INQUIRY & INVESTIGATION

Functional Frogs: Using Swimming Performance as a Model to Understand Natural Selection and Adaptations

NABT BioClub RECOMMENDATION

GABRIELLE FLUD, JULIE ANGLE, MONIQUE N. SIMON, DANIEL S. MOEN

Abstract

Evolution by natural selection and adaptation are core concepts in biology that students must see and correctly understand their meaning. However, using these concepts in evidence-based learning strategies in the classroom is a difficult task. Here, we present a 5E lesson plan to address the Next Generation Science Standards performance expectation HS-LS4-4, to "construct an explanation based on evidence for how natural selection leads to adaptation of populations." The Functional Frogs lesson provides multiple hands-on activities to engage students in the development of hypotheses, collection and analysis of empirical data on frog swimming, presentation of results, and construction of explanations supported by evidence for the results. The lesson's central idea is for students to understand the trait values that provide an advantage in the aquatic environment, increasing a frog's survival. The link between morphological changes and survival is used to explain how natural selection acts on populations, leading to adaptive evolution.

Key Words: *NGSS; natural selection; adaptations; 5E instructional model; frogs; high school education.*

○ Introduction

In an essay first published in the *American Biology Teacher*, Theodosius Dobzhansky (1973) stated that, "nothing in biology makes sense except in the light of evolution." The underlying message of this statement stresses the need to teach biological evolution. While evolution is a unifying and explanatory theory for all of biology, some teachers may struggle to incorporate the concept into their curriculum or even struggle to actively engage students in evidence-based learning for how natural selection leads to the adaptation of populations (American Association for the Advancement of Science, 2011; Hermann, 2013). Since a goal of science education is to achieve scientific literacy, students need to understand a few overarching biological core concepts, and evolution is one of these necessary concepts (Woodin et al., 2010).

> *The* Functional Frog *lesson provides teachers with a compelling framework to actively engage students in learning how natural selection leads to adaptations.*

Functional Frogs is a 5E lesson that addresses the Next Generation Science Standards performance expectation HS-LS4-4 by introducing students to (1) key morphological structures of frogs during a frog Gallery Walk, (2) *Vernier Video Analysis* software to calculate the swimming velocities of five frog species, (3) the process of synthesizing data to construct explanations that address how changes to morphological structures can give individuals a survival advantage, and (4) determining which trait values provide individuals with an advantage in specific environments.

The Functional Frogs lesson is an outcome of a Research Experience for Teachers (RET) program funded by a National Science Foundation CAREER award (see Acknowledgments). The aim of our RET program was to provide high school science teachers with a professional learning experience designed to strengthen their pedagogical content knowledge on evolution. The RET program integrates teachers' research experience in the area of swimming locomotion in frogs, specifically looking at morphological variation, with pedagogical training to learn how to transition their research into classroom practice.

Relations among Form, Function, Ecology, and Natural Selection

An essential part of science is to gather empirical evidence to test hypotheses that derive from a scientific theory. In the case of the theory of evolution by natural selection, these tests may take one of three main forms: (1) whether a specific trait is variable across individuals, (2) whether it has a heritable (genetic) basis, or (3) whether different values of a specific heritable trait are associated with higher survival or reproductive success (which are components of fitness). All three of these hypotheses underpin how natural selection acts on heritable variation within populations, leading to an increase in frequency of trait values that increase mean population fitness (i.e., adaptation).

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In evolutionary biology, it is common to study traits that represent the form (or "morphology") of an individual, meaning the size and shape of the body or of a specific structure. For instance, several researchers have analyzed the evolution of skull size or shape of different kinds of organisms, such as lizards (Sanger et al., 2013; Stayton, 2005) or frogs (Simon et al., 2016). Morphological traits are a good choice for studying evolution because they often show moderate to high heritability, they show variation across individuals (populations have small and large individuals, or wide and thin skull bones), and they can be linked to functional demands that are thought to be important for survival and reproduction. This link between morphology and functional demands is called a form–function relationship, such as how skull size relates to biting force or how wing shape relates to flight speed. Such relationships connect directly to fitness if the variation in morphology translates to variation in functional performance, which in turn translates to variation in survival or reproductive success. These morphology–performance–fitness relations have been measured in most types of organisms (Irschick et al., 2008).

