

Resources for Teaching and Learning about Evolution¹

These Teacher Notes provide:

- Suggestions for Teaching Evolution to Students with Religious Concerns (page 1)
- Natural Selection, including major concepts, common misconceptions and recommended learning activities (pages 1-5)
- Species, Descent with Modification, and the Evidence for Evolution, including major concepts, common misconceptions and recommended learning activities (pages 5-7)
- Recommended General Resources for Teaching about Evolution (pages 7-8).

Learning activities that are explicitly aligned with the Next Generation Science Standards² are designated (NGSS).

Suggestions for Teaching Evolution to Students with Religious Concerns

“Defusing Discomfort” (The Science Teacher, February 2017, pages 26-30) describes how to use a reflective writing assignment to help students with religious scruples feel open to learning the science of evolution. The author recommends that, before you begin classroom teaching about evolution, you have students complete a private writing assignment in response to a prompt such as:

“Before we begin our discussion on evolutionary theory, please reflect on your personal philosophical or religious views with regard to evolutionary theory. What are the differences between science and religion?”

These writing assignments are graded based on the thoughtfulness of the student’s response, not on the student’s opinions.

An alternative approach that emphasizes classroom discussion, rather than a private writing assignment, is presented in “Beyond ‘Teaching the Facts’: How to Teach Evolution to Religious Students Who Don’t ‘Believe’” (<http://asutechwebs.blogspot.com/2016/05/beyond-teaching-facts-how-to-teach.html>).

Natural Selection

Major Concepts

- A typical population of biological organisms produces more offspring than can survive to reproduce.
- Different individuals in a population have different characteristics; this is variation.
- Fitness is the ability to survive and reproduce.
- A characteristic which is influenced by genes and can be inherited by a parent’s offspring is called a heritable trait.
- A heritable trait that increases fitness is an adaptation.
- An adaptation tends to become more common in a population. Because the adaptation increases fitness, individuals with this trait generally produce more offspring. Because the trait is heritable, offspring generally have the same trait as their parents. Therefore, the adaptation tends to become more common in the population. This process is called natural selection.

¹ By Ingrid Waldron, Department of Biology, University of Pennsylvania, 2024. These Teacher Notes are available with clickable links at <https://serendipstudio.org/exchange/bioactivities/evolrec>

² <http://www.nextgenscience.org/> and <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>

- Another way to describe the process of natural selection is as follows. Since (1) individuals with an adaptation are more likely to survive and reproduce and (2) parents pass their alleles to their offspring, the allele(s) that result in an adaptation tend to become common in the population.
- Natural selection results in changes in the frequency in a population of an adaptation and the allele(s) that result in the adaptation. Natural selection does *not* cause changes in an individual.
- Evolution by natural selection only occurs if there is variation in a heritable trait which contributes to differences in fitness.
- Which characteristics are adaptations depends on which type of environment the population is in. The same population will evolve differently in different environments.
- If an environmental condition changes, an adaptation that increases fitness in the new environment will become more common in the population. If the change in the environmental condition is reversed, the effects of natural selection will be reversed.
- In biological populations, evolution by natural selection usually occurs slowly over multiple generations.

Concepts from Next Generation Science Standards – Disciplinary Core Ideas³

- LS4.B Natural Selection. "Natural selection occurs only if there is both (1) variation in the genetic information between organisms in the population and (2) variation in the expression of that genetic information – that is, trait variation – that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population."
- LS4.C Adaptation. "Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change."

Several Common Misconceptions⁴

- Individual organisms can evolve during a single lifespan.
- Natural selection involves organisms trying to adapt.
- The "needs" of organisms account for the changes in populations over time (goal-directed or teleological interpretation).
- The fittest organisms in a population are those that are strongest, fastest, and/or largest.
- Evolutionary theory implies that life evolved (and continues to evolve) randomly, or by chance.

³ <http://www.nextgenscience.org/> and <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>

⁴ Most of these misconceptions are excerpted from Misconceptions about evolution, available at http://evolution.berkeley.edu/evolibrary/misconceptions_teacherfaq.php

Recommended Learning Activities

The activities described below will introduce the major concepts and counteract common misconceptions.

