

# Chewing on Change:

EXPLORING THE EVOLUTION OF HORSES IN RESPONSE TO CLIMATE CHANGE



#### CHEWING ON CHANGE: Exploring the Evolution of Horses in Response to Climate Change

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**ABOUT THE COVER:** Artist's reconstruction of *Sifrhippus sandrae* (right) touching noses with a modern Morgan horse (left) that stands about 5 feet high at the shoulders and weighs approximately 1000 lbs.

Credit Illustration by Danielle Byerley, Florida Museum of Natural History

## Authors' Note

s biology teachers, we are familiar with the quote from Theodosius Dobzhansky: "Nothing in biology makes sense except in the light of evolution." Despite the importance of evolution in biology, many students have difficulty with this topic and come to the classroom with negative perceptions of the theory of evolution. In addition, macroevolution takes place over such long time periods (apart from some bacteria and viruses) that the process can be hard for students to conceptualize and appear as a topic that is not relevant to their lives.

We have also found that students struggle to understand natural selection. It is often taught as a list of rules or steps that students memorize, and therefore, they rarely internalize this important mechanism of evolution. Our hope is that by using a familiar organism, the horse, and engaging in the authentic practices of science including the opportunity to examine fossils, take measurements and make claims based on scientific evidence, students begin to appreciate the elegance and predicative power of evolutionary theory.

The activities in this unit require no prerequisite understanding of evolution or vocabulary associated with evolution. We believe that by focusing on concepts and then presenting the information in a more formal way will result in greater student acceptance and understanding of evolution. We also believe this hands-on inquiry approach to introducing evolution will aide in students' ability to apply what they learn about horse evolution to other areas of biology.

## Introduction and General Teacher Background Information

he earliest known horses evolved 55 million years ago (Ma). Early horses were small dog-sized animals that lived in forests. Throughout their 55 million year history horses have diverged into many species, several of which coexisted, particularly during the Miocene that had the highest diversity of species. Horses are part of the order Perissodactyla (odd-toed ungulates) which also includes tapirs and rhinoceroses. Horses are members of the Equidae family and modern day horses are members of the genus Equus, the only extant genus of the Equidae family. Other living members of the genus Equus include donkeys and zebras. Horse evolution is an excellent example of macroevolution (changes that occur at or above a species level) because so much fossil evidence has been found, including a great number of fossils from North America (MacFadden, 2005).

Fossils provide physical evidence of changes that have occurred in organisms throughout long periods of time. Loose teeth last longer than any other skeletal part and as a result teeth have provided a great deal of information about horse evolution. Each fossil horse tooth has at least 50 different features that can be counted and measured (Sloan –Lab). These measurements provide evidence of the macroevolution of horses.

From 55-20 Ma horses lived in forests, feeding on the soft forest leaves with short-crowned teeth. As the climate became cooler and drier, better-adapted grasses grew more successfully and grasslands began to cover more of the earth, replacing previously lush forests. Grasses have phytoliths (small pieces of silica and minerals) inside their cells, resulting in more tooth wear in grazing animals. In a grassland environment, high-crowned (long) teeth are an adaptation since longer teeth take more time to wear down (Darthmouth & Janis, 2011).

Between 20-15 Ma fossil evidence indicates tooth morphology diversified and the number of shorter-



crowned species that relied on soft leaves declined. During the same time period, other species of horses evolved high-crowned teeth that were better adapted to a grazing diet. Some of these high-crowned species also underwent further adaptation and evolved to eat a diet of both leafy plants and grasses. Around 7 million years ago The molars and premolars of the horse are known as cheek teeth. The cheek teeth slowly erupt to compensate for the constant grinding which wears away 2-3 mm per year. For this reason, horses have very long teeth that are referred to as hypsodont, or "high tooth."

grasslands underwent another change that affected horse evolution. In the last 7 million years tropical and temperate grasslands have shifted from mainly grasses that used the  $C_3$  photosynthesis pathway to modern day grasslands that are composed mainly of grasses that use the  $C_4$  photosynthetic pathway (MacFadden, 2005).

Genetic diversity (which results in phenotypic variation) is the raw material for natural selection. Although paleontologists are usually limited to studying individual organisms, occasionally a dig site will have numerous individuals of the same species. For example, paleontologists at the University of Florida conducted a study of 80 individuals of the genus *Parahippus* found at Thomas Farm. *Parahippus* is the common ancestor at the branching point between Old World and New World horses. Fossilized teeth show variation in tooth structure



Here, two large *Dinohippus* horses can be seen grazing on grass, much like horses today. But unlike modern horses, a three-toed *Hypohippus* tiptoes through the forest, nibbling on leaves. A small, three-toed *Nannippus*, shown here eating shrubs, ate both grass and leaves. *Matt Shanley/AMNH* 

within a species that can be measured and provide particularly useful data for examining variation within a population and learning more about the population ecology of the species (Hulbert, 1984).

Although horses provide an excellent example of macroevolution, there are some misconceptions about horse evolution that need to be addressed with students. Over half of the natural history museums in the United States currently have exhibits that depict horse evolution as an orthogenic process. Orthogenesis is the concept that evolution occurs in a linear pattern with one species turning into another as evolution proceeds. This depiction reinforces the misconception that evolution results in more perfect organisms and is predestined. However, paleontologists have realized for decades horse evolution is more correctly depicted as a complex branching phylogeny (MacFadden, 2012).

#### FOR FURTHER INFORMATION:

American Museum of Natural History: http://www.amnh.org/exhibitions/past-exhibitions/horse

MacFadden, B. J. (2005). EVOLUTION: Fossil Horses— Evidence for Evolution. *Science* 307 (5716): 1728–1730. doi:10.1126/science.1105458. PMID 15774746

MacFadden, Bruce J (2003 digitization of 1999 reprint). Fossil Horses: Systematics, Paleobiology, and Evolution of the Family Equidae. Cambridge & New York: Cambridge University Press. ISBN 0-521-47708-5

Hulbert, Richard C. (1984) Paleoecology and Population Dynamics of the Early Miocene (Hemingfordian) Horse Parahippus Leonensis from the Thomas Farm Site, Florida Journal of Vertebrate Paleontology, Vol. 4, No. 4. (547-558) http://www.jstor.org/stable/4523015

PBS Nature — Horses, http://www.pbs.org/wnet/ nature/episodes/horses/introduction/3153/

## Tips about this Curriculum

#### LESSON PLAN FORMAT

All lessons in this curriculum unit are formatted in the same manner. In each lesson you will find the following components:

#### **KEY QUESTION(S)**

Identifies key questions the lesson will explore.

