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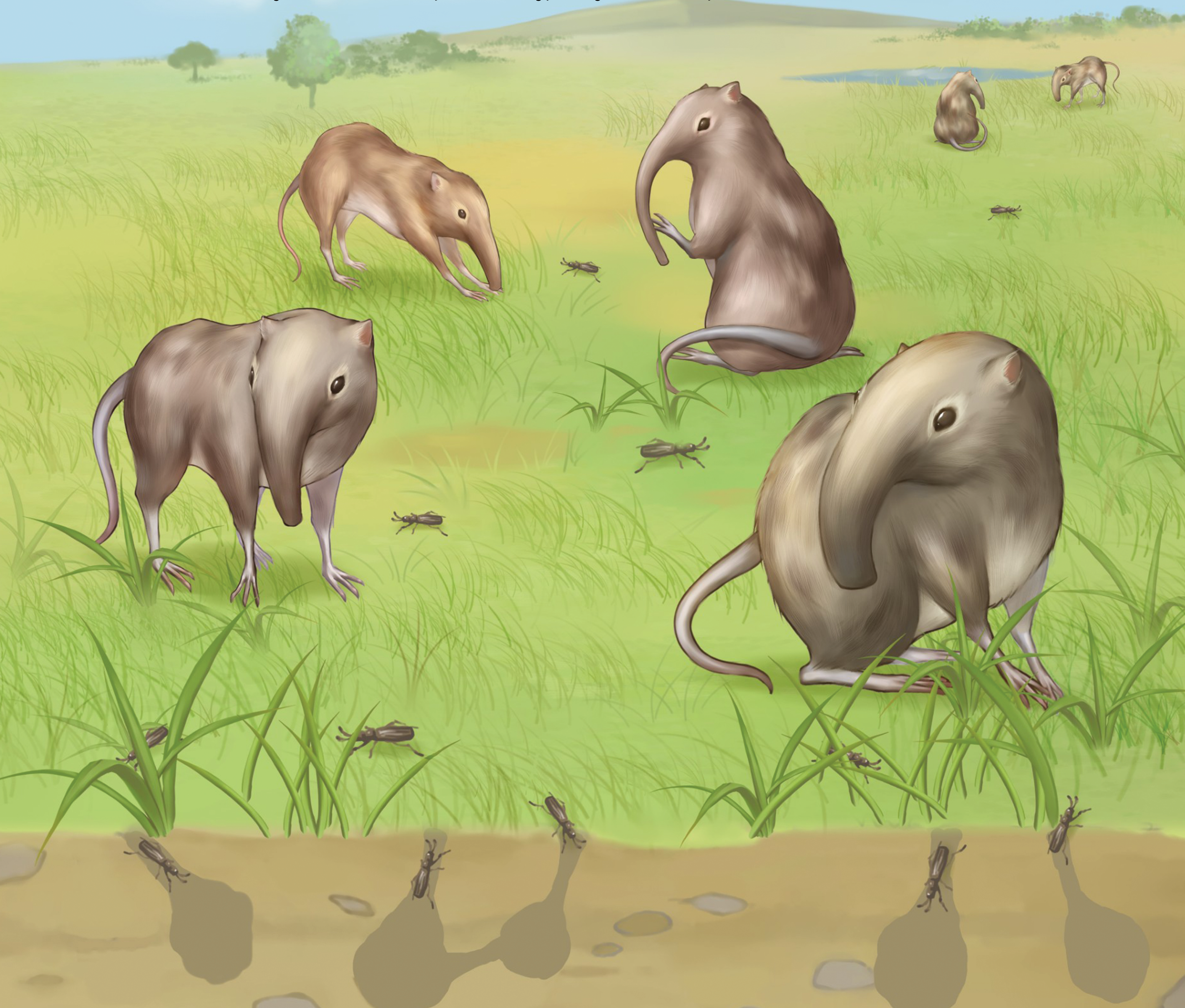
Investigating Biological Evolution