- For high school students, I recommend:
 - the hands-on activity [Evolution by Natural Selection](#) *or* two shorter analysis and discussion activities, [What is natural selection?](#) and [Natural Selection and the Peppered Moth](#)
 - [How have mutations and natural selection affected fur color in mice?](#)
- For middle school students, I recommend:
 - pages 1-7 of the hands-on activity [Evolution by Natural Selection](#) *or* the analysis and discussion activity [What is natural selection?](#)

Evolution by Natural Selection

https://serendipstudio.org/sci_edu/waldron/#evolution

In this minds-on, hands-on activity, students develop their understanding of natural selection by analyzing specific examples and carrying out a simulation. The questions in the first section introduce students to the basic process of natural selection, including key concepts and vocabulary. The second section includes a simulation activity, data analysis, and questions to deepen students' understanding of natural selection, including the conditions that are required for natural selection to occur. In the third section, students interpret evidence concerning natural selection in the peppered moth and answer questions to consolidate a scientifically accurate understanding of the process of natural selection, including the role of changes in allele frequency. (Analysis and discussion versions of the first and third sections are available; see first two activities listed below.) (NGSS)

What is natural selection?

<https://serendipstudio.org/exchange/bioactivities/NaturalSelectionIntro>

This minds-on, analysis and discussion activity introduces students to the process of natural selection, including key concepts and vocabulary. In addition, students analyze several examples to learn about the conditions that are needed for natural selection to occur. This activity is an expanded version of the first section of the hands-on activity “Evolution by Natural Selection”. (NGSS)

Natural Selection and the Peppered Moth

<https://serendipstudio.org/exchange/bioactivities/NaturalSelectionMoth>

In this minds-on analysis and discussion activity, students interpret evidence concerning natural selection in the peppered moth and answer questions to consolidate a scientifically accurate understanding of the process of natural selection. The evidence presented includes (1) the results of experiments that evaluated predation by birds on different color forms of the peppered moth in different environments, (2) the genetic basis for the different color forms, and (3) trends in both the environment and the color forms of the peppered moth in industrialized and rural regions in England and the US. This activity is very similar to the last section of the hands-on activity “Evolution by Natural Selection”. (NGSS)

How have mutations and natural selection affected fur color in mice?

<https://serendipstudio.org/exchange/bioactivities/NaturalSelectionMice>

In this analysis and discussion activity, students figure out how mutations and natural selection can result in matches between the fur color of various populations of rock pocket mice and the color of their environments. Next, students view a video that presents relevant research findings,

and students answer the embedded multiple-choice questions. Finally, students answer multiple questions and analyze several scenarios to enhance their understanding of mutations and natural selection. (NGSS)

Additional Recommended Learning Activities

“The Making of the Fittest: Got Lactase? The Co-Evolution of Genes and Culture”

(<http://www.hhmi.org/biointeractive/making-fittest-got-lactase-co-evolution-genes-and-culture>).

This includes a video about natural selection for lactase persistence and student activities, including “Lactase Persistence: Evidence for Selection” and “Lactose Intolerance: Fact or Fiction”. (The video is also available in Spanish.)

"Selection and the Blond Beach Mouse" (<https://www.nsta.org/ncss-case-study/selection-and-blond-beach-mouse>). This case study engages students in understanding the adaptive value of blond fur for deer mice that live in sandy beach areas, as well as the molecular genetic mechanisms that result in blond fur. This PowerPoint presentation incorporates multiple questions for students, including questions related to the distinction between proximate and ultimate causes, a challenge to plan an experiment, and questions to analyze the results of a related published experiment. For a typical high school class, I recommend using Part I and the simplified version of Part II, and omitting Part III.

Each of the following resources propose a more extensive sequence of activities for teaching students about natural selection.

- “How do populations change over time?”
<https://www.colorado.edu/program/inquiryhub/curricula/inquiryhub-biology> – click on “Go to the iHub Biology Course Materials Google Drive”, and then click on “How do populations change over time?”
This series of 29 lessons (~48-50 50-minute periods) analyzes the evolution of antibiotic resistance and divergence between two junco populations. (NGSS)
- “Natural Selection & Evolution of Populations” (<https://www.openscienced.org/instructional-materials/b-4-natural-selection-evolution/>)
This series of 11 lessons will take approximately 23 days. This activity is focused on the question “How does urbanization affect nonhuman populations, and how can we minimize harmful effects?” (NGSS)
- "Making Sense of Natural Selection" (The Science Teacher 80 (6): 43-49, 2013) (NGSS).
For example, to familiarize students with variation in natural populations, you can use "Natural Selection and Variation in Birds"
(http://csip.cornell.edu/Curriculum_Resources/CSIP/Ardia/default.html).
- “Deer Mouse Fur Color: From the Field to the Beach” and “Evolution in Garden Peas”
<https://learn.concord.org/connectedbio>
In each sequence of lessons, students engage in the practices of science using a series of interactive computer simulations to create model(s) of evolutionary change across levels of biological organization, from molecules and cells to organisms and populations. (NGSS)