#### **OVERALL TIME ESTIMATE**

Indicates total amount of time needed for the lesson, including advanced preparation.

#### **LEARNING STYLES**

Visual, auditory, and/or kinesthetic.

#### VOCABULARY

Lists key vocabulary terms used and defined in the lesson. Also collected in master vocabulary list.

#### **LESSON SUMMARY**

Provides a 1-2 sentence summary of what the lesson will cover and how this content will be covered. Also collected in one list.

#### STUDENT LEARNING OBJECTIVES

Focuses on what students will know, feel, or be able to do at the conclusion of the lesson.

#### **STANDARDS**

Specific state benchmarks addressed in the lesson. Also collected in one list.

#### MATERIALS

Items needed to complete the lesson. Number required for different types of grouping formats (Per class, Per group of 3-4 students, Per pair, Per student) is also indicated.

#### **BACKGROUND INFORMATION**

Provides accurate, up-to-date information from reliable sources about the lesson topic.

#### **ADVANCE PREPARATION**

This section explains what needs to be done to get ready for the lesson.

#### **PROCEDURE WITH TIME ESTIMATES**

The procedure details the steps of implementation with suggested time estimates. The times will likely vary depending on the class.

#### **ASSESSMENT SUGGESTIONS**

Formative assessment suggestions have been given. Additionally, there is a brief summative assessment (pre-/post-test) that can be given. Teachers should feel free to create additional formative and summative assessment pieces.

#### **EXTENSIONS**

(ACTIVITIES/LITERATURE) There are many activities and reading sources available to augment and enhance the curriculum. They have been included. If you find additional ones that should be added, please let us know.

#### **RESOURCES/REFERENCES**

This curriculum is based heavily on primary sources. As resources and references have been used in a lesson, their complete citation is included as well as a web link if available. All references and resources are also collected in one list.

#### **STUDENT PAGES**

Worksheets and handouts to be copied and distributed to the students.

#### **TEACHER PAGES**

Versions of the student pages with answers or the activity materials for preparation.

#### **COLLABORATIVE LEARNING**

The lessons in this curriculum have been developed to include many collaborative learning opportunities. Rather than presenting information in lecture format and teacher driven, the activities involve the students in a more engaged manner. For classrooms not accustomed to using collaborative learning strategies, have patience. It can be difficult to communicate instructions, particularly for students who are visual learners. For these students, use of visual clues such as flowcharts and graphics can help them understand how they are to move to different groups.

#### GROUPS

Some of these lessons are carried out in groups. While it is not necessary for students to remain in the same groups the entire unit, if they work well together, it may foster students to think deeper as they are comfortable with their teammates and willing to ask questions of each other.

#### **INQUIRY-BASED**

The lessons in the curriculum invite students to be engaged and ask questions. They work through background information in a guided fashion, but are challenged to think beyond what they have read or done. The teacher serves as the facilitator in these activities, not the deliverer of information.

#### **TECHNOLOGY**

Lessons have been written to be mindful of varying availability of technology in schools and homes.

#### CONTENT

Often we teach in a manner that is very content heavy. With high-stakes testing the norm, students are pushed to memorize and recall numerous isolated facts. There is so much content that must be covered in a biology class, for example, that often it is difficult to synthesize those discrete facts into a compelling context or a story. This unit provides the opportunity to introduce and explore the evolution of horses from both the macro and micro evolutionary levels using 3D printed models and digital images of actual fossil samples from the Florida Museum of Natural History (FLMNH).

#### **IMPLEMENTATION NOTES**

This curriculum should be modified and adapted to suit the needs of the teacher and students. The authors suggest that students have a basic understanding of the geologic time scale. An activity such as "The Geologic Time Scale Lab" (many versions of this activity using rolls of receipt paper are readily available online) would serve this purpose in approximately one additional instruction day.

#### **EXTENSIONS**

Possible/recommended extension activities that can be completed in addition to the written curriculum are included.

#### SCIENCE SUBJECT

Biology

#### **GRADE AND ABILITY**

9-12 grade Standard/Honors/Advanced Placement

## Lesson Summaries

#### **LESSON ONE**

#### EXPLORING THE GEOLOGIC TIME SCALE VIA CHANGES IN FOSSILIZED HORSE TEETH IN RESPONSE TO THE EVOLUTION OF PLANTS

As an opening activity the class is presented with a slide show of illustrations representing the physical landscape of each of the five epochs explored in this lesson. As a class students make observations about the types of flora present in each epoch. Next, in collaborative learning groups, students measure and sketch physical characteristics of fossilized horse teeth from a 3D printed study set provided by the FLMNH. Each group produces a graph that summarizes the trend between age of the fossil and hypsodonty index (HI, essentially the length of the tooth divided by the width). Plant information cards summarizing each epoch are also provided to each group and superimposed on the student graph. Guided analysis questions allow students to develop an explanation for the change in horse teeth in response to plant evolution.

#### **LESSON TWO**

## Examining Intraspecies Variation and Changes in a Single Horse Population

In this lesson students examine images of a collection of horse teeth from the same population. Students take HI measurement data (same procedure as Lesson One) to determine if this collection of teeth represents individuals from the same species. Students use the graphs produced in Lesson One to determine which species this population likely belonged to. Additionally, students determine if there is intraspecies variation in this population, using an embedded horse tooth variation guide in the student page: Examining Intraspecies Variation and Changes in a Single Horse Population. Finally, students make predictions as to what might happen to horse teeth in future generations if plant life drastically differed again on Earth.