Moreover, the morphology of different species inhabiting the same environment is often similar, suggesting a link between ecology and form–function evolution (Wainwright & Reilly, 1994). Anurans (frogs and toads) are an excellent group to study this form–function–ecology link, because diverse body forms are associated with a diversity of microhabitats across species. Adult frogs may live in trees (arboreal), in the water (aquatic), on the ground (terrestrial), in waterfall cascades (torrential), in burrows (burrowers), or some combination of these microhabitats (semiaquatic frogs, for example). This diversity in microhabitat use indicates that different frog species perform different functions more or less frequently, such as jumping, walking, climbing, or swimming. And these microhabitats are associated with specific aspects of body form (e.g., adhesive toepads in arboreal frogs; Moen et al., 2016). Therefore, frogs show a diversity of morphological, functional, and ecological features that make them suitable to explore questions about adaptations and evolution by natural selection.

Frog Swimming as a Model to Understand Adaptation to Different Microhabitats

Although more frog species are arboreal or terrestrial than aquatic or semiaquatic (Moen & Wiens, 2017), most frogs must swim at some point in their lives, at least to reproduce in water bodies (Gomez-Mestre et al., 2012). However, frog species that spend more time in the aquatic environment should be under stronger selection for high swimming performance than species that spend less time in water (Moen, 2019). The outcome of this expectation can be tested by comparing the swimming mechanics and the morphological traits associated with swimming across different frog species inhabiting different microhabitats.

A frog swimming cycle can be divided into three phases: (1) the propulsive phase (or power stroke; the beginning of kicking until the legs are fully extended), (2) the gliding phase (legs fully extended until they start flexing to initiate a new kick), and (3) the recovery phase (the beginning of leg flexion to the initial position prior to a new kick). Many mechanical variables can be measured from these phases, yet focusing on the power stroke allows one to estimate maximum acceleration and maximum velocity (Nauwelaerts et al., 2005), two variables thought to be relevant for escaping predators (Moen, 2019). Hence, performance in these variables has straightforward links with survival in swimming frogs, connecting function with fitness and natural selection.

Different frog species can show divergent maximum acceleration and maximum velocity, partly because of differences in morphology (Nauwelaerts et al., 2007; Richards, 2010). This variation across species in swimming mechanics is tied to some morphological traits more than others. These traits include leg length and leg muscle mass (Moen, 2019), as well as potentially the area of foot webbing (Moen et al., 2016). In the *Functional Frogs* lesson, we focus primarily on comparing the maximum velocity of five species of frogs, while guiding students to collect data from videos of frogs swimming. Students make evidence-based interpretations about the morphological traits that may underlie differences in swimming velocity across species. The five species differ both in morphology and ecology, with some inhabiting the aquatic environment more than others. Therefore, the lesson helps guide students through important steps of scientific practices to achieve a greater understanding of how adaptations arise in nature through examining individual variation in morphology and locomotor performance across different environments.

Broad Lesson Goal

The purpose of the *Functional Frogs* lesson is to position students to construct evidence-based explanations that address how different values of specific traits give some individual frogs a survival advantage over other frogs (see Table 1). During the 5E lesson, students predict which frog species will have the best swimming performance based on morphological structures, use *Vernier Video Analysis* software to track the motion of individual frogs to calculate maximum swimming velocity, construct arguments to explain how changes to morphological structures can give individuals an advantage in an aquatic microhabitat, and then extrapolate their collective knowledge to construct explanations about which trait values would be most beneficial for different environments.

Specific Lesson Objectives

At the end of the *Functional Frogs* lesson, students should be able to:

- Predict which frog species will have the best swimming performance based on morphological structures.
- Design a poster that describes the morphological features, microhabitat, and other relevant biology of their assigned frog species.
- Use *Vernier Video Analysis* software to collect data on the power stroke and calculate the maximum swimming velocity for each individual frog.
- Calculate the mean velocity for their frog species using individual maximum velocities of the four individuals.
- Synthesize data to construct an explanation about how changes to morphological structures can give individuals an advantage in an aquatic environment.
- Identify and explain three adaptations that could provide frogs with a survivability advantage.

○ Procedure

Engage: Gallery Walk

The purpose of the Engage phase is to introduce students to key morphological structures using the diversity of frog species as a model of the form–function–ecology link. This is an introductory activity that

Table 1. Overview of the activities found in the 5E stages.