Building a model of natural selection in third grade

By Gillian Puttick, Sara Lacy, Sally Crissman, and Deb Kelemen



ABSTRACT

Evolution by natural selection is fundamental to understanding life, yet it is hard to teach and usually only taught in middle or high school. However, it is now a disciplinary core idea for Grade 3 *Next Generation Science Standards*. Our research shows that young children are fully capable of building coherent ideas about the abstract mechanisms that underpin natural phenomena like natural selection. Students therefore deserve curricular materials that support that capability. (https://www.evolvingmindsproject.org/)

Keywords: 3–5; *NGSS*; cause and effect; biological evolution/unity and diversity; stability and change

"Nothing makes sense in biology except in light of evolution."—Theodosius Dobzhansky

Evolution by natural selection is fundamental to understanding life. It is one of the big scientific ideas. It explains why animals have specialized body parts, why we have the origin of new species, why we have this amazing diversity of plants and animals on Earth.

The idea of evolution by natural selection—how variants of traits that are beneficial to plants or animals become more common over multiple generations in a population when the environment changes—is both important and hard to teach. Teachers hold many misconceptions about the mechanism of natural selection (Sickel and Friedrichsen 2013) and are ill-prepared to teach this foundational idea; only half of all states require elementary teachers to pass a content licensure test in core areas (Putman and Walsh 2021).

Commonly, in elementary grades students learn about structure-function relationships—what structures or behaviors help organisms survive—without understanding how these came about. Natural selection is often seen as too complex or abstract for elementary students, which is why it is typically only taught in middle or even high school (Kelemen, Emmons, Seston, and Ganea 2014; Shtulman, Neal, and Lindquist 2016). However, biological evolution is now a disciplinary core idea for Grade 3 *Next Generation Science Standards*. Moreover, we have found that young children are fully capable of building coherent ideas about the abstract mechanisms that underpin natural phenomena (Kelemen 2019). They therefore deserve curricular materials that support that capability.

The idea of evolution by natural selection is deeply counterintuitive (Coley and Tanner 2012). By the time natural selection is taught, students' preconceptions based on their everyday experience are difficult to dislodge (Kelemen 2019). Everyday experience and language suggest that change over time involves the uniform magical transformation of all members of a species, e.g., at some point, giraffes got long necks, and (b) evolution is goal-directed, leading students to believe that change over time occurs for a purpose, e.g., "Giraffes wanted to be able to reach leaves in trees and so they got longer necks," or to serve a need, e.g., "Giraffes got long necks because they needed to get food" (e.g., Gregory 2009; Brown, Ronfard, and Kelemen 2020). What if natural selection is taught in elementary science classrooms before these preconceptions become entrenched?

Another challenge is that the mechanism of natural selection includes multiple abstract ideas (e.g., variability, differential reproduction, time). Children need opportunities to gain evidence provided by a set of real-world cases that serve as specific examples of these abstract ideas, for example, exploring trait variation as an everyday natural phenomenon or observing fossils as evidence for change over time. What if students had a model to serve as a conceptual framework that helps them learn about natural selection?

In this article, we describe four lessons from a bigger set of 12 lessons in the Evolving Minds Curriculum, written for third-grade classrooms, that focuses on the mechanism of natural selection. Each lesson is built around an investigation question, elicits student ideas, highlights evidence that addresses the investigation question, and focuses on meaning making in whole-class discussion. The first three lessons support children to understand that (1) biological change happens, (2) individuals in a population vary, (3) traits can be beneficial or harmful in a changed environment, and (4) the proportion of beneficial traits in a population changes over time. In the fourth lesson, students find evidence in a storybook to construct a model of the mechanism of natural selection which they can apply to new cases. See the curriculum at https://www.evolvingmindsproject.org/.

The Evolving Minds Curriculum

The Evolving Minds curriculum presents natural selection as a model that consists of six key steps to organize ideas like variability and differential reproduction, which children derive and draw together from firsthand investigations and storybooks:

1. A population of living things in its environment.
2. Traits vary (in the population).
3. The environment changes.
4. Some trait variants may be beneficial in this environment.

5. Individuals with beneficial trait variants have more offspring. Those offspring usually look like them.
6. When this process happens again and again over many generations, the population looks different than it used to look.

