspiring many ecologists to begin engaging with the public. Guest presentations in local high school classrooms provide excellent outreach opportunities for ecologists. The time commitment can be as short as a single class period, and academics in particular will find the classroom setting familiar and the abilities and interests of high school students similar to those of beginning undergraduates. Additionally, benefits of working within a single classroom can ripple out to other students, parents, and the greater community (Leidner and Pouyat 2009, Lowman and Randle

2009). Many local schools are eager to create partnerships with scientists (e.g., see ‹www.nationallab-day.org› ‹www.plantingscience.org›).

Scientists have the necessary expertise and enthusiasm to communicate effectively about their research (Nadkarni 2004, Messinger et al. 2009). However, we have observed that many ecologists are daunted by the idea of adapting their complex research for a high school setting, especially when the research is focused on highly theoretical questions or on uncharismatic organisms. We argue that virtually any ecological research project has the potential to enrich a high school classroom. Here, we describe a two-phase process that can be used to create lessons that incorporate original ecological research. The two-phase process for lesson development is:

Establish learning objectives using a two-dimensional design matrix (Fig. 1)
Work from these objectives to adapt your research into a suitable lesson.

At the end of this article, we provide two example lesson plans, based on a recent *Ecology* research article (Collinge and Ray 2009), that further illustrate how to use this lesson development process.

Design matrix

The process of using the design matrix (Fig. 1) to establish learning objectives (the first phase of our method) is meant to be broadly applicable. Accordingly, we base learning objectives on the scientific research process (i.e., the scientific method) because it has an obvious, logical connection to any research project, and because the scientific process is addressed by most high school science curricula. Additionally, we suggest the use of a popular teaching method: inquiry-based learning (IBL; e.g., Colburn 2000, Audet and Jordan 2005). Active, student-driven learning, including IBL, fosters student engagement and is an effective way to teach scientific concepts and the scientific method (e.g., National Research Council 2000, Handelsman et al. 2004). Integrating original research into a classroom setting can be an effective way to utilize IBL.

Along the vertical axis of the design matrix are four major steps of the scientific research process. The horizontal axis of the matrix represents a continuum of IBL, proceeding from learning activities that have a relatively high degree of instructor guidance (guided or bounded inquiry) to those that have very little instructor guidance (open-ended inquiry; e.g., D'Avanzo 1996, Bonnstetter 1998, Audet and Jordan 2005). Because instructor guidance can streamline classroom activities by reducing the occurrence of dead-end or tangential student explorations, guided inquiry generally requires less classroom time than open-ended inquiry. The value of open-ended inquiry is that it allows students to more realistically mimic the scientific process, often resulting in a deeper student understanding of the lesson concepts and the scientific method.

When designing a lesson for a high school classroom, consider (1) how much time is available, and (2) the ability, or expertise, of the students. Student expertise is related not only to grade level, but also to students' previous experiences with IBL, the scientific method, and the research topic. At one extreme, when there is ample time for your lesson and students are advanced, it will be possible to develop an extended module that uses open-ended inquiry techniques to cover all steps of the scientific research process. In our experience, a complex lesson of this sort requires meeting with a class of high school seniors at least once a week for an entire semester. When time is more limited or beginning students are the target audience, you will need to provide more guidance or focus on a limited portion of the scientific research process, resulting in a simpler lesson.

First phase

Learning objectives are concise statements that summarize the expected, observable outcomes of a lesson (e.g., see the learning objectives in our example lesson plans at the end of the article). The design matrix (Fig. 1) aids you in carefully establishing learning objectives based on the scientific process and the anticipated degree of instructor guidance. You can work with the host teacher to answer questions such as: How much time is available, and, given the abilities of the students with whom you will be working, what can you accomplish in that amount of time? Which steps of the scientific process do you want to emphasize? Do you feel comfortable facilitating an open-ended IBL activity, or do you prefer guided inquiry? The answers to these questions will help to determine your orientation within the design matrix.

A typical impulse is to dive into developing the steps of a lesson before establishing learning objectives, giving scant attention to the first phase of the process. However, it is crucial to dedicate sufficient effort to this first phase in order to design a lesson that is of appropriate length and complexity for the target audience. This phase of the lesson development process is analogous to creating candidate model sets for model selection using an information-theoretic approach (Burnham and Anderson 2002), or to compiling a short list of main conclusions before writing a scientific manuscript (Magnusson 1996). It need not take an inordinate amount of time, but it should be done thoughtfully and completely. There is a wealth of general information on developing learning objectives on the Internet (e.g., see ‹www.park.edu/cetl/quicktips/writinglearningobj.html›).