#### **LESSON THREE** Proposing Changes to Orthogenesis and Communicating Evolution in Museums

Students are presented a current problem observed in the majority of natural history museums in which orthogenesis is used to display the evolution of horses. The use of orthogenesis, rather than the widely accepted branching phylogenetic tree, often leads to misconceptions about evolution amongst visitors of the general public to such exhibits (MacFadden et al, 2012). Teachers can provide students with a fictional letter from the curator of a natural history museum requesting their help with this problem or have students complete a close read of the paper by MacFadden and colleagues (2012) to explore this issue. Students then use their fossil data graphs from Lesson One in addition to information about ancestral horse species presented on horse cards to complete a poster proposal to summarize how the fossil records clearly show a branching phylogenetic evolution of the horse.

#### VOCABULARY

**EPOCH:** a period of time in history

FOSSIL: Any preserved evidence of life from a past geological age, such as the impressions and remains of organisms embedded in stratified rocks

**GENETIC VARIATION:** variation in alleles of genes, occurs both within and among populations. Genetic variation is important because it provides the genetic material for natural selection.

INTRASPECIES: arising or occurring within a species; involving the members of one species

**INTERSPECIES:** arising or occurring between species

Morphology-the form and structure of an organism

**ORTHOGENETIC:** the hypothesis that life has an innate tendency to evolve in a unilinear fashion due to some internal or external "driving force."

PALEONTOLOGIST: a person who studies forms of life existing in prehistoric or geologic times, as represented by the fossils of plants, animals and other organisms

**PLICATION:** a fold or corrugation

#### **PHYLOGENETIC TREE:**

evolutionary tree, a branching diagram or "tree" showing the inferred evolutionary relationships among various biological species based upon similarities and differences in their physical or genetic characteristics

#### LESSON SEQUENCING GUIDE

Since the classroom teacher knows his or her students best, the teacher should decide the sequencing of lessons. The suggested sequencing guide below is based on 45 minute class periods.

DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
LESSON ONE:	LESSON ONE:	LESSON TWO:	LESSON THREE:	(Optional
Exploring the	Exploring the	Examining	Proposing Changes	Presentations)
Geologic Time	Geologic Time	Intraspecies	to Orthogenesis and	LESSON THREE:
Scale via Changes	Scale via Changes	Variation and	Communicating	Proposing Changes
in Fossilized Horse	in Fossilized Horse	Changes in a Single	Evolution in	to Orthogenesis and
Teeth in Response	Teeth in Response	Horse Population	Museums	Communicating
to Co-evolution of	to Co-evolution of			<b>Evolution in Museums</b>
Plants	Plants			

#### **NEXT GENERATION SUNSHINE STATE STANDARDS – FLORIDA SCIENCE**

BENCHMARK	LESSON 1	LESSON 2	LESSON 3
SC.912.L.15.1 Explain how the scientific theory of evolution is supported by the fossil record, comparative anatomy, comparative embryology, biogeography, molecular biology, and observed evolutionary change.	Х	Х	Х
SC.912.L.15.13 Describe the conditions required for natural selection, including: overproduction of offspring, inherited variation, and the struggle to survive, which result in differential reproductive success.		Х	Х
SC.912.L.15.15 Describe how mutation and genetic recombination increase genetic variation.		х	Х
SC.912.L.15.3 Describe how biological diversity is increased by the origin of new species and how it is decreased by the natural process of extinction.	Х	Х	Х
SC.912.L.15.4 Describe how and why organisms are hierarchically classified and based on evolutionary relationships.	х	х	Х
SC.912.N.1.1 Define a problem based on a specific body of knowledge	Х	Х	×
SC.912.N.1.3 Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking, and the active consideration of alternative scientific explanations to explain the data presented.	Х	Х	Х
SC.912.N.1.6 Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.	х	х	Х
SC.912.N.3.1 Explain that a scientific theory is the culmination of many scientific investigations drawing together all the current evidence concerning a substantial range of phenomena thus, a scientific theory represents the most powerful explanation scientists have to offer.	Х	Х	Х

## ADVANCED PLACEMENT BIOLOGY ESSENTIAL KNOWLEDGE AND SCIENCE PRACTICES

ESSENTIAL KNOWLEDGE & SCIENCE PRACTICES	LESSON 1	LESSON 2	LESSON 3
Essential knowledge 1.A.1: Natural selection is a major mechanism of evolution	х	х	Х
Essential knowledge 1.A.2: Natural selection acts on phenotypic variations in populations.	х	х	х
Essential knowledge 1.A.3: Evolutionary change is also driven by random processes.		х	х
Essential knowledge 1.B.2: Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested.			х
Essential knowledge 1.C.1: Speciation and extinction have occurred throughout the Earth's history			х
Essential knowledge 1.C.3: Populations of organisms continue to evolve.			Х
Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.			X
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.	х	х	Х
Science Practice 5: The student can perform data analysis and evaluation of evidence.	х	х	Х
Science Practice 6: The student can work with scientific explanations and theories.			Х

#### NEXT GENERATION SCIENCE STANDARDS (NGSS)

	LESSON 1	LESSON 2	LESSON 3
HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.	х		х
HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.	х	х	
HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	Х	Х	Х
		1	
Crosscutting Concept 1. Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	Х		
Crosscutting Concept 2. Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.	Х	Х	Х
Crosscutting Concept 6. Structure and function. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.	Х		
Crosscutting Concept 7. Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study	Х	х	х

Notes:	

#### **LESSON 1**

Exploring the Geologic Time Scale via Changes in Fossilized Horse Teeth in Response to Co-evolution of Plants

#### VOCABULARY

**EPOCH:** a period of time in history

**FOSSIL:** any preserved evidence of life from a past geological age, such as the impressions and remains of organisms embedded in stratified rocks

MORPHOLOGY: the form and structure of an organism

**PALEONTOLOGIST:** a person who studies forms of life existing in prehistoric or geologic times, as represented by the fossils of plants, animals and other organisms

#### LESSON SUMMARY

As an opening activity the class is presented with a slide show of illustrations representing the physical landscape of each of the five epochs explored in this lesson. As a class students make observations about the types of flora present in each epoch. Next, in collaborative learning groups students measure and sketch physical characteristics of fossilized horse teeth from a 3D printed study set provided by the FLMNH. Each group produces a graph that summarizes the trend between age of the fossil and hypsodonty index (HI, essentially the length of the tooth divided by the width). Plant information cards summarizing each epoch are also provided to each group and superimposed on the student graph. Guided analysis questions allow students to develop an explanation for the change in horse teeth in response to plant evolution.