Student understanding of natural selection can be enhanced by having them apply their understanding to analysis of additional phenomena, as presented in the following activities:

- “Coronavirus Evolution and the Covid-19 Pandemic”
(<https://serendipstudio.org/exchange/bioactivities/coronavirusOrigin>) (NGSS)
- “The Origin of Species: The Beak of the Finch” (<https://www.biointeractive.org/classroom-resources/origin-species-beak-finch>), a 16-minute video with the discussion and analysis activity, “Natural Selection and the Evolution of Darwin’s Finches”

(<https://www.biointeractive.org/classroom-resources/natural-selection-and-evolution-darwins-finches>) and possibly also "Evolution in Action: Graphing and Statistics" (<http://www.hhmi.org/biointeractive/evolution-action-data-analysis>) (The video and first activity can also serve as an introduction to speciation.)

- You may also want to show the video, "Malaria and Sickle Cell Anemia" (<https://www.youtube.com/watch?v=Zsbhv12nVNE>). This video describes the research that led to our understanding of how natural selection resulted in relatively high frequencies of the sickle cell allele in some populations exposed to malaria.
- "Evolution and Adaptations" (<https://serendipstudio.org/exchange/bioactivities/evoadapt>) is an analysis and discussion activity for students who have a basic understanding of natural selection. In common experience, the term "adapting" usually refers to changes during an organism's lifetime. In contrast, evolutionary biologists use the term "adaptation" to refer to a heritable trait that increases fitness. To help students reconcile these different concepts, this activity introduces the concept of phenotypic plasticity (the ability of an organism to adapt to different environments within its lifetime). Questions guide students in analyzing how the balance between the advantages and disadvantages of a characteristic (e.g. an animal's color) can vary in different circumstances, how phenotypic plasticity can be a heritable trait that can optimize fitness in a variable environment, and how natural selection can influence the amount of phenotypic plasticity in a population. (NGSS)

Species, Descent with Modification, and Evidence for Evolution

Concepts

- Reproductive barriers between species allow each species to evolve a distinctive suite of adaptations.
- The evidence for evolution comes from the fossil record, genomics, embryology and comparative anatomy.

Concepts from Next Generation Science Standards – Disciplinary Core Ideas

- LS4.A: Evidence of Common Ancestry and Diversity. "Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence."
- LS4.C: "Changes in the physical environment whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline – and sometimes the extinction – of some species."

Common Misconceptions⁵

- Species are distinct natural entities, with a clear definition. The boundaries between different species can be easily recognized.
- Evolution is not science because it is not observable or testable. Evolution is "just" a theory.

⁵ These misconceptions are excerpted from Misconceptions about evolution, available at http://evolution.berkeley.edu/evolibrary/misconceptions_teacherfaq.php

Recommended Learning Activities

What is a species?

<https://serendipstudio.org/exchange/bioactivities/species>

In this analysis and discussion activity, students evaluate different approaches to defining a species. The goal is to define a group of organisms that is evolving separately from other groups of organisms and thus can evolve their own suite of adaptive characteristics. Students analyze data from various examples to appreciate that the difficulties of defining a species arise from real properties of the process of evolution. (NGSS)

How does evolution result in similarities and differences?

<https://serendipstudio.org/exchange/bioactivities/EvolSimil>

In this hands-on, minds-on activity, students analyze the similarities and differences between bat and squirrel skeletons and between bat and insect wings. Students learn about the two ways that evolution produces similarities: (1) inheritance from a shared evolutionary ancestor (homologous characteristics) and (2) independent evolution of similar characteristics to accomplish the same function (analogous characteristics). In the laboratory investigation, students observe the external anatomy and locomotion of earthworms, mealworms, and crickets. Students use these observations and the concepts they have learned to figure out which two of these animals are more closely related evolutionarily. (NGSS)

How Whales Evolved – Evidence and Scientific Arguments

[https://serendipstudio.org/exchange/bioactivities/whale evolution](https://serendipstudio.org/exchange/bioactivities/whale%20evolution)