Second phase

The second phase of the lesson development process is to work from the learning objectives to adapt your research into a suitable lesson. Here, it is important to continuously be aware of your chosen orientation within the design matrix, so it may be helpful to return occasionally to Fig. 1 as you fully develop the lesson. Below, we offer several other ideas to consider during this phase of lesson development.

Make it interesting

Your lesson is more likely to engage high school students when they are “hooked” within the first few minutes, so a captivating introduction is key. A simple way to make a captivating introduction is by sharing interesting or provocative images (see example lesson plans); field equipment also makes a good prop. Make the lesson as relevant to the students as possible (Hulleman and Harackiewicz 2009), perhaps connecting your research to local community issues or emphasizing real-world applications (see example lesson plans). Linking your lesson to the established curriculum will be attractive to host teachers and provides familiarity to the students. Recognize that motivators will often be quite different in urban, suburban, and rural school districts. Reynolds (2009) explores these and other helpful strategies for effectively communicating science to the public. In the end, your enthusiasm and energy may be the most important hook of all.

Keep it simple

In our example lesson plans, we present several ways to simplify the content of a complex research project so that it is appropriate for high school students. For example, instead of incorporating all of the information in Collinge and Ray (2009), including relatively complex concepts like community assembly theory, we emphasize only one or two elements of their study (e.g., physical and biological variables important in vernal pool restoration). Limiting the number of learning objectives is another effective simplification strategy. In our example lesson plans, we intentionally focus on only 2–3 learning objectives. Additionally, omit jargon, and define ecological terms and concepts (e.g., disturbance, productivity, diversity) as simply as possible.

Complex experimental designs and analytical techniques (e.g., ordination, modeling) may interest us as researchers, but can quickly overwhelm and frustrate students. You need not underestimate the students' abilities, but keep data analysis and interpretation as uncomplicated as possible, or plan on dedicating ample time and instructor assistance for explanation. Figures derived from your own data can greatly enhance a lesson. However, it is important to ask yourself which parts of the figure or analysis can be deleted without sacrificing the message. For example, error bars can be removed unless variability is the explicit focus of a learning objective, and rather than requiring students to sit through an explanation of a *t* test, ask them to visually analyze simple bar graphs. In our second example lesson plan, students are asked to make and interpret a scatter plot, but we avoid using regression analysis.

Adaptability

Using our method, a single research project can be adapted into a variety of lessons that encompass different portions of the design matrix (Fig. 1). When developing multiple lessons, each new lesson can be developed from scratch, or lessons can be "nested." Nesting, which is often the more efficient of the two approaches, refers to the idea that simple lessons can easily be expanded to cover a greater portion of the design matrix, and complex lessons can easily be simplified. Thus, several simple lessons can be visualized as being nested within a single complex lesson.

For example, you may develop a 40-minute lesson focused on generating hypotheses related to your research. Because of limited time, this lesson will likely require a good deal of instructor guidance, orienting your lesson in the upper left corner of the design matrix. Given more classroom time, the same lesson can be used by simply reducing the level of instructor guidance, moving the lesson to the right on the design matrix. Alternatively, the lesson could be expanded vertically to cover additional steps of the scientific process, such as interpreting results. Our example lesson plans further demonstrate how a single research project can be adapted into multiple lessons using a nesting approach.

Summary

In summary, there are three major points to keep in mind when using our method to conduct outreach activities in local high schools. First, dedicate sufficient effort to the first phase of lesson development in order to make learning activities appropriately complex. Second, use strategies for piquing and maintaining student interest, and simplify your lessons. Third, a single research project can be adapted to create many different lessons. The adaptability inherent in our method means that it can also be used to develop lessons for undergraduate classrooms.

After taking the initial plunge into high school outreach, we recommend consulting the extensive resources available in the educational literature and on theIinternet (e.g., D'Avanzo 2003*a*, *b*, Handelsman et al. 2004, Laursen et al. 2007, Ebert-May and Hodder 2008, Stewart et al. 2009). Existing educational resources, including those highlighted in this forum in the past, can be used to extend our method in several important ways (e.g., using assessment techniques to improve future lessons.)