#### STUDENT LEARNING OBJECTIVES

- Students will construct an explanation based on evidence from fossilized horse teeth for how natural selection leads to adaptation of populations.
- Students will be able articulate how species evolve in response to climate change and other species (coevolution).

#### MATERIALS

- · 3D printed fossil horse teeth study set (1 set of 15 teeth per student group)
- Calipers (1 per student group)
- · Colored pencils or crayons (green, orange, and yellow)
- Soft leaf and rough grass samples for grinding
- · Mortar and pestle (either one for demonstration or one per group)
- Epoch Plant Cards
- Student Page: Exploring Changes in Horse Teeth Lab Procedure

#### **KEY QUESTION(S):**

What can fossilized horse teeth and changes in plant species tell us about the evolution of horses during the Cenozoic Era?

#### **OVERALL TIME ESTIMATE:**

Two 45 minute class periods

#### **LEARNING STYLES:**

Visual, Kinesthetic, Auditory, Cooperative



#### **BACKGROUND INFORMATION**

The rationale behind this lesson was to provide the students with a genuine scientific method for investigating how change occurs in a taxon over time. Hypsodonty is simply a scientific term for the height of a tooth relative to its overall size. Hypsodonty indices (HIs) are often used by scientists who study mammals as a proxy for this tooth height. One could imagine that simply measuring the crown height of a large animal, such as a mammoth, would provide a much larger crown height as compared to any horse. However, horse teeth are significantly smaller, but some horses have longer teeth relative to their size. Therefore, measuring hypsodonty, by dividing crown height by anterior-posterior length, allows for control on the size of a tooth to obtain a more accurate representation of tooth length. (Stromberg [2005] provides an excellent overall of the use of hypsodonty in paleontology)

Horses are used in this curriculum for several important reasons. First of all, they are easily recognizable to the general public and not an animal only known from fossils. Importantly, fossil horses have an extraordinary fossil record in North America with fossil specimens coming from the early Eocene (~55 Ma) to just 10,000 years ago. Lastly, the major change in dietary strategy in horses from browsing (like the feeding style of a giraffe) to grazing (like horses today) is strongly correlated with climate change — and therefore ecological change — and seen evolutionarily in the higher-crowned teeth of more recent horses.

#### **ADVANCE PREPARATION**

· 3D print Fossil Horse Teeth Study Set

(Implementation note: The 3D printing files for the fossil horse teeth are located at MorphoSource.org. Our friends at Paleoteach have created a tutorial for using the MorphoSource database and downloading the files for printing. You can access the tutorial here: http://www.paleoteach.org/specimens/fossil-horses/database-inquiry/ You may need to convert these files into a different format, depending on the 3D printer. MeshLab is opensource software that can convert the files into the STL format, which is what our printers at the University of Florida require. 3D printing needs to be planned well in advance of implementation, as depending on the speed of the printer, the number of sets you are printing, and the potential backlog of the 3D printer, it may take several days for your 3D models to be ready.)

- Read Background Information
- · Print Epoch Cards in color (consider laminating for future use) (1 set per group)
- Print Student Page: Exploring Changes in Horse Teeth Lab Procedure and Data Sheet (1 copy per group)
- Watch video discussing how to use the calipers and take crown length and APL measurements (https://youtu.be/SWr2jMu322g)
- Prepare images of epoch landscapes for projection (http://prod.cpet.ufl.edu/wp-content/uploads/2014/12/ Epochs-slideshow.pptx)
- Examine teeth from study set and practice taking crown length and APL measurements to demonstrate to students
- Locate samples of  $C_3$  and  $C_4$  plants for use during Day Two, Part IV or identify samples on campus for students to discover as browsers and grazers.

#### PROCEDURE AND DISCUSSION QUESTIONS WITH TIME ESTIMATES

#### **DAY ONE**

- 1. **1-3 MINUTES** Distribute the 3D printed study sets, calipers and Student Page: Exploring Changes in Horse Teeth Lab Procedure and Data Sheet to each group (2-3 students are suggested for groups for the duration of this curriculum module)
- 2. **5-7 MINUTES** Project paintings with artists' renderings of each of the major epochs on the screen and ask students to make and record observations in Pre-Lab section of the Exploring Changes in Horse Teeth Lab Procedure and Data Sheet

(Implementation note: Do this as a whole class discussion and guide students to see the environmental differences, particularly drawing their attention to the moist, warm environment and flora present in each. As a wrap up for this lesson, return to these pictures and discuss how horses evolved in response to the environment, introducing additional adaptations students are likely familiar with such as a longer neck better adapted for grazing and change to standing on one toe that allows for an elongated leg that is better adapted for running in the hard ground of grasslands to escape predators.)

- 3. **8-10 MINUTES** Draw students' attention to the Horse Tooth Variation Guide embedded in Part II of the and Student Page: Exploring Changes in Horse Teeth Lab Procedure and Data Sheet. Show the How to measure horse teeth video. Demonstrate how to make the measurements and check for correct APL alignment using the modern horse head with embedded teeth in jaw, as necessary and if available.
- 4. 25 MINUTES Circulate as students record data and make variation observations of the study set specimens (Parts I & II)

#### **DAY TWO**

- 1. **1-3 MINUTES** Redistribute study sets and other materials as necessary to students.
- 2. **2 MINUTES** Instruct students to create a scatter plot style graph of the data they collected the previous day, on the provided graph paper in Part III of the and Student Page: Exploring Changes in Horse Teeth Lab Procedure and Data Sheet. (Implementation note: two versions of the graph paper have been provided, depending on the level of the students and the teacher's learning goals.)
- 3. **15-20 MINUTES** Circulate as students create graphs in Part III and also quietly pass out the Epoch Cards that will be required for Part IV-one set to each group.
- 4. **20 MINUTES** Instruct students to use the Epoch Cards, physically ground samples of a of a  $C_3$  and  $C_4$  plant and the information embedded in the Student Page: Exploring Changes in Horse Teeth Lab Procedure and Data Sheet to complete Part IV. Circulate and support student exploration as necessary.

