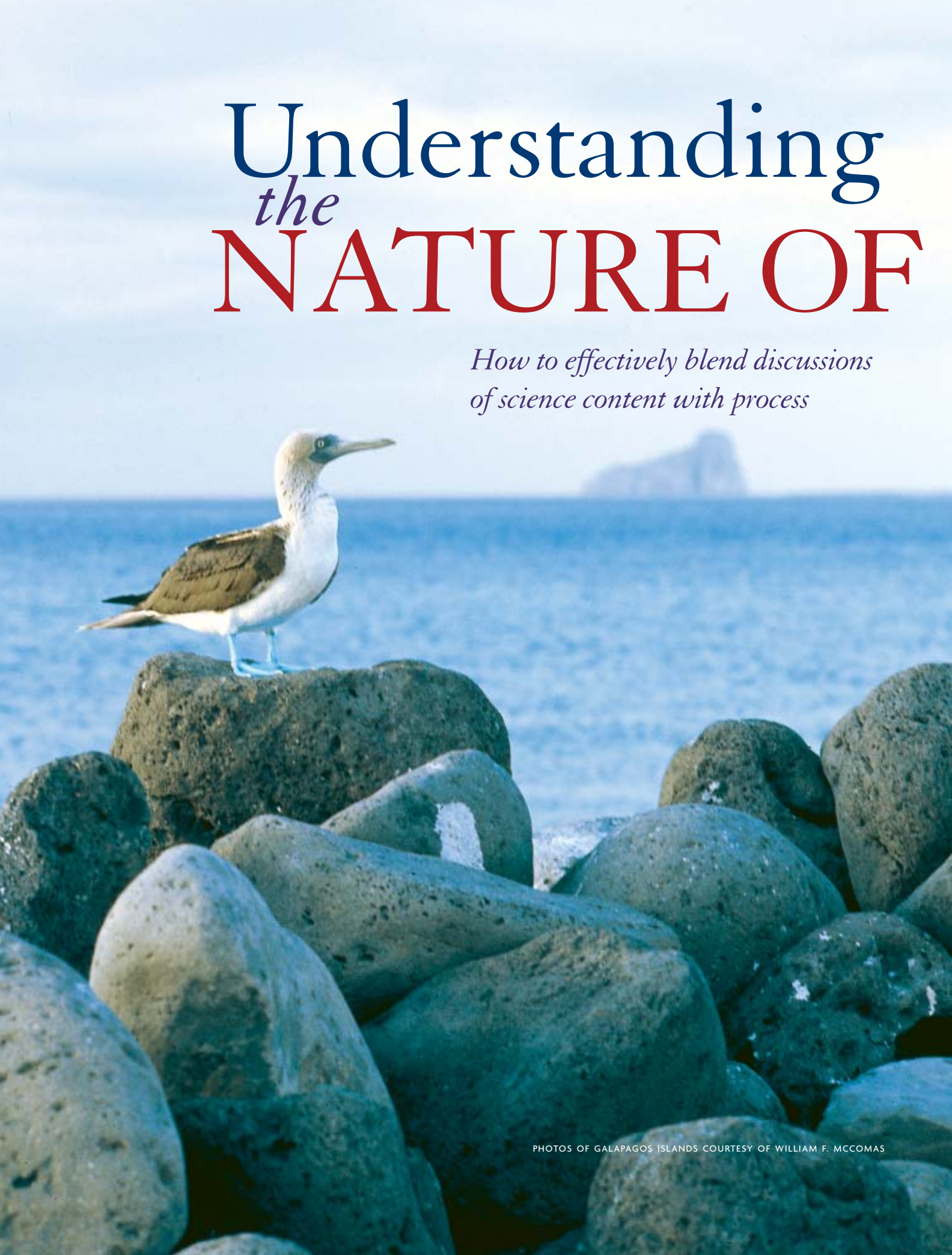
Understanding *the* NATURE OF

How to effectively blend discussions of science content with process



PHOTOS OF GALAPAGOS ISLANDS COURTESY OF WILLIAM F. MCCOMAS

SCIENCE Through Evolution


Marine iguanas

Paul Narguizian

"Nothing in biology makes sense except in the light of evolution" (Dobzhansky 1973, 125). This statement by geneticist Theodosius Dobzhansky is frequently cited as rationale for including the topic of evolution in science curricula. As the common thread in biology, the topic of evolution and its related historical development can help students make sense of diverse biological concepts. The discussion of evolution provides educators with something else—a significant opportunity to teach important lessons involving the nature of science (NOS).


Frigate birds

The strategies addressed in this article focus on how to effectively blend discussions of science content with process. An examination of evolution, along with the mechanism of natural selection, can provide science teachers with a wealth of resources to pull from when delivering science content to biology students. This article also focuses on several core NOS ideas as they pertain to evolutionary biology. These ideas include the concept that laws and theories are related, but distinct, kinds of scientific knowledge; that science demands and relies on empirical evidence; and that science is influenced by history, culture, and society.