Finally, we suggest that ecological outreach is often more satisfying and effective when conducted collaboratively. Like personal commitments to exercising regularly, commitments to public outreach are probably more likely to endure and expand when you have the support of similarly engaged ecologists. So grab a colleague and give it a try!

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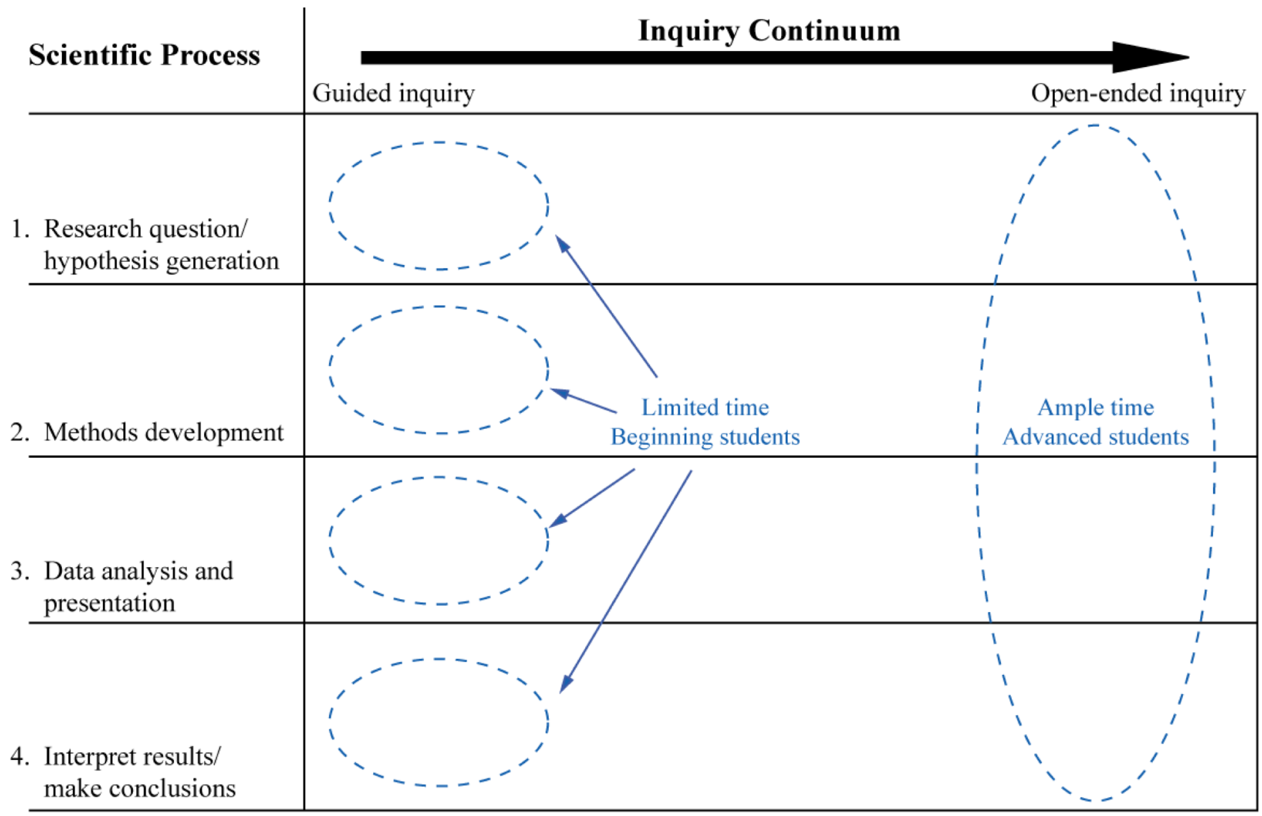

Fig. 1. Design matrix for use in the development of inquiry-based lessons that emphasize the scientific research process. To determine lesson orientation in the design matrix, instructors consider both the availability of classroom time and student expertise. At one extreme, given limited time and beginning students, lessons will likely use guided inquiry and be limited to one step of the scientific process. At the other extreme, given ample time and advanced students, a single lesson can use open-ended inquiry and incorporate all steps of the scientific process. Modified from Bonnstetter (1998) and Grant and Vatnick (1998).

