Good is Good Enough?

Lesson Set 2 of 5

Teacher Prep

Age Levels: 9th-12th grade

Time Commitment: 6–8 days
(if all activities completed)

Key Vocabulary/Concepts:
epoch, fossil, variation, genetic variation, morphology, orthogenetic, paleontologist, phylogenetic tree, mutation, population, species, natural selection, inherit, environment, extinction

Materials:
- Laptops or other computer access
- Internet access
- Sticky notes (in-person) or Google Jamboard (remote)
- 3" x 5" notecards (in-person) or Google Jamboard (remote)
- Student-facing printouts for each lesson
- Calipers
- 3D-printed fossilized horse teeth

Apps and Software:
- Google Jamboard or Google Drawings
- MorphoSource K–12 Horse Evolution
- Sketchfab 3D teeth images with measurements

Introduction

This lesson set explores how variation within a population is a driving factor in natural selection and therefore in evolution. Students investigate how an ecological change, such as climate change, can be a major selection pressure in evolution. Students utilize a genuine scientific practice for investigating how change occurs in a taxon over time, using fossil horse teeth.

Horses have an extraordinary fossil record in North America, with specimens coming from the early Eocene (about 55 million years ago, or Ma) to just the last 10,000 years. Over this span, there were changes in the ecosystem due to changes in the climate. The major dietary strategy in horses changed from browsing, like giraffes, to grazing, like modern horses. Their teeth changed correspondingly to have higher crowns. Therefore, measuring the hypsodonty – the height of the tooth relative to its overall size (anterior-posterior length) – is one way to track the dietary strategy of this lineage.

Teacher Goals

1) Provide structured opportunities for students to ask questions that drive the learning process.
2) Develop students' ability to describe evolution as a branching process with no specific goal, rather than a linear process aimed at a specific goal.
3) Facilitate student use of scientific practices, including analyzing fossils and making claims based on scientific evidence.
4) Guide student discussion so that students attain understanding that populations include naturally occurring variation, upon which natural selection acts.

Evolution Lesson Set Series

https://ncse.ngo/supporting-teachers/classroom-resources

EVOLUTION

Student Learning Goals

1) Generate questions in order to clarify the process of natural selection.
2) Explain how species evolve in response to climate change and the evolution of other species (coevolution).
3) Describe the role of genetic variation in populations on evolution, adaptation, natural selection, and speciation.
4) Differentiate between orthogenetic and phylogenetic evolution and explain the flaws in orthogenesis.
5) Construct a phylogenetic tree based on measured fossil data.

Background

Teacher Knowledge

Nature of Science

We recommend that students work through the NCSE Nature of Science lesson sets at some point during the year. However, if this is not possible, be sure to introduce students to FLICC, a framework for understanding science denial, prior to presenting this lesson set. *Part E: The Characteristics of Science Denial* in Nature of Science Lesson Set 1: Science is a Way of Knowing is especially valuable. It takes students through several examples of FLICC in action while dismantling common misconceptions about the COVID-19 pandemic. Learn more about FLICC.

Scientific Concepts

Evolution explains many aspects of biology and is an indispensable part of a life science curriculum. The scientific community regards evolution as the unifying principle of all biology. The biological unity of life on our planet can be understood by examining anatomical features, genetics, or embryological development; this evidence can be used to identify a common ancestry among different species. Likewise, the diversity among life on our planet can be understood through the lens of evolution. Understanding how natural selection leads to speciation is a part of that story.

This lesson set is meant to help students understand the role that variation has in natural selection while at the same time practicing the skills scientists use to understand extinct species and their relation to modern species. This lesson set asks students to evaluate a current model of this relationship, create a revised model based on new information, and justify their revisions with evidence. If a refresher on evolution is necessary, consider checking out the University of California Museum of Paleontology "Understanding Evolution" resource or Nature Education's primer "Speciation: The Origin of New Species" before introducing this curriculum to your students.

Discussion Points

- How do scientists use fossil evidence to explain evolutionary relationships?
- How do environmental pressures, such as changing climate, impact evolution?
- Can evolution of one species happen in response to evolution of another species?
- What is the role of genetic variation in evolution?
- How do we model evolutionary relationships? What are the flaws in past models?