(Implementation note: student groups can be provided plant samples to grind and observe differences at the group level, as a whole-class demonstration, or as a station that student groups visit. Teachers can also consider having students be browsers and grazers and explore the schoolyard for their own representative samples.)

#### **ASSESSMENT SUGGESTIONS**

· Collect Data Sheet (embedded in the Student Lab Procedure) from lab groups

#### **EXTENSIONS**

Exploring the relationship between changes in  $CO_2$  levels in the environment and the evolution of  $C_4$  plants (IN DEVELOPMENT)

#### **RESOURCES/REFERENCES**

MacFadden, Bruce J. "Fossil Horses-Evidence for Evolution." Science 307 (2005): 1728-1729.

- MacFadden, Bruce J. "Fossil Horses from "Eohippus" (Hyracotherium) to Equus, 2: Rates of Dental Evolution Revisited." Biological Journal of the Linnean Society 35.1 (1988): 37-48.
- Presentation by Dr. Bruce MacFadden: Fossil Horses: Icons of Evolution Exhibits https://vimeo.com/120397381 (The video quality is not great, but Dr. MacFadden provides an excellent overview of the topic that inspired this curriculum.)
- Stromberg, Caroline A. E. "Evolution of hypsodonty in equids: testing a hypothesis of adaptation." *Paleobiology* 32.2 (2005): 236-258.

#### HORSE TOOTH DATA TABLE (3D PRINTED SPECIMENS)

Epoch	Age (Ma)	Location	Species	Catalog Number	Crown Height (mm)	APL (mm)	HI (height/ APL)
	55	Wyoming	Sifrhippus sandrae	UF 252687	2.9 mm	6.1 mm	0.48
	33	Nebraska	Mesohippus bairdi	UF 137889	9.2 mm	13.8 mm	0.67
	18	Thomas Farms,	Anchitherium clarencei	UF 221401	12.6 mm	19.9 mm	0.63
		Gilchrist County, Florida	Parahippus leonensis	UF/FGS 6597	15.9 mm	16.7 mm	0.95
			Archaeohippus blackbergi	UF/FGS 11166	7.7 mm	10.1 mm	0.76
			Parahippus barbouri	UF 270648	14.6 mm	16.1 mm	0.91
	9	Love Site, Alachua County, Florida	Calippus elachistus	UF 53577	35.0 mm	13.9 mm	2.52
			Calippus cerasinus	UF 60323	36.2 mm	17.2 mm	2.11
			Neohipparion trampasense	UF 62299	48.2 mm	21.4 mm	2.25
	5	Bone Valley,	Dinohippus mexicanus	UF 124196	60.7 mm	24.2 mm	2.51
		Polk County, Florida	Neohipparion eurystyle	UF 208601	61.7 mm	23.6 mm	2.61
			Nannipus aztecus	UF 302417	37.7 mm	14.3 mm	2.64
	2	2 Santa Fe River Bed, Columbia County, Florida	Nannipus peninsulatus	UF 22614	49.9 mm	18.3 mm	2.73
		Haile Site 15A, Alachua County, Florida	Equus (plesippus) simplicidens	UF/TRO 32072	76.1 mm	29.3 mm	2.60
	0.1	Waccasassa River Site 9, Levy County, Florida	Equus ferus	UF/TRO 2149	79.9 mm	28.0 mm	2.85

#### EPOCH CARDS EOCENE FLORA (55.8-33.9 MA)

At the beginning of the Eocene, the high temperatures and warm oceans created a moist, balmy environment, with forests spreading throughout the Earth from pole to pole. Apart from the driest deserts, scientists hypothesize the Earth was entirely covered in forests. Polar forests were quite extensive. Fossils and preserved remains of trees such as swamp cypress and dawn redwood from the Eocene have been found in the Arctic. Fossils of subtropical and even tropical trees and plants from the Eocene have also been found in Greenland and Alaska. Tropical rainforests grew as far north as northern North America and Europe. Palm trees were growing as far north as Alaska and northern Europe during the early Eocene, although they became less abundant as the climate cooled.

Cooling began mid-epoch, and by the end of the Eocene continental interiors had begun to dry out, with forests thinning considerably in some areas. The newly evolved grasses were still confined to river banks and lake shores, and had not yet expanded into plains and savannahs. The cooling also brought seasonal changes. Deciduous trees, better able to cope with large temperature changes, began to overtake evergreen tropical species. By the end of the epoch, deciduous forests covered large parts of the northern continents, including North America, Eurasia and the Arctic, and rainforests only remained in equatorial South America, Africa, India and Australia. Antarctica, which began the Eocene fringed with a warm temperate to sub-tropical rainforest, became much colder as the epoch progressed; the heat-loving tropical flora was wiped out, and by the beginning of the Oligocene, the continent hosted deciduous forests and vast stretches of tundra.



http://ichef.bbci.co.uk/naturelibrary/images/ic/credit/640x395/e/eo/eocene/eocene\_1.jpg

#### OLIGOCENE FLORA (33.9 - 23 MA)

Angiosperms continued their expansion throughout the world as temperate deciduous forests replaced tropical and sub-tropical forests. Grasslands began to expand and forests (especially tropical ones) began to shrink. Grasses, a product of the cooler, drier climate, became one of the most important groups of organisms on the planet. As they spread extensively over several million years, they fed herds of grazing mammals, sheltered smaller animals and birds, and stabilized soil, which in turn reduced erosion. They are high-fiber, low-protein plants and must be eaten in large quantities to provide adequate nutrition. Because they contain tiny silica fragments, though, they are tough to chew and wear down animal teeth. Grasses, which grow throughout the blade, are adapted to recover quickly after their tips are grazed. However, even at the end of the epoch, grass was not as common as one would observe in a modern savannah today.