Example lesson plans

We developed two example lesson plans based on a recent *Ecology* research article (Collinge and Ray 2009). These two examples demonstrate how "nesting" lessons can be an efficient approach to lesson development. *Note:* it will be helpful to read the abstract of the Collinge and Ray (2009) article before examining the lesson plan examples.

We chose this research article because, as plant ecologists, we have some knowledge of the subject matter. More importantly, however, there are several challenges to transforming Collinge and Ray (2009) into a successful classroom lesson. From the perspective of a typical high school student, this study contains unfamiliar subject matter, including relatively complex concepts (e.g., community assembly theory), study design, and statistical analyses. Additionally, most high school students would not consider herbaceous, annual plants to be very charismatic organisms.

We make these lessons interesting to students by drawing on the real-world application of this research to the restoration and creation of vernal pools. For the sake of brevity, the lesson plans make use of several technical terms (jargon) that are likely unfamiliar to students, including colonization, community, community composition, dispersal, endemism, hydrology, and variable. In the classroom, be sure to either avoid or carefully define terms such as these.

The first, simple lesson is nested within the second, more complex lesson. It focuses on hypothesis development, and is therefore oriented in the upper left corner of the design matrix (Fig. 1). It is suited to a 40-minute classroom period with advanced students (e.g., an honors or AP science class of juniors or seniors) or a longer period (≥1 hour) with beginning students.

The second, more complex lesson plan expands from the first lesson to encompass a greater portion of the design matrix. This lesson covers hypothesis generation, data collection and analysis, and making conclusions. Because it requires more instructor guidance, it is oriented toward the left side of the design matrix. However, in comparison to the first lesson, the second lesson's scope is expanded vertically, encompassing more steps of the scientific process. The lesson is intended for two or three 40-minute classroom periods (or equivalent) in an advanced class. Given more time, this lesson could also be shifted to the right side of the design matrix by reducing instructor guidance, allowing for open-ended inquiry (see also the "Other adaptations" section below for more ideas on how to modify the second lesson plan).

Lesson 1. Simple lesson for limited time or beginning students

Learning objectives:

1. Students will be able to develop testable scientific hypotheses.
2. Students will be able to distinguish between physical and biological characteristics of an ecological system.

Lesson outline:

1. Begin by sharing the learning objectives with the students. Give a short (~ 5-minute) introduction of vernal pools, emphasizing their uniqueness (e.g., endemism, interesting hydrology) and the importance of their conservation and restoration. Show interesting photographs and be sure to avoid jargon, which may confuse and frustrate students.

2. Pose a question to the class: "What do we need to know about vernal pools in order to create new pools that are similar to natural pools?" Encourage students to come up with different hypotheses about variables that are important in vernal pools, such as pool size, hydrology, or colonization history. Allow students to brainstorm and offer some suggestions if they overlook key concepts.

3. Give a brief explanation of the difference between physical and biological variables. As a class, categorize variables that resulted from the brainstorming activity.

4. Have students break into small groups and identify a few physical and biological variables that may be important in creating vernal pools. They should state how and why each variable might affect the vernal pool community.

5. Come back together as a class and work as a whole to state these ideas as formal, testable hypotheses.

6. If there is time, go back into small groups and talk about specific ways to test their hypotheses.

7. End with a short (5-minute) explanation of the actual study findings, especially those that are relevant to the students' hypotheses. Emphasize how we can incorporate these findings into a wetland creation or restoration project. Review and discuss the learning objectives.

Lesson 2. More complex lesson for ample time or advanced students

Learning objectives:

1. Students will be able to develop testable scientific hypotheses based on simulated observations.

2. Students will be able to distinguish between physical and biological characteristics of an ecological system

3. Students will be able to tabulate data, and create and interpret a scatter plot.

Lesson outline:

1. Begin by sharing the learning objectives with the students. Give a short (~ 5 min) introduction of vernal pools, emphasizing their uniqueness (e.g., endemism, interesting hydrology) and the importance of their conservation and restoration. Show interesting photographs and be sure to avoid jargon, which may confuse and frustrate students.