Prerequisite Student Knowledge

Students should have a basic understanding of natural selection and the relationship between natural selection and evolution. Additionally, students should have a general understanding of the geologic time scale, fossils, and how both are used to organize Earth's history.

FALLACY
FACT

Core Misconceptions

✗ **MISCONCEPTION:** ***Organisms evolve what they need to survive.***

✔ **FACT: Evolution is constrained by the genetic variation in a population, and changes in genetic variation are uninfluenced by an organism's needs.**

✗ **MISCONCEPTION:** ***Evolutionary fitness is physical superiority (bigger, better, faster).***

✔ **FACT: Evolutionary fitness is not about physical superiority but the ability to survive to reproduce.**

✗ **MISCONCEPTION:** ***Natural selection produces organisms with characteristics that are optimal in their environment.***

✔ **FACT: Natural selection works with materials that are available—the genetic variation within the population – derived from the organism's complex evolutionary history.**

Teacher Instructions

Anchoring Phenomenon

Anchor: My Little Pony

- Show students Equus—Story of the Horse Episode 1: Origins (6:25). ***Note:*** *If you use another source for this, it is important to show only from 5:23 to 10:25. Watching more of the video will give away some of the answers to future lessons in the set and compromise the inquiry part of the lesson.*
- Ask students to consider the following questions:
  - *How do you think horses changed from the size of small dogs to their current size?*
  - *Why do you think horses underwent such a dramatic evolutionary change?*
- Show students *Cat vs. Horse Comparison*. Ask students to complete a Notice and Wonder by answering the following questions:
  - *What do you notice?*
  - *What do you wonder?*
- Introduce students to the acronym VISTA: variation, inheritance, selection, time, and adaptation. Tell students that this is a simple acronym that can help them remember the five basic steps that lead to natural selection. Provide them with an example such as the following:
  - Variation: Within any population, a trait may have a natural amount of variation. The length of a giraffe's neck is such a trait. All giraffe necks are long, but some may be slightly shorter and some may be slightly longer.
  - Inheritance: Sometimes a variable trait is able to be passed to offspring (i.e., it can be inherited by the next generation). Giraffes with longer necks tend to have calves with longer necks; giraffes with shorter necks tend to have calves with shorter necks.
  - Selection: Sometimes a heritable variable trait is linked to the evolutionary fitness of the individual. Giraffes with longer necks may be better at browsing for food than giraffes with shorter necks, and if so, they are more likely to survive and have more offspring. Evolutionary biologists say that longer necks in giraffes are "selected for."
  - Time/Adaptation: Over time, repeated selection leads to the development of traits that make individuals better adapted to their environment: these are called adaptive traits or adaptations. Adaptive traits tend to become more common in a population over time. Long necks seem to be adaptations in giraffes.

Driving Question Board

- If you're working in-person or without access to digital media, then create a physical version of the Driving Question Board (that can be displayed prominently in the classroom. Provide students with sticky notes so they can add their questions to the board.
  Note: *The sample Driving Question Board (DQB) can be found in the Teacher Resource Folder. Please make a copy of the template before beginning the activity.*

Anchoring Phenomenon (continued)

Driving Question Board (continued)

- Organize students into pairs. This will allow each student to have someone to help develop their questions. On the class Driving Question Board (DQB), have each student pair type or write one or more open-ended horse evolution questions on separate sticky notes, along with their initials. Open-ended questions require answers beyond yes or no or a single word. If students are struggling to think of open-ended questions, have them consider questions related to VISTA. Sample open-ended questions include:
  - *What variations occur in horse populations?*
  - *How is height inherited in horses?*
  - *What role did the environment play in horse survival?*
  - *How many generations do horses need to undergo natural selection?*
- Read a few of the student-generated questions aloud to the class. Inform the class that you will view all sticky notes later and organize them into groupings. After class ends, arrange similar questions into categories and add subtitles above the sticky notes.
- The DQB is meant to guide instruction and therefore should be referenced periodically, e.g., at the start of a class or when transitioning between activities, to highlight what questions have been answered and where the storyline is headed next. Not all student-generated questions will be answered. At the end of the storyline, teachers may elect to have students do research to address the unanswered questions.