The Galapagos Islands

Darwin observed the differences and similarities among related organisms found on the Galapagos Islands and the mainland of South America.

Laws and theories

Definitions in science are important. Often teachers and students alike have difficulty defining law and theory in science. It does not help matters that the word *theory* is used so loosely in everyday speech, as in "Well, it's only a theory." In the language of science, laws and theories are related, but separate, types of scientific knowledge. Laws consist primarily as statements or generalizations made about natural phenomena. Theories, however, consist of the explanation for how the law works (McComas 2003). The idea that organisms change through time—the *law* of evolution—was suspected years before Charles Darwin began his investigations. However, Darwin is credited for providing a theoretical explanation of the causative mechanism of evolution. This is correctly called the *theory* of evolution by natural selection.

By examining the work of Darwin and discussing evolution along with the theory of natural selection, science teachers can teach science content while providing their students an opportunity to explore the scientific meaning of law and theory. By doing so, students will have an opportunity to appreciate the important role played by scientific laws, theories, and language in science.

Science and empirical evidence

The relevant data or evidence in support of evolution include information from the fossil record, embryology, biochemical and molecular relatedness among organisms, geologic and geographic distribution of organisms, comparative anatomy, and developmental biology (Hofmann and Weber 2003). These are all vital clues that establish both the reality of evolution itself and the validity of its mechanism, but they do not all represent the same kind of scientific data. A classroom discussion of evolution provides an ideal opportunity to explore the different ways scientists collect evidence including historical, observational, and experimental sources of data. To explore and advance the subject of evolutionary biology, scientists have used the following important information-gathering tools.

Historical evidence

A major source of information regarding both the fact and mechanism of evolution comes from the record of life preserved as fossils and the ever-changing landscape of Earth itself; both are significant kinds of historical evidence. One can trace the historical evidence used by Darwin in his geological research of South America (Ghiselin 2003). During the initial few years of his famous voyage on the *H.M.S. Beagle*, Darwin looked at the geological relationships in South America, specifically trying to tie in his hypothesis that South America had undergone widespread elevation. By looking at independent lines of geological evidence, Darwin sought ways to explain the *stratigraphic*—geologic elevations and depressions caused by erosion and other natural phenomena—relationships in South America.

The fossil record is a fundamental part of the evidence for evolution. The idea that fossil remains of organisms from the lower strata are more primitive but related to those of the upper strata had already been known long before Darwin conceived of the mechanism of evolution by natural selection. By examining fossils in the classroom and discussing the role of such evidence, students can better understand the role of inferences and can interpret historical evidence.

Observational evidence

Observation is another important tool in science. Teachers can refer to the observations conducted by Charles Darwin during his five-year voyage around the globe on the *Beagle* (1831–1836). While on the voyage, Darwin made numerous observations of plant and animal life, took notes, and later considered what his observations might mean. On one of his stops to South America, he observed living armadillos. Darwin compared the living organisms with fossils of ancient armadillos and noted the shared and distinct features. Darwin observed the differences and similarities among related organisms found on the Galapagos Islands and the mainland of South America. In addition, Darwin made careful observations of animal behavior in support of this thinking about evolution. Teachers today can include a discussion of primate behavior as another line of observational evidence (NAS 2001).

Experimental evidence

Experimentation in science is a critical evidence-gathering tool. Many think that experimentation is the only mode of gathering data in science, but in reality, experimentation is only one of the many tools used in gathering evidence. Allen and Baker define an experiment as "a planned intervention into a natural process to observe the effects of that intervention" (2001, 35). It is unlikely that Darwin conducted much of this sort of experimentation while aboard the *Beagle*. Twenty years lapsed between Darwin's return from his voyage to the presentation of his idea of natural selection in the famous treatise, *On the Origin of Species* in 1859. During that time, Darwin performed numerous scientific experiments to test his hypotheses and to see if the results of those experiments would provide evidence that supported or disproved natural selection (Ghiselin 2003).


Galapagos giant tortoise

Teachers can refer to one of Darwin's experiments in which he took seeds and immersed them in seawater over different periods of time to determine whether they would still germinate (Wuerth 2004). Students can try the same experiment in class and draw conclusions to whether seeds from the "mainland" could withstand the oceanic journey to nearby "islands." Microevolution can also be used as experimental evidence in the classroom by addressing such issues as antibiotic and pesticide resistance.

Through evidence gathered by historical, observational, and experimental means, Darwin first came to the conclusion that evolution had, in fact, occurred. He pushed the evidence further by ultimately developing his proposed mechanism of evolution. The theory of evolution by natural selection, even in Darwin's time, was essentially correct even though some vital fields such as genetics were in their infancy in the late 1800s. In the intervening century, scientists have continued to apply a wide range of techniques, critique, and analysis resulting in an even richer understanding of the law and theory of evolution.