2. Pose a question to the class: "What do we need to know about vernal pools in order to create new pools that are similar to natural pools?" Encourage students to come up with different hypotheses about variables that are important in vernal pools, such as pool size, hydrology, or colonization history. Allow students to brainstorm and offer some suggestions if they overlook key concepts.

3. Give a brief explanation of the difference between physical and biological variables. Have students categorize variables that resulted from the brainstorming activity, and then focus them on the variables that will be used in the simulation (see below).

4. Explain that the class is going to conduct a simulated pilot study. They will be making observations to determine variables that might influence the types of plants that grow in vernal pools.

5. Play a few rounds of the simulation together as a class until the students understand the rules (see below). Then, students break up into small groups and play independently.

6. The simulation is conducted as follows

   a. Give each student in each group a gameboard that represents a vernal pool (Fig. 2A). The simulated vernal pool will have unique characteristics related to size, hydrology, and colonization history.

      Example: A student may receive a pool that is large, dries out in August, and contains 10 individuals of Species A, 5 individuals of Species B, and 1 individual of Species C.

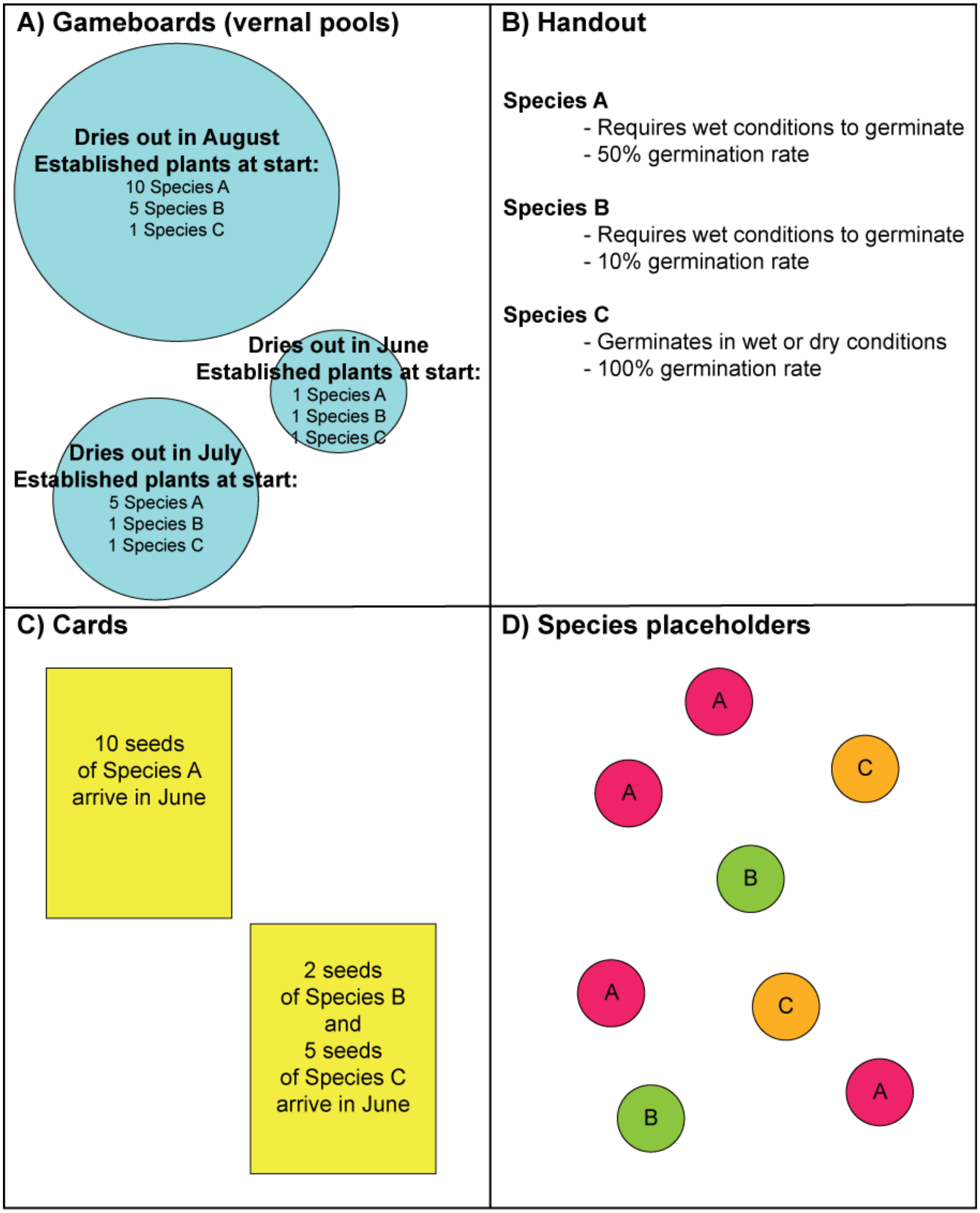

Fig. 2. Examples of (A) gameboards, (B) handout, (C) cards, and (D) species placeholders that could be created to perform the simulation in Lesson 2.

b. Give each student a handout that describes characteristics of each species (Fig. 2B).

Example: Species A requires wet conditions to germinate and its germination rate is 50%.

c. Give each group a deck of cards (Fig. 2C) and several small placeholders that represent the different species (Fig. 2D). Each card describes a colonization event. Students will take turns drawing a card, helping each other decide how many placeholders to add to their simulated vernal pool

Example: The card may read: "10 seeds of Species A arrive in June." If the student has a large pool that dries out in August, he or she will add 5 placeholders to the pool because the conditions are wet in June (a germination requirement for Species A) and the germination rate for this species is 50%. In contrast, if a student's pool is small and dries out in June, no seeds of Species A will germinate, and so no placeholders for Species A will be placed in the pool.

d. Note: Students must retain the cards that they draw. They will use them later to determine the total number of seeds introduced to each pool.

e. Have the students play several rounds, as time allows. Periodically check in with each group to be sure they understand the simulation and are beginning to grasp the underlying concepts. Which pools do they think will accumulate the most individuals by the end of the simulation? Will certain species be more abundant? Why?