Storyline Activities

Part A: Survival of the Toothiest

- ***Note:*** *This lesson requires teacher preparation prior to beginning. Read through Survival of the Toothiest Teacher Instructions.*
- Begin class by presenting students with either the *Epoch Cards—Extended Descriptions or Epoch Cards—Simplified Descriptions*. These are illustrations that represent the physical landscape of each of the five epochs explored in this lesson. As a class, create a list of observations of the types of flora present in each epoch. Guide students to see the environmental differences between each epoch. Students should fill out their observations in Part A on the *Survival of the Toothiest Student Handout.*
- Organize students into collaborative learning groups and pass out the 3D-printed fossilized horse teeth. Using the *Horse Tooth Data Table* in the student handout, students should determine which model tooth corresponds to each listed fossil, then group the teeth by location found and epoch.
- After organizing the teeth, students should choose one horse tooth from each epoch and sketch it in Part B on the *Survival of the Toothiest Student Handout.*

Storyline Activities (continued)

Part A: Survival of the Toothiest (continued)

- Pass out calipers and demonstrate for students how to measure the height and anterior–posterior length of each tooth for Part C in the *Survival of the Toothiest Student Handout*. Alternatively, show Measuring Horse Teeth (3:37) to demonstrate this process to students. Demonstrate for students how to calculate the hypsodonty index (HI) of each tooth using the following formula:
  - HI = crown height ÷ APL
- Using the grid and directions found in Part D on *Survival of the Toothiest Student Handout*, students should graph the tooth measurements.
- Pass out the *Plant Cards* to each group of students for Part E in the *Survival of the Toothiest Student Handout*. Students should compare and contrast the characteristics of these plants using the data table in their handout. Students should then return to the *Epoch Cards* from the first part of this activity and identify which types of plants were most prominent in each epoch.
- Review the guided analysis questions with the students and ask students to summarize their learning by explaining how the change in horse teeth was a response to plant evolution.
- **Anchor to Activity—Tying it All Together:** Guide the discussion back to what the students had covered in the anchor, *My Little Pony*. Go back to the DBQ and identify any questions that might have been answered in this activity. Ask students to identify new questions they might have at this time, focusing on variation between species.

Part B: Intraspecies Investigations

- Distribute the fossil horse tooth samples, calipers, and the *Intraspecies Investigations Student Handout* to students. From the handout, read the background out loud with the students.
- Students will again measure the crown height and anterior-posterior length for each fossil tooth sample, then calculate the hypsodonty index as they did in the prior activity.
- In addition to the HI for each sample, students will identify the protocone shape and plication complexity. More details can be found in the *Intraspecies Investigations Teacher Instructions*, located in the teacher resources folder above.
- After students have had time to complete their calculations, fill in the data table, and complete the analysis questions, ask them to explain how horse teeth might have been different today if past environmental pressures had been different.
- **Anchor to Activity—Tying it All Together:** Guide the discussion back to what students had covered in the anchor, *My Little Pony*. Go back to the DQB and identify any questions that might have been answered in this activity. Ask students to identify new questions they might have at this time, focusing on variation within a population.
- **Anchor to Activity—Tying it All Together:** Return to the acronym VISTA: variation, inheritance, selection, and time. Remind students that this is a simple acronym that can help them remember the five basic steps that lead to natural selection. Ask students to explain the role of variation in this population of horses within the greater context of natural selection using VISTA.

Storyline Activities (continued)