Students use the model as a tool to construct narratives of change over time. To support students to do this, we created a learning sequence that integrates student investigations (using science practices that allow students to gather evidence and engage with the ideas) and storybooks. In classrooms, we see students become highly engaged in finding evidence in the investigations and the storybooks, as they apply the model to new cases.

Why Storybooks?

We have found that picture storybooks—or animations of storybooks—can be key components in learning about natural selection. Storybooks are child-friendly, and the illustrations help students understand the text. Research studies show that storybooks that incorporate all the steps of the model can help children construct explanations that link causes (e.g., variation) to effects (e.g., changes in the traits of a population of organisms) in a coherent history (Kelemen, Emmons, Seston, and Ganea 2014) We have seen carefully crafted storybooks result in significant student learning about how natural selection leads species to have environmentally specialized bodies and to evolve into new species (Ronfard, Brown, Doncaster, and Kelemen 2021).

Why Active Firsthand Investigations?

Investigations of real-world phenomena support three-dimensional learning by addressing the three strands in the *Next Generation Science Standards* (disciplinary core ideas, crosscutting concepts, and science practices). These investigations allow students to directly explore their own questions, while small-group work offers opportunities to collaborate, practice scientific language, and exchange ideas. Firsthand activities also provide connections to students' everyday experiences of the natural world. Most important, directly observing phenomena provides a rich "library of cases" upon which to build deeper understanding.

In this article, we describe four 40-minute lessons from a bigger set of 12 lessons in the Evolving Minds Curriculum, which typically takes 12–13 class periods. The unit focuses on the mechanism of natural selection and the fossil evidence that links ancient and contemporary species. The anchoring phenomenon is Change over Time. Besides supporting science learning, and literacy skills, the unit also targets math skills. Each learning activity is (1) built around an investigation question, (2) elicits student ideas, (3) highlights evidence that addresses the investigation question, and (4) focuses on meaning making in small groups and in whole-class discussion. Small-group work and full class discussions support student thinking and co-constructing evidence-based models and explanations. Furthermore, student writing and student talk in both can serve as formative assessments.

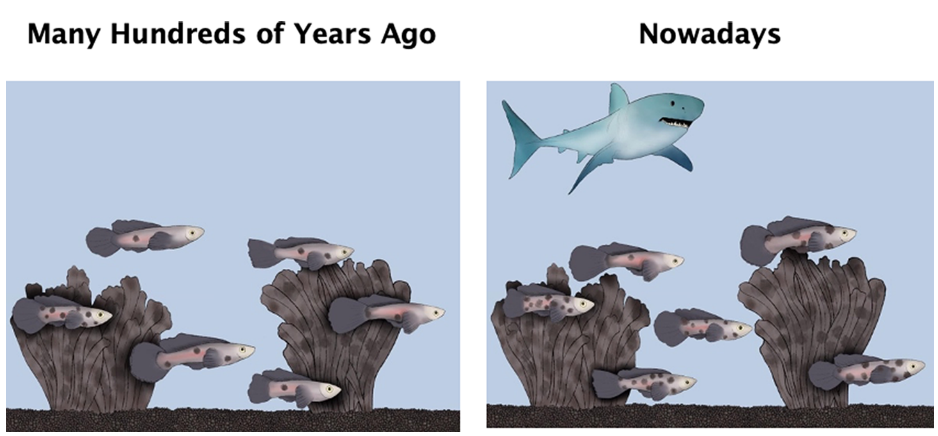
Lesson 1: Long-Ago and Nowadays Scenario

We begin by asking, "What's the story of how animals and plants change over time?" To investigate, students examine two intriguing images for one of four animals (guppies, owls, cane toads or okapis): a population of the animal many hundreds of years ago and a population of the animal nowadays (Figure 1).

Students in small groups spend 15 minutes noticing changes in the environment and changes in the population. They brainstorm how changes in a population could have happened. Individually, they take 10 minutes to respond in their notebooks to prompts asking them about the changes

FIGURE 1

Two guppy populations.



they see and their ideas about how the changes might have happened.