7. Based on their observations from the simulation, student groups should develop hypotheses about how different variables affect vernal pool plant community composition. They may focus on vernal pool size, hydrology, colonization history, species characteristics, etc. Have each group state their ideas as testable hypotheses and make some predictions. Depending on the amount of time available, the instructor may provide more or less guidance at this step.

8. Next, ask the students to collect some data from the simulation to test their hypotheses. Since the students will formulate a variety of hypotheses in step 7 (above), and there are a number of possible variables in the simulation (e.g., colonization history, pool size, species characteristics), the instructor should pick one or two variables to analyze with the class.

Example: Students can quantify dispersal limitation, which is a focus in Collinge and Ray (2009). In this case, students would collect data by counting the number of simulated dispersal events, using the reserved cards (see steps 6c and 6d) to determine the total number of seeds of Species A introduced to each pool. They would then quantify colonization success by counting the number of placeholders of Species A on the gameboard. This latter number represents the number of individuals that colonized the pool. Students would repeat the data collection for all species.

9. Have each group tabulate their data. Then the instructor can pool the data and analyze it with the class, either in a group-work or whole-class format.

   Example: Continuing with the example in step 8, students can create a scatterplot in which the y*-axis represents the number of individuals of species A on the gameboard and the* x*-axis represents the number of seeds of species A introduced to the pool (i.e., colonization success vs. dispersal rate). Or, another example would be to focus on species characteristics so that the students would first count the number of placeholders for each species in each pool, determine the average number of placeholders (or individuals) for each species across all pools, and then plot species averages against the germination rate of each species on a bar graph, (species with higher germination rates will have more individuals, on average).*

10. Ask students to interpret the data, compare their results to their hypotheses and predictions, and draw some logical conclusions. Check in with students as they work through these processes.

11. Tie the conclusions back to the introduction. How might the information they collected inform restoration? What type of field research might they conduct to confirm observations made in the simulation? Review and discuss the learning objectives.

Other adaptations

If more time is available, Lesson 2 can be shifted to the right of the design matrix (Fig. 1) by reducing instructor guidance. For example, the instructor might introduce the concept of the simulation, but allow the students to develop their own "rules" for how to play. Alternatively, this lesson could encompass more of the scientific process by asking students to develop simple methods to test their hypotheses. There are also dozens of ways to modify the simulation to make it less complex (e.g., eliminate details on species' germination rates) or more complex (e.g., add details on competitive species interactions).