Part C: Where the Wild Things Aren't

- Ask students to name organisms that are endangered. Once a list has been created, ask students to create a definition of the word "endangered."
- Share the Endangered Species Act definition of endangered: "any species which is in danger of extinction throughout all or a significant portion of its range…" Ask students to compare and contrast with their personal definitions. Ask students to infer why "throughout all or a significant portion of its range" is included in this definition.
- Project the image of a Przewalski's horse and describe to the students that this species had gone extinct in the wild, but today there are 2,000 individuals living in the wild, thanks to conservation efforts. Indicate to students that they will be learning about this horse.
- Pass out *Where the Wild Things Aren't—Prezewalski's Horse Student Handout* with copies of the article "Scientists Clone an Endangered Przewalski's Horse for the First Time, And It's So Cute '' by Michelle Star. Provide students time to read the article, then answer the questions.
- Review the answers to the questions, creating classroom definitions for "bottleneck" and "genetic drift."
- **Anchor to Activity—Tying it All Together:** Guide the discussion back to what students had covered in the anchor, *My Little Pony*. Go back to the DQB and identify any questions that might have been answered in this activity. Ask students to identify new questions they might have at this time, asking students to focus on genetics and genetic variability.
- **Anchor to Activity—Tying it All Together:** Return to the acronym VISTA: variation, inheritance, selection, and time. Remind students that this is a simple acronym that can help them remember the five basic steps that lead to natural selection. Ask students to explain why the lack of genetic variability is problematic for the survival of a species using VISTA.

Part D: Museum Misconceptions

- Pass out copies of *Email from Dr. MacFadden*. Introduce the lesson to students by reading the letter out loud. Ask students to summarize MacFadden's request in their own words.
- Provide students with the *Evolution of the Horse Museum Display Rubric* and explain to students that they will make a display that accurately represents the evolutionary relationship between different extant and extinct species of horses. Pass out the *Horse Species Cards* as well as any other materials students may need—butcher paper, markers, scissors, etc.
- Provide students with enough time to create a phylogenetic tree. As students are working, actively monitor their progress, using probing questions to guide them through the process.
- Pass out the *Close Reading Guide* to students and read the steps out loud. Pass out the MacFadden et al. paper "Fossil Horses, Orthogenesis, and Communicating Evolution in Museums." After students complete the close read, use the following questions to guide discussion:
  - *What were the topic and main points of the paper?*
  - *What facts/details really stand out to you? Why?*
  - *What is the author's point about communicating evolutionary relationships in museums?*
  - *Did the author provide sufficient evidence to support the point?*

Storyline Activities (continued)

Part D: Museum Misconceptions (continued)

- Using their knowledge from "Fossil Horses, Orthogenesis, and Communicating Evolution in Museums," ask students to provide feedback about other students' phylogenetic trees by completing a gallery walk. Pass out sticky notes to each student, enough to leave a note on each model. On the sticky notes, students should offer feedback using both of the following sentence stems:
  - *I notice...*
  - *Next step...*
- Once students have provided feedback to their peers, bring students back to their original groups and provide time for them to revise their models. Allow students to self-assess using the *Evolution of the Horse Museum Display Rubric*.
- Pass out the *Museum Misconceptions Student Handout*. After students have completed the analysis questions, review the answers as a whole class. Then revisit the DQB.
- **Anchor to Activity—Tying it All Together:** Provide students with the opportunity to go back to the original questions they asked. Give time for students to reflect on what their question was, how what they learned related to their question, and what new questions they have. Prompt students to think about how scientists might learn the answers to these questions or how they might go about researching answers to the questions themselves. Students should share their reflections either in small groups or with the whole class.

Time After Deep Time Check-in: Good is Good Enough? Timeline Cards

- Students will sequence the major events that occurred in equine evolution by putting the timeline cards in the order of occurrence they think best reflects equine evolutionary changes. The *Good is Good Enough?* cards are one component of a bigger timeline that ties all the National Center for Science Education evolution lesson sets together.

Extension Activities

Deeper Dive

- How Horses Took Over North America (Twice) (9:07)
- Return to Freedom Presents Wild Horse Nation: Equine Evolution
- The Genetic Bottleneck
- Bottleneck Genes
- Genetic rescue and biodiversity banking (9:14)
- Observing Variation

Online Resources

» Equus – Story of the Horse Episode 1: Origins (6:25)

» Measuring Horse Teeth (3:37)

Primary Literature/Works Cited

Bokor, J., Broo, J., & Mahoney, J. (2016). Using Fossil Teeth to Study the Evolution of Horses in Response to a Changing Climate. *The American Biology Teacher*, 78(2), 166–169.

Harvard Graduate School of Education. (2016). *PZ's Thinking Routines Toolbox*. Project Zero. http://www.pz.harvard.edu/thinking-routines

MacFadden, Bruce J. Fossil Horses—Evidence for Evolution. *Science* 307 (2005): 1728–1729