Historical, cultural, and social influences

One cannot study the work of Charles Darwin and the tremendous influence he had on biology without considering the impact of his younger colleague, Alfred Russel Wallace. The story is well known. Even though Darwin had given much thought to the mechanism for evolution, he was not quite ready to publish. That changed when he received a letter from Wallace—far away in the islands of what is now Indonesia—that outlined a very similar theory of evolution to the one he had been considering.

It is well documented that Darwin and Wallace individually, and concurrently, discovered the mechanism of evolution through their studies of biogeography, specifically island biogeography (Ghiselin 2003). Darwin wanted to honor the younger man's contribution but also sought to receive credit for the discovery. It would be of interest to students and teachers alike to consider the impact made on Darwin when he received Wallace's letter, which is discussed in a number of


Galapagos finch on Opuntia cactus

Finches provide a classic example of biological divergence by representing differences in beak shape among closely related species.

sources including Brackman (1980). Today we recognize Wallace alongside Darwin as the codiscoverer of natural selection (Shermer 2002).

Of course questions arise as to why Darwin waited so long in publishing his idea in the first place. One can look at the times in Victorian England and see how societal and cultural influences of the period held Darwin back. Not only did he recognize that many people, including scientists, would have a hard time accepting his idea of natural selection, but the important issue existed that an acceptance of evolution might give some a reason to reject religion. With this story teachers have an opportunity to explore a number of important social aspects in NOS.

Implications and instructional strategies

A multitude of instructional strategies are available for teachers to use in the classroom that target a variety of learning styles among students. These strategies include *reading assignments, laboratory experiments,* and *classroom debate*.

Reading assignments

Fortunately, science teachers have access to numerous books, articles, and websites devoted to the study of evolution and NOS. These resources can assist teachers in designing biology curriculum that addresses science content alongside issues or core ideas in the NOS (Wuerth 2004).

An article I have used in the past as part of my biology curriculum, titled *The Discovery & Nature of Evolution by Natural Selection: Misconceptions & Lessons from the History of Science* (McComas 1997), outlines Darwin's role on the *Beagle* and describes many misconceptions held by Darwin on his voyage. The article also contains numerous examples of myths associated with Darwin and the voyage of the *Beagle*.


Blue-footed boobies

Consideration of these myths allows for a longer discussion on NOS, how Darwin practiced science, what he really encountered on his five-year voyage, and how he arrived at the conclusion (based on his data) that natural selection is the mechanism which drives evolution. Numerous books on Darwin's life abound. Books that are useful include *Evolution: A History of an Idea* (Bowler 1989), *Darwin* (Appleman 2000), *The Triumph of the Darwinian Method* (Ghiselin 2003), and *Evolution: The Remarkable History of a Scientific Theory* (Larson 2004).

Laboratory experiments

Howard Piltz describes an activity that simulates evolution by natural selection to help students learn in a more concrete way how natural selection operates (2004). In this simulation, students take on the role of finches that have variations in the shape of their "beaks." The finches provide a classic example of biological divergence by representing differences in beak shape among closely related species.

For more advanced students, teachers can refer to a more extensive laboratory experiment titled *Bird Bills and Seed "Crackability": Modeling Evolution* (TERC 1997; Calabi 1997). This activity models a severe drought—a well-documented event that occurred on the Galapagos Islands (Grant 1999; Weiner and Knopf 1995)—that affected the finch population on the islands. "On the Web," at the end of this article, features more teacher resources for laboratories exploring evolution and NOS.

Debate

Teachers can also plan debates in class. Questions or position statements on evolution can be designed in which students provide historical, observational, or experimental evidence to defend or refute evolution and natural selection. In doing so, teachers provide an opportunity for students to engage in higher order thinking questions and also take part in group discussions.

A responsibility

Biology teachers have a responsibility to teach students about evolution and natural selection, as well as deliver content that supports understanding the processes of science. By presenting students with engaging activities in both areas, teachers and students alike can take part in a richer experience, one that will make understanding both the scientific content and NOS more enjoyable and authentic. ■

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On the Web

PBS Evolution: *www.pbs.org/evolution*. This website contains teacher materials and student handouts on evolution.

University of California Museum of Paleontology at UC Berkeley and the National Center for Science Education: *evolution.berkeley.edu/evosite/evohome.html.* This is a good website for labs that explore evolution and NOS.

Woodrow Wilson Access Excellence: *www.accessexcellence.org/AE/AEPC/WWC/1995/.* Students can explore various experiments and resources pertaining to evolution education through this website.

Issues in Evolution—ActionBioscience: *www.actionbioscience.org/evolution/index.html.* At this site, students can read articles by scientists, science educators, and other science students on issues related to evolution.