http://palaeos.com/cenozoic/oligocene/images/mesohippus.jpg

#### **MIOCENE FLORA (23-5.3 MA)**

Plant studies of the Miocene have focused primarily on spores and pollen. Such studies show that by the end of the Miocene 95% of modern seed plant families existed. A mid-Miocene warming, followed by a cooling is considered responsible for the retreat of tropical ecosystems, the expansion of northern coniferous forests, and increased seasonality. Prior to this time all plants were classified as  $C_3$  because the  $CO_2$  is first incorporated into a 3-carbon compound. In  $C_3$  the enzyme rubisco is involved in the uptake of  $CO_2$ . While  $C_3$  plants function very well in cool, moist conditions as the temperature warmed, a new photosynthetic pathway evolved. This new pathway was called  $C_4$  because the  $CO_2$  is first incorporated into a 4-carbon compound.  $C_4$  plants photosynthesize faster than  $C_3$  plants under high light intensity and high temperatures.

Although the  $C_4$  pathway is more complicated (requires more enzymes and specialized plant anatomy),  $C_4$  plants do not need to keep stomata open as much and lose less water to transpiration (evaporation of water through stomata). The  $C_4$  pathway also causes the uptake of more silica (a glass-like material) that resulted in the diversification of modern grasses and sedges. The evolution of gritty, fibrous, fire-tolerant grasses led to a major expansion of grass-grazer ecosystems, with roaming herds of large, swift grazers pursued by predators across broad sweeps of open grasslands, displacing desert, woodland, and browsers.



Rhinoceros, camels, and horses of the Miocene era. This is the original painting for the mural in the recently restored Hall of Prehistoric Mammals in the Lila Acheson Wing of the American Museum of Natural History in New York City.

#### PLIOCENE FLORA (5.3 – 2.6 MA)

The change to a cooler, dry, seasonal climate had considerable impacts on Pliocene vegetation, reducing tropical species worldwide. Deciduous forests proliferated, coniferous forests and tundra covered much of the north, and grasslands spread on all continents (except Antarctica). Tropical forests were limited to a tight band around the equator, and in addition to dry savannahs, deserts appeared in Asia and Africa. In the higher latitudes, cool-weather plants evolve. Hardy plants that can tolerate a short growing season, such as sedges, mosses, and lichens, inhabit the almost permanently frozen tundra. In slightly warmer regions, taiga forests consist mostly of evergreens. In lower latitudes, grasslands are marked by fewer and fewer trees. These habitats offer limited food sources for animals and support less diversity.



http://imnh.isu.edu/digitalatlas/geog/parks/hagerman/images/muralsm.jpg

#### PLEISTOCENE FLORA (2.6 - 0.01 MA)

During the Pleistocene, glaciers repeatedly advance from the Arctic north over Europe and North America, then retreat. The first major glacial flow occurs about 1.6 Ma. Ice, up to a mile thick in places, spreads from Greenland over the Arctic Sea into northern Europe and Canada. As the ice advances, temperatures ahead of the flow drop significantly.

The temperature change has a profound impact on life. Mammoths, rhinos, bison, reindeer, and musk oxen all evolve to have warm, woolly coats to protect them from frigid conditions. These new mammals feed on the small bushes and hardy grasses that tolerate cold as they follow the moving line of glaciers. Glacial retreats allow for the temporary return of warm-weather plants such as oak and beech trees, lush grasses, and flowers. During these "interglacial" periods, species that sought shelter in the warmer south return to their old habitats.



http://en.wikipedia.org/wiki/Pleistocene

## Exploring Changes in Horse Teeth — Lab Procedure and Data Sheet

#### **INTRODUCTION**

Horses are beloved creatures, and paleontologists have compiled one of the most extensive fossil records of any animal that has existed in North America. In this lab you will examine 3D printed models of fossil horse teeth from the Florida Museum of Natural History vertebrate paleontology collection housed at the University of Florida to determine what patterns of change have occurred in horses.

#### PRE-LAB

Observe five paintings from different epochs (periods in time) as they are projected. For each image, write down three observations in the space below. Since plants are the basis of an ecosystem, at least one of your observations must deal with the vegetation.

Painting 1 - Eocene Epoch (55.8-33.9 Ma)

Painting 2 - Oligocene Epoch (33.9-23 Ma)

Painting 3 - Miocene Epoch (23-5.3 Ma)

Painting 4 - Pliocene Epoch (5.3 - 2.6 Ma)

Painting 5 - Pleistocene Epoch (2.6 - 0.017 Ma)

#### PROCEDURE

#### PART I

- 1) Use the horse data table to familiarize yourself with the 3D models and determine which model tooth corresponds to each listed fossil.
- 2) Choose ONE horse tooth from each epoch and sketch it in the space provided below. (NOTE: you have multiple specimens from each epoch in the provided study set. Just choose one and make a quick representative sketch to indicate relative size and complexity.)

#### REPRESENTATIVE HORSE TEETH SKETCHES FROM EACH EPOCH



#### **PART II**

1) Using the calipers measure the height of each tooth. Measure from the bottom of the crown (NOTE: This does NOT include the root of the tooth) to the highest point on top surface (See diagram A). Next, measure the anterior-posterior length (APL) of each tooth. This is the length from the part of the tooth closest to the horse's muzzle to the part of the tooth closest to the back of the horse's jaw. (See diagram B and a modern horse head with teeth embedded in the jaw for clarification, if necessary). Record the measurements on the data sheet provided below.