Phase	Overview	Learning activities	Materials	Estimated time (minutes)
Engage	An activity to introduce key structures in frogs through collaboration and a creative gallery walk.	Students design a poster that describes the morphological features, habitat, and other relevant biology of their assigned frog species. Students predict which frog species will have the best swimming performance based on morphological structures.	11 × 13 poster, coloring utensils, access to online field guide (or access to amphibian field guides from the library), tape, pencil, student handouts, computer	Approximately 130
Explore	In groups, students track the swimming motion of their assigned frog species using an online software program.	Students use *Vernier Video Analysis* software to collect data and identify the resultant velocity at each data point for each frog. Students calculate the mean velocity for their frog species using the maximum resultant velocity from each individual.	*Vernier Video Analysis*, computer, student handouts, pencil	Approximately 110
Explain	Groups present their findings from the explore phase and integrate key terminology about morphological structures learned during the Engage phase.	Synthesize data to construct an explanation about how changes to morphological structures can give species a competitive advantage in an aquatic environment.	Computer, presentation software (Google Slides, PowerPoint, etc.), student handouts, pencil	Approximately 55
Elaborate	Students independently apply their knowledge of adaptations and trait values to explain frog survivability in new environments.	Identify and explain three adaptations that could provide frogs with a survivability advantage.	Student handouts, pencil	Approximately 30

builds the foundational knowledge students need to progress through the activities in the *Functional Frogs* 5E lesson. After a brief review of the four driving mechanisms of natural selection (see Supplemental Material "EngageTeacherHandout" available with the online version of this article for details), filled with examples of adaptations, students engage in a class discussion on characteristics shared among frog species, as well as characteristics that differ among frog species when considering their specific microhabitat. This whole class discussion is facilitated by the teacher using interactive and colorful slides, also provided in the EngageTeacherHandout (see Figures 1 and 2). After the discussion, students gather in small groups and are assigned one of five species of frog to further investigate and design an informative field guide poster that displays or explains the specific morphology of their species' feet and microhabitat. Lastly, students participate in a Gallery Walk, where the field guide posters are put on exhibit (see Figures 3 and 4). Using information displayed on the field guide posters, students rank the proposed swimming performance of the five frog species with a score of 1 being the fastest and a score of 5 being the slowest.

Explore: Swimming Performance

The Swimming Performance activity in the Explore phase provides students with opportunities to collect data as they track the motion of four individual frogs from the same species. This activity demands some preexploration by the teacher on how to use the software (*Vernier Video Analysis*, a free software for a 30-day trial period) to analyze the videos of actual frogs swimming (the same videos students observe). The videos were collected in the Moen lab at Oklahoma State University using high-speed cameras. Prior to the activity, the teacher should download the videos from Dryad (available at https://doi.org/10.5061/dryad.9w0vt4bkc; Flud et al., 2023). During each video of a frog swimming, there are three different phases (propulsion/power stroke, glide, and recovery). However, it is the power stroke that students use for data collection. Additionally, there may be multiple power strokes within a single video, thus students are guided to choose one power stroke per video to collect data on. Students place points on the snout of the individual from frame to frame to track the complete motion of each frog throughout the observed power stroke. These data points are auto-populated into a data table and a graph using *Vernier Video Analysis* software. The software calculates an individual frog's horizontal and vertical velocities from the data points. Students use the velocity data to calculate each frog's resultant velocities using the Pythagorean theorem, which is included in the software. Then students identify the maximum resultant velocity for each individual frog and use these values to calculate a mean velocity for their frog species.