In a 10-minute make-meaning discussion, we elicit ideas about change over time from students, emphasizing that all ideas are welcome and valuable. Students begin to think in terms of the fact that *individuals with different trait variants make up populations. These populations* change over time when *environments change*, all key concepts that elaborate the mechanism of natural selection. Students are now primed to engage more deeply with trait variants in the second lesson.

Students' initial ideas in notebook entries and during discussion provide formative assessment data for teachers and students: What are our initial ideas about change over time? Activities in the lessons that follow provide evidence to answer to the question, "How did change happen?" Online, we share examples of evidence of student understanding in talk and writing for all four lessons (see Supplemental Resources).

Lesson 2: Seeking Evidence for Variation

We begin by posing the investigation question, "Are all radish rootlets and snail shells the same? What's the evidence?" To gather evidence to answer the investigation question, small groups of students take 25 minutes to closely observe a population of radish seedlings, looking at one of two traits, root length or root curliness, and observe a population of snail shells, focusing on the traits of shell color or size of opening. In response to the investigation question prompt, they find and record evidence of *variation* in their selected traits since variation is key to building an explanation of how change happens in the years between many hundreds of years ago and nowadays (Emmons and Kelemen 2015).

To make meaning in a class discussion, students take 15 minutes to discuss the evidence before them. The teacher listens for recognition that there are little differences or *trait variants* within each population: Even if snail shells share the trait of having an opening, openings show variation in size—which is often something we don't notice! To connect the relevance of this evidence to everyday life, students think of populations of familiar organisms (butterflies, carrots, squirrels, leaves). They discuss traits of those populations and describe little differences they have noticed. They see that variation occurs naturally within any plant or animal population.

Lesson 3: Graphing Variation of Traits in a Population

We begin with the investigation question, "How hairy is a population of radish plants?" Students examine live plants to see if they can detect any hairs. It may be a surprise for students to find that there are tiny hairs on the leaves and stems of radishes and on other plants, too! In small groups, students count hairs on close-up photographs of individual radish plants and record their data on sticky notes. They then create a class graph to represent class data (20 minutes) (Figure 2). The graph creates a picture that describes the trait variation within a population. To make meaning, students return to the investigation question and discuss how the graph helps tell about the distribution of hairiness trait variants in this population (15 minutes).

Listening to their discussion and reading students' notebook writing, teachers see that students are becoming adept at using the concept of *trait variants* within a population that was introduced in the prior lesson. At the end of the lesson, students turn and talk to speculate: Suppose we planted seeds from these plants. In the plants that grow up

FIGURE 2

Creating a class graph.

from the seeds, what do you think a graph of the number of hairs will look like?

After 3 lessons, students will have considered the first three steps of the 6 Key Steps model: "population," "traits vary," "environment changes." They will also have started to think about inheritance.

Lesson 4: Using a Storybook to Develop a Model of Natural Selection

In this lesson, students add three important new ideas to their developing understanding of natural selection, that: (1) Depending on environmental conditions, individuals within a population that possess a beneficial trait variant are healthier, (2) those healthier individuals have more offspring which tend to look like them, and thus (3) over many generations the proportion of individuals within a population that has a beneficial trait variant increases. They conclude by reviewing their model.

We begin by asking students the investigation question, "Why do piloses have thinner trunks nowadays?" Students spend 10 minutes watching an animation of a storybook, How the Piloses Evolved Skinny Noses (see Piloses video), about realistic fictional animals called "piloses." This story is based on a real case of natural selection in anteaters, but the storybook presents an entirely unfamiliar animal as students first build their model because research shows this can avoid confusions arising from preconceptions about familiar species. In the piloses, the proportion of individuals in the population with thinner trunks (noses) increases over many generations. Students see that most of the piloses have wider trunks but after catastrophic climate change—which causes the bugs that they eat to move into deep underground tunnels—individuals with wider trunks are at a disadvantage. In contrast to piloses with thinner trunks, ones with wider trunks have fewer babies. Because babies tend to look like their parents, in each of the subsequent generations, the proportion of piloses in the population with thinner trunks increases. After the video, we ask students to match and paste story strips next to images showing the sequence of events, thus summarizing the story (Figure 3).