Students begin by comparing the characteristics of whales, mammals and fish to decide whether whales should be classified as mammals or fish. To support their conclusion, students make a scientific argument (claim, evidence, reasoning). Students learn about the evolution of whales and other cetaceans by analyzing evidence from comparative anatomy, embryology, fossils, and DNA and proteins. Finally, students make a scientific argument for the claim that whales and other cetaceans evolved from land mammals. (NGSS)

How Eyes Evolved – Analyzing the Evidence

<https://serendipstudio.org/exchange/bioactivities/evoleye>

This analysis and discussion activity focuses on two questions. How could something as complex as the human eye or the octopus eye have evolved by natural selection? How can scientists learn about the evolution of eyes, given that there is very little fossil evidence? To answer these questions, students analyze evidence from comparative anatomy, mathematical modeling, and molecular biology. Students interpret this evidence to develop a likely sequence of intermediate steps in the evolution of complex eyes and to understand how each intermediate step contributed to increased survival and reproduction. The Teacher Notes suggest additions to the Student Handout that can be used to introduce concepts such as the role of gene duplication in evolution and/or homology and analogy. (NGSS)

Additional Recommended Learning Activities

Evolution: DNA and the Unity of Life

<https://teach.genetics.utah.edu/content/evolution/>

An 8-week unit that includes the following five modules. These modules typically contain short videos, questions for students to answer, and development of a scientific argument. Some also contain a hands-on activity.

Shared Biochemistry begins with a video that uses two bioengineering examples to raise the question, “Why can living things decode the information in each other’s genes?” Next, students learn about proteins, DNA and transcription and translation. Then, students compare amino acid sequences for proteins from various organisms to evaluate evolutionary relatedness. “The Trouble with Cognitive Bias” is a brief video that introduces scientific argumentation, after which students evaluate two scientific arguments.

Common Ancestry explores fossil, anatomical, embryological, and molecular evidence to evaluate evolutionary relatedness.

Heredity explores the sources of genetic variation, including mutation and recombination.

Natural Selection analyzes multiple examples of natural selection and adaptation.

Speciation is a module where students learn about different definitions of a species and the difficulties with these definitions. Then, they learn about reproductive barriers that decrease allele mixing, so natural selection and genetic drift can begin the process of speciation. Then, students analyze data about hawthorn and apple flies to consider whether they are becoming separate species.

Evolution (<https://ncse.ngo/origin-species>) is a curriculum unit with 5 sets of approximately 5 lessons each, entitled The Origin of a Species, Good Is Good Enough?, It’s Time to Lose the Ladder, No More Monkeying Around, and The Road to Extinction.

How do small things make a big difference? Microbes, ecology and the tree of life (<https://neuron.illinois.edu/units/how-do-small-things-make-a-big-difference>) is a curriculum unit with six lessons. In the first two lessons, students analyze the types of evidence that scientists have used to create successive models of evolutionary history, as summarized in successive versions of the tree of life. For example, students analyze molecular data to understand the evidence for the three-domain tree of life. Lessons 3-6 are more focused on ecology.

The online activity, “**All in the Family**”

(<https://why.pbslearningmedia.org/resource/tdc02.sci.life.evo.allinthefamily/all-in-the-family/>) provides a challenging and sophisticated introduction to homology, analogy and related evolutionary concepts for high school or college students

“The Origin of Species: Lizards in an Evolutionary Tree”

(<https://www.biointeractive.org/classroom-resources/origin-species-lizards-evolutionary-tree>), an 18 minute video that examines speciation of Anoles on Caribbean islands, with examples of adaptations for different niches and a helpful explanation of reproductive isolation. (This video is also available in a Spanish-language version.)

Recommended General Resources for Teaching about Evolution

Understanding Evolution (<http://evolution.berkeley.edu/>) provides an introduction, teaching materials and resource library. One useful resource for planning your teaching is a compilation of misconceptions about evolution and responses to these misconceptions (http://evolution.berkeley.edu/evolibrary/misconceptions_faq.php). (Another useful compilation of misconceptions and responses is available at <http://www.talkorigins.org/faqs/faq-misconceptions.html>).

Evolution (<http://www.pbs.org/wgbh/evolution/>) provides information about many important aspects of evolution and a variety of resources for teachers and students.

HHMI BioInteractive (<http://www.hhmi.org/biointeractive/evolution-collection>) has multiple additional resources for teaching evolution.

Teaching about Evolution and the Nature of Science

(http://www.nap.edu/download.php?record_id=5787#) is a helpful resource for learning about the types of evidence that support our understanding of evolution, with relevant learning activities.