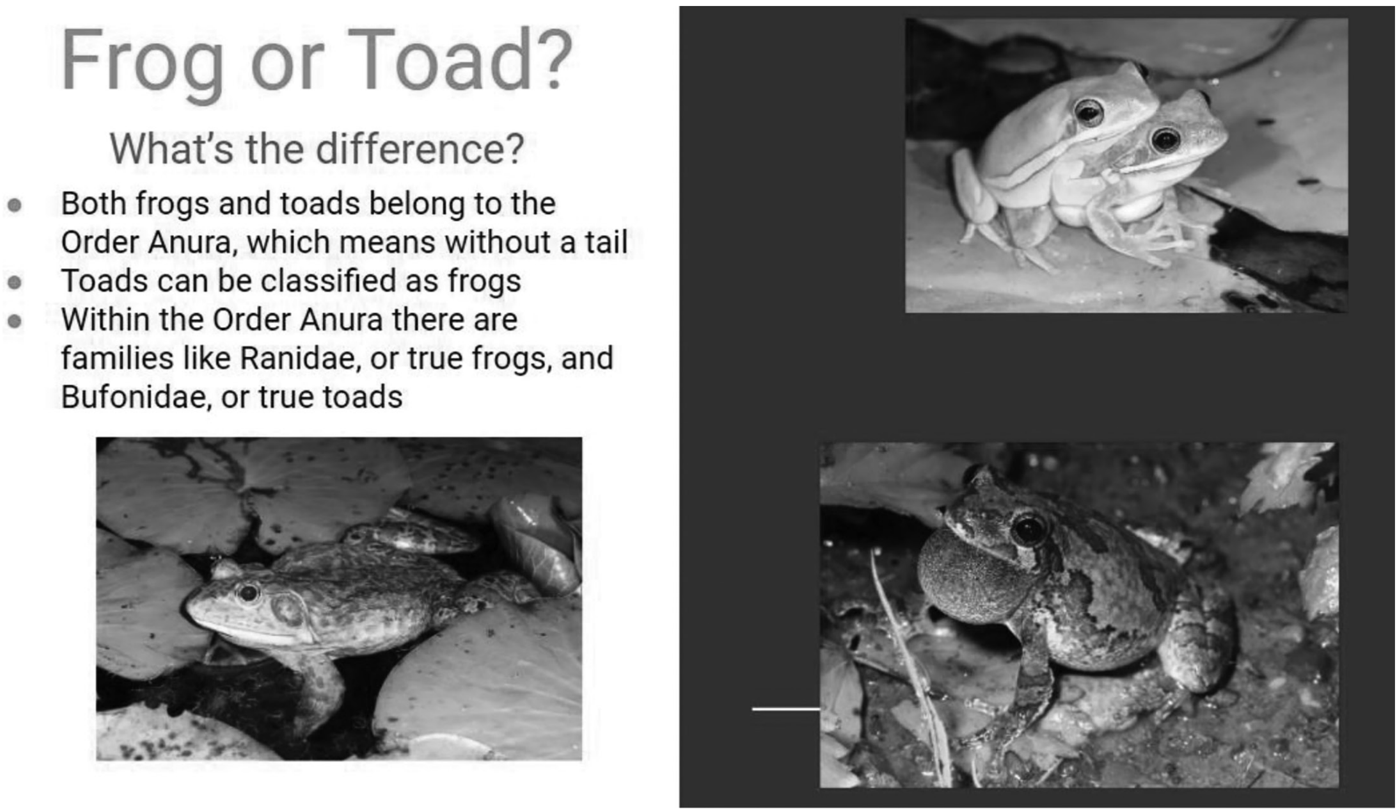

Figure 1. Slide 2 from the frog morphology slides in teacher materials.