Next, we ask students to express each step in the piloses story as a generalization; they take 15 minutes to match six generalized statements to the story strips. To make meaning, the class returns to the investigation question to discuss the sequence of story strips and come to consensus that the storybook provides evidence of how change happened to the population. Together, they discuss and agree that the statements provide a generalized summary (10 minutes) and that they have now developed a model: the 6 Key Steps of Natural Selection:

1. A population of living things in its environment.
2. Traits vary (in the population).
3. The environment changes.
4. Some trait variants may be beneficial in this environment.
5. Individuals with beneficial trait variants have more offspring. Those offspring usually look like them.
6. When this process happens again and again over many generations, the population looks different than it used to look.

In subsequent lessons, the students can use their model of natural selection to test the idea that any population of animals or plants could change over time. With the addition of each new real-world case, students reason not only about the evolution of specialized traits within populations (adaptation), but also the emergence of new species

FIGURE 3

The 6 Key Steps of Natural Selection as told in the piloses story.

	The piloses story	6 Steps
	Long ago a population of piloses lived in a grassy meadow	A population of living things in its environment
	Many piloses had wider trunks while some had thinner trunks; all could get bugs to eat	Traits vary
	It got hot and dry; the bugs went underground	Environment changes
	Piloses with wider trunks struggled to reach the bugs so they were less healthy, while those with thinner trunks could, so they were healthy	Some trait variants may be beneficial in the new environment
	Healthier piloses had more offspring and offspring usually looked like their parents	Individuals with beneficial trait variants have more offspring, who usually look like them
	This process repeated over many generations. Piloses with thinner trunks became more common than piloses with thicker ones, nowadays the population looks very different.	When this process happens over and over for many generations, the population looks different than it used to look

(speciation) and sources of evidence for these changes over time (fossils). Through this, they learn about the connections that unify all living things.

To end the unit, students complete a fun capstone activity in which they apply their knowledge and imagination to create a poster depicting a change over time story (either adaptation or speciation) for the okapis from Lesson 1. They imagine what could happen in the future if the environment changes (Figure 4) and draw a few individuals with the trait variants that they think might be most common in a future population. In a final class discussion they engage with the key learning goal: Evolution by natural selection never ends. In fact, it is going on around us now!

Strategies for Supporting Diverse Learners

The curriculum includes several resources and tips for English Language Learners that teachers have also found helpful for all students. First, it provides a set of illustrated *word cards* and strategies for using them (e.g., pairing them with their meaning in everyday language and modeling how to use them). Teachers will find that, over time, students incorporate this scientific vocabulary in their own speaking and writing. Second, guidelines for supporting small groups of two to four students to work together include (1) providing objects or materials to think with, (2) framing the activity as a time to explore and discuss ideas, (3) being clear about

FIGURE 4

A sample student poster depicting the mechanism of natural selection that has resulted in a new species, the *Sokums*.

what students are expected to do, how much time they have, and what they are accountable for individually, and as a group, when time is up. Teachers tell us that, for example, "Students make meaning as they speak and get immediate feedback from other people so they can refine their thinking," and "It's [small group work] 100% important! That's how kids build their ideas and construct their thoughts and the meaning." Third, students come to whole-class discussion—typically arranged in a discussion circle so they can see each other—understanding that they will discuss that lesson's investigation question. Teachers call on students to use evidence from small-group work to support their responses and ask them to respond to their peers' contributions.

Conclusion

Preconceptions about evolution by natural selection can be tenacious. However, our research shows that as early as third grade, young children are fully capable of using the mechanism of natural selection to explain why species have specialized body parts (adaptations), why new species evolve (speciation), and that fossils can provide evidence of change and evolutionary connections among species. Using lessons that support students' exploration of animals and plants, and analogizing across multiple cases of change over time leads to powerful acquisition of the foundational model of evolution by natural selection. Concepts about evolution are often deeply misunderstood when they are encountered for the first time in middle and high school. Given a coherent sequence of activities and experiences, we found that this fundamental understanding is not only well within the abilities of third-grade students, but it can also provide a powerful foundation for future learning.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

SUPPLEMENTAL RESOURCES

Supplemental resources for this article can be accessed online at https://doi.org/10.1080/00368148.2024.2436679.

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