Figure from MacFadden (1988) Fossil horses from "Eohippus" (Hyracotherium) to Equus, 2: rates of dental evolution revisited

- 2) Calculate the hyposodonty index (HI) of each tooth using the following formula: HI = crown height/APL. Record the HI values on the data table.
- 3) Complete the epoch column: \*Ma = millions of years ago Current epoch: Holocene Pleistocene epoch: 2.588Ma-0.0117Ma (2.5my) Pliocene epoch: 5.332-2.588Ma (2.7my) Miocene epoch: 23.03-5.332Ma (2.7my) Oligocene epoch: 33.9-23.03Ma (10my) Eocene epoch: 55.8-33.9Ma (22my)

#### HORSE TOOTH DATA TABLE (3D PRINTED SPECIMENS)

Epoch	Age (Ma)	Location	Species	Catalog Number	Crown Height (mm)	APL (mm)	HI (height/ APL)
	55	Wyoming	Sifrhippus sandrae	UF 252687			
	33	Nebraska	Mesohippus bairdi	UF 137889			
	18	Thomas Farms,	Anchitherium clarencei	UF 221401			
		Gilchrist County, Florida	Parahippus leonensis	UF/FGS 6597			
			Archaeohippus blackbergi	UF/FGS 11166			
			Parahippus barbouri	UF 270648			
	9	Love Site,	Calippus elachistus	UF 53577			
		Alachua County, Florida	Calippus cerasinus	UF 60323			
			Neohipparion trampasense	UF 62299			
	5	Bone Valley, Polk County, Florida	Dinohippus mexicanus	UF 124196			
			Neohipparion eurystyle	UF 208601			
			Nannipus aztecus	UF 302417			
	2	Santa Fe River Bed, Columbia County, Florida	Nannipus peninsulatus	UF 22614			
		Haile Site 15A, Alachua County, Florida	Equus (plesippus) simplicidens	UF/TRO 32072			
	0.1	Waccasassa River Site 9, Levy County, Florida	Equus ferus	UF/TRO 2149			

#### PART III:

- 1) Graph the tooth measurements using the grid below. Time is the independent variable (x-axis) and the tooth hypsodonty index (HI) is the dependent variable (y-axis).
- 2) Add the names of the 5 Epochs below the corresponding year ranges: Eocene, Oligocene, Miocene, Pliocene and Pleistocene to the graph of Time vs. HI



#### STUDENT PAGE

#### PART III:

- 1) Graph the tooth measurements using the grid below. Time is the independent variable (x-axis) and the tooth hypsodonty index (HI) is the dependent variable (y-axis).
- 2) Add the names of the 5 Epochs below the corresponding year ranges: Eocene, Oligocene, Miocene, Pliocene and Pleistocene to the graph of Time vs. HI



#### PART IV: CHANGES IN HORSE TEETH IN RELATIONSHIP TO CHANGES IN PLANTS

Complete the following using the provided Epoch Cards:

- 1) Using the criteria listed below shade/color directly onto the graph from Part III the primary type of plant life present in each epoch. (Note: color the entire space on the graph above the epoch name, not just the epoch name).
  - If the plant life during the epoch could be categorized as:
    - Mainly forests: Green
    - · Forests and grasslands (not savannas): Orange
    - Primarily grasslands and savannas: Yellow
- 2) Observe the sample plants provided. What are the primary differences between forest leaves and grasses? From the fossil study set, which kind of teeth would be more effective for eating grasses?

3) According to the plant cards,  $C_4$  plants became more prevalent during the Miocene epoch. Use the following figures of phytoliths in conjunction with the epoch cards and samples of  $C_3$  and  $C_4$  extant plants, to complete the chart below to compare the characteristics of  $C_3$  and  $C_4$  plants.

C <sub>3</sub> Plant Characteristics	C <sub>4</sub> Plant Characteristics

#### C3 & C4 GRASS PHYTOLITHS

from: http://www.bio.uu.nl/~palaeo/research/namibia/namibia.htm



Oxytenanthera abyssinica (C3 grass, South African Savanna)



Ischaenum afrum (C4 grass, South African Savanna & Grassland)

Figure NOTE: Phytoliths are rigid, microscopic structures of varying sizes and shapes found in plants, typically containing silica and other minerals.

4) Using the graph developed in Part III above and the plant information cards, propose the relationship between plant evolution and horse evolution.

5) In this exercise you saw that the Earth's climate changes over time. If Earth's climate was to change again and tropical forests covered the majority of the land, how would you expect the morphology of horse teeth to change? (Assume horses have enough genetic diversity present for tooth modifications.... that's a big assumption to make!)

6) What might happen to modern horses if the climate changed and tropical forests covered the majority of the earth and there was no diversity present in the genes for tooth modification?

Notes:	

### LESSON 2 Examining Intraspecies Variation and Changes in a Single Horse Population

#### VOCABULARY

**GENETIC VARIATION:** variation in alleles of genes, occurs both within and among populations. Genetic variation is important because it provides the genetic material for natural selection.

**INTRASPECIES:** arising or occurring within a species; involving the members of one species

**INTERSPECIES:** arising or occurring between species

**PLICATION:** a fold or corrugation

#### LESSON SUMMARY

In this lesson students examine images of a collection of horse teeth from the same population. Students take HI measurement data (same procedure as Lesson One) to determine if this collection of teeth represents individuals from the same species. Students use the graphs produced in Lesson One to determine which species this population likely belonged to. Additionally, students determine if there is intraspecies variation in this population, using an embedded horse tooth variation guide in the student page: Examining Intraspecies Variation and Changes in a Single Horse Population. Finally, students make predictions as to what might happen to horse teeth in future generations if plant life drastically differed again on Earth.

#### STUDENT LEARNING OBJECTIVES

- Students will be able to differentiate between interspecies and intraspecies variation.
- Students will be able to identify the impact of gene variation in populations on evolution, adaptation, natural selection and speciation.

#### MATERIALS

- · Fossil horse teeth from a single population image page (1 per group)
- · Calipers (1 per group)
- Student Page: Examining Intraspecies Variation and Changes in a Single Horse Population (1 per group)

#### **KEY QUESTION(S):**

What factors cause intraspecies variation? Why is intraspecies variation important for the survival of that species?

#### **OVERALL TIME ESTIMATE:**

One 45 minute class period

#### **LEARNING STYLES:**

Visual, Kinesthetic, Auditory, Cooperative



#### **TEACHER NOTE**

After the students take measurements on the image set, the authors suggest that this would also be a good time for students to have direct instruction on natural selection. The major ideas are as follows:

- 1) Populations produce more offspring than can survive. Individuals in the population are NOT identical (as shown by the variation in horse teeth) due to environmental and genetic factors. The genetic factors are heritable.
- 2) Individuals with advantageous traits (which are coded for by genes) are more likely to survive and reproduce more offspring than other individuals. As a result the genes that code for the advantageous trait (such as tooth length) increase in frequency in the gene pool.
- 3) Over time the population may evolve to the point that every member has the advantageous trait. (Note: Individuals are selected but only populations evolve.)
- 4) Natural selection adapts a population to an environment. If the environment changes, different traits may become more advantageous and the population may evolve again in a different direction.

#### **BACKGROUND INFORMATION**

The thinking behind this lesson was to take a deeper look at the more micro-scale side of evolution and the processes that contribute to natural selection. More specifically we wanted the students to understand why variation within a species is so crucial to the evolution of that species. After looking at the evolution of horses from a 55 million year span, we though it necessary that the students attain a deeper understanding of the process of natural selection to supplement the learning from their Lesson 1 activities of macro-scale evolution.

Over 50 different morphological characters (specific aspects in the shape) can exist within a single horse tooth (Stirton, 1941 gives a great example of these characters). Several of these were looked at during the Lesson 1, such as crown height, anterior-posterior length, and hypsodonty. These three characters all require measuring certain portions of the tooth. In Lesson 2 we introduce two new character states, an isolated or connected protocone and simple or complex plications. The traits that different from the three in Lesson 1 in that they do not require measurement and can be observed just by looking at the tooth. Additionally, instead of investigating fifteen teeth from fifteen species, we give the students images of six teeth from one species (though they hypothesize as to whether the teeth come from one species or several species). Therefore, the students can observe how variable a single species can be and postulate as to why that is beneficial from an evolutionary standpoint. One last thing that should be pointed out is that the crown height of a tooth is a character that can vary depending on the age of the individual when it died, or in other words how much wear the given tooth has. The crown heights and HIs of the teeth in Lesson 2 are much smaller than those of the *Parahippus leonensis* tooth in Lesson 1. We needed to choose worn teeth for Lesson 2, otherwise the important features (protocone and plications) would not have been identifiable. However, the students should focus on comparing the APLs as that is not a feature that is dependent on the age of the organism.

#### **ADVANCE PREPARATION**

- Read Background Information
- · Print copies of the Fossil horse teeth from a single population image page (1 per group)
- Familiarize yourself with the images in the study set and the embedded Horse Tooth Variation Guide in the Student Page: Examining Intraspecies Variation and Changes in a Single Horse Population
- Print copies of Student Page: Examining Intraspecies Variation and Changes in a Single Horse Population One per group
# PROCEDURE AND DISCUSSION QUESTIONS WITH TIME ESTIMATES

- 1. **1-3 MINUTES** Distribute the fossil study set image page, calipers, and Student Page: Examining Intraspecies Variation and Changes in a Single Horse Population to each group.
- 2. **1-2 MINUTES** Draw students' attention to the Horse Tooth Variation Guide embedded in page two of the student page. Briefly explain the protocone and plication observations they should try to make.
- 3. **30 MINUTES** Circulate as students record data and make variation observations of the study set images (Parts I & II)
- 4. **10 MINUTES** The authors envision two options at this point in the lesson:
  - a. Give students direct instruction on Natural Selection (see teacher's note above) and assign the conclusion questions for homework
  - b. Lead students in a whole group discussion of the conclusion questions

# ASSESSMENT SUGGESTIONS

Collect Student Page: Exploring Intraspecies Variation and Changes in a Single Horse Population

# **EXTENSIONS**

• Implications of Climate Change on Modern Domesticated Horse (IN DEVELOPMENT)

# **RESOURCES/REFERENCES**

MacFadden, Bruce J. "Fossil Horses-Evidence for Evolution." Science 307 (2005): 1728-1729.

Stirton, R.A. "Development of Characters in Horse Teeth and the Dental Nomenclature." *Journal of Mammalogy* 22.4 (1941): 434-446.

### LESSON 2: ANSWER KEY

Unknown	Cro	own Height (m	ım)	Anterior	Posterior Len	HI (actual crown	
Fossil #	measured conversion actual factor		measured	conversion factor	actual	height/actual APL)	
1	23.1	x 0.42	9.7 mm	35.7	x 0.42	15.0 mm	0.65
2	25.2	x 0.42	10.6 mm	38.6	x 0.42	16.2 mm	0.65
3	17.1	x 0.42	7.2 mm	35.5	x 0.42	14.9 mm	0.48
4	25.5	x 0.42	10.7 mm	39.0	x 0.42	16.4 mm	0.65
5	22.6	x 0.42	9.5 mm	38.3	x 0.42	16.1 mm	0.59
6	28.1	x 0.42	11.8 mm	35.2	x 0.42	14.8 mm	0.80
						Average	

### PART I. HI

(Measured crown height, measured APL, and the conversion factors may vary depending on printer settings. Actual crown height, actual APL, and HI should be about the same.)

Answers will vary depending on the teeth selected by the students.

# PART II. HORSE TOOTH VARIATION

Fossil	1	2	3	4	5	6
Protocone	Connected	Connected/ Intermediate	Connected	Isolated	Isolated Isolated	
Plications	Simple	Complex	Simple	Complex/ Intermediate	Complex	Complex/ Intermediate



#1





#2









#4





# Exploring Intraspecies Variation and Changes in a Single Horse Population

# PART I

Six teeth were found at the same dig site and paleontologists need to decide if they belong to the same species or different species. Take crown height and anterior posterior length (APL) measurements of the teeth to calculate the HI index. (HI = height/APL). Notice that the length of the ruler in the photos is larger than it is in reality. This means that we need to determine the conversion factor for crown height and APL to calculate the actual length of the teeth. With your caliper measure the length of the 10 mm scale on the ruler. Divide the 10 mm scale by the length