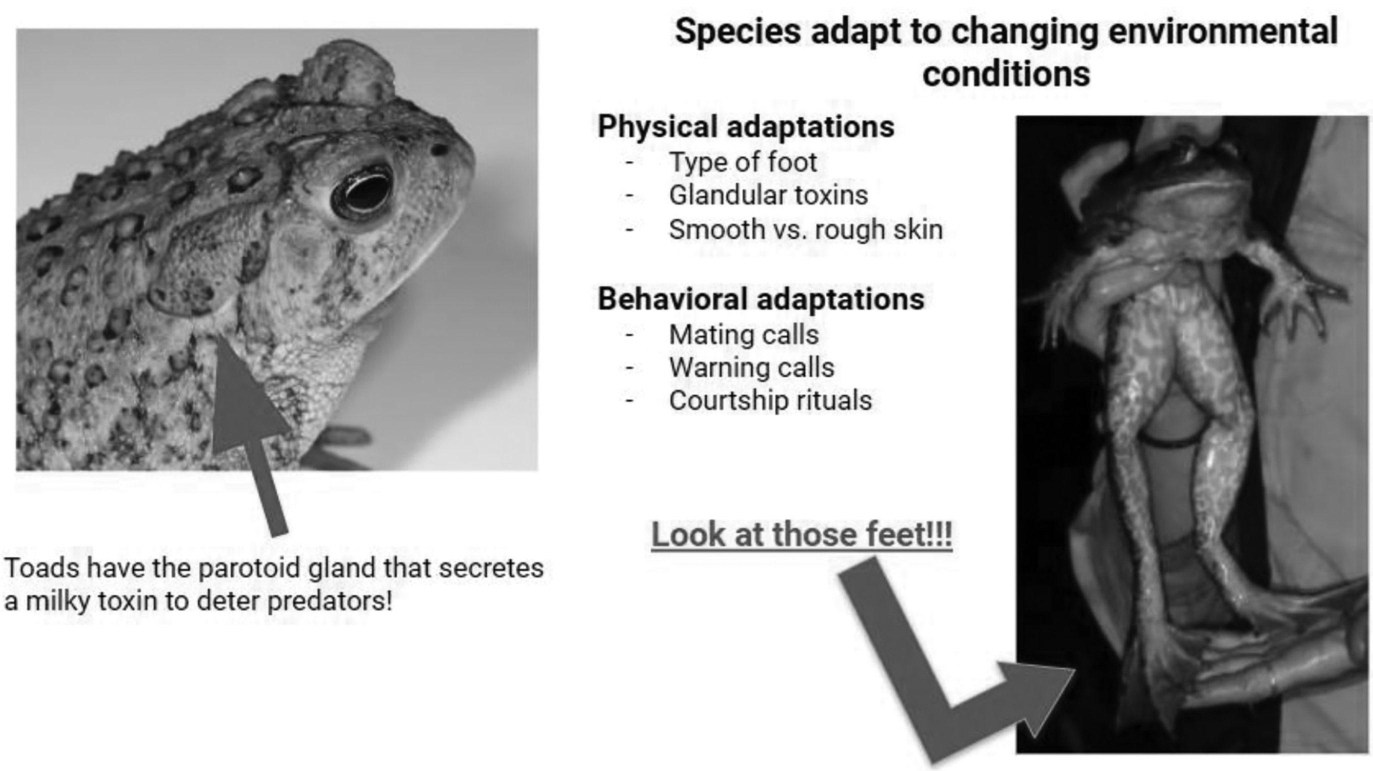

Figure 2. Slide 5 from the frog morphology slides in teacher materials.

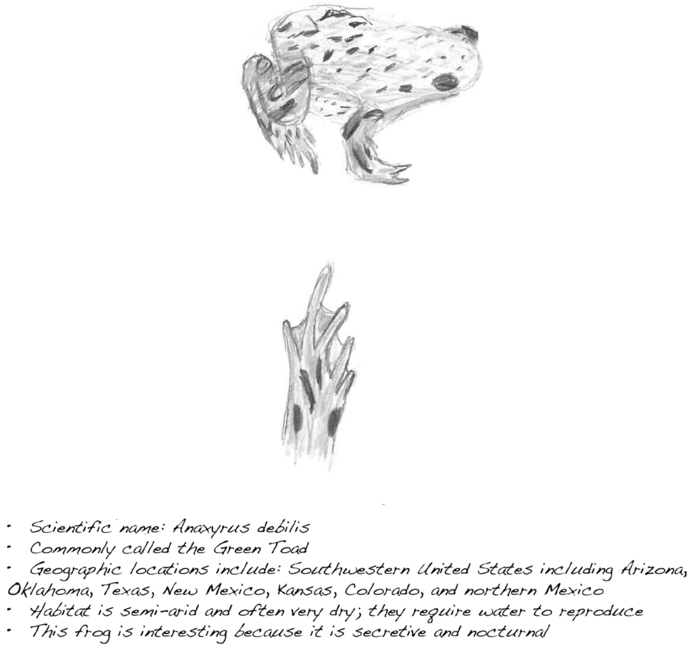

Figure 3. Student group example of the field guide poster from the Engage phase. Note that while this species occurs in Oklahoma, it is not part of our set of videos to analyze.

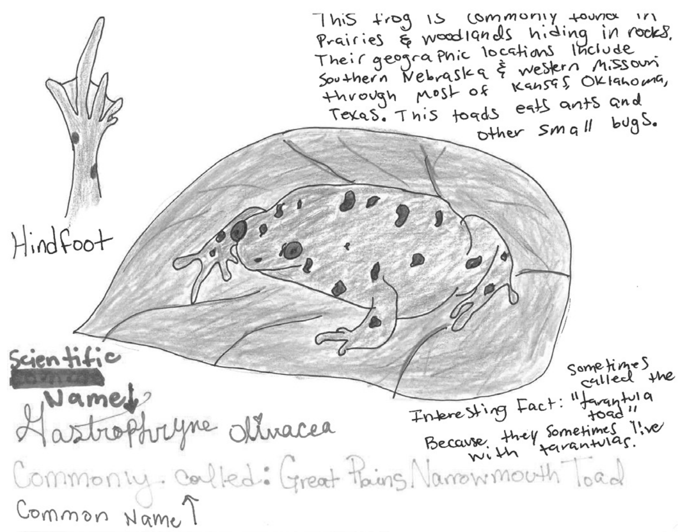

Figure 4. A second example of a student-drawn field guide poster from the Engage phase.

Explain: Frog Expo

The purpose of the Frog Expo activity in the Explain phase is for students to use information learned from the Gallery Walk activity in the Engage phase and data collected from the Swimming Performance activity in the Explore phase to construct an argument to explain how changes to morphology can give individuals a survival advantage. The broader educational goal of this activity is to reinforce students' understanding of how scientific knowledge is produced. In this lesson, students use the provided information on frog morphology to generate hypotheses. They later test the predictions derived from these hypotheses with empirical data they collect. A tenet of the nature of science is that it is based on empirical evidence that is durable yet tentative to provide explanations for phenomena. Thus, scientists use evidence to support their scientific claims. Based on the limited data gathered during the Gallery Walk activity, students made initial claims (hypotheses) on the swimming performance of each frog species. In the Frog Expo, students then use data collected from the Swimming Performance activity to construct an oral presentation to share their findings on mean velocity of their specific frog species. Similar to practicing scientists talking with their peers at national conferences, students communicate their results with their peers. Information gleaned from presentations on maximum swimming velocity of each of the five frog species is used to either support or refute each group's initial hypothesis, as previously stated in the Engage phase.

Elaborate: Adaptations and Explanations

The Adaptations and Explanations activity provides students with opportunities to apply the knowledge acquired throughout the *Functional Frogs* lesson to construct explanations about how some trait values are beneficial to an individual in a specific environment and thus can be considered adaptations. Students are tasked to use a list to identify adaptations that could increase survivability for an individual frog in a specific environment, considering potential predators in each environment. Provided with a list of potential adaptations, students receive a description and a picture of two different environments. After reading the description of the environments, students identify three of the potential adaptations they predict would benefit a frog, providing it with a biological advantage for increased survivability, such as better escaping predators.

Evaluate: Assessment

Because each phase of the *Functional Frogs* lesson contains one or more assessments, we chose to forgo a formal summative assessment. However, our lesson provides multiple opportunities for students to demonstrate their knowledge of how evolution through natural selection can lead to an increase in survivability. During the Engage phase, students create a poster that accurately reflects the morphological structures and habitat of their assigned frog species, then present this poster in the Gallery Walk activity. Based on information learned during the Gallery Walk, students hypothesize which species of frog has the highest mean swimming velocity. To test their hypothesis, each student group is assigned a frog species and tasked to determine the species mean velocity using *Vernier Video Analysis* software in the Explore phase. Students are assessed on their submitted lab report. To simulate the practices of scientists, students present their research findings to an audience of their peers in the Explain phase. Students are assessed on how they present their data but also on their explanation for how changes to morphology can give individuals a survival advantage. The Elaborate phase is designed to assess students' ability to extrapolate their new knowledge about how different traits can provide individuals with a survival advantage in different environments. All assessments are located in both teacher and student handouts.

○ Conclusion

Evolution is a unifying and explanatory theory for all of biology. The *Functional Frog* lesson provides teachers with a compelling framework to actively engage students in learning how natural selection leads to adaptations. Students take on some of the same roles as scientists, as they hypothesize, collect, and organize data, and defend their conclusions based on evidence. An additional feature of this lesson is that students use *Vernier Video Analysis* software to collect data from the same videos used by scientists in ongoing research on frog locomotion.

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GABRIELLE FLUD (gabriellekflud@gmail.com) is a secondary life-science teacher and science department chair at Catoosa Public High School in Catoosa, OK. JULIE ANGLE (julie.angle@okstate.edu) is a professor of science education and the Bill and Billie Dean Buckles Innovation in Teaching Endowed Professor at the College of Education and Human Sciences at Oklahoma State University. MONIQUE N. SIMON (moniquen@ucr.edu) is an assistant project scientist in the Department of Evolution, Ecology, and Organismal Biology at the University of California, Riverside. DANIEL S. MOEN (dmoen@ucr.edu) is an assistant professor in the Department of Evolution, Ecology, and Organismal Biology at the University of California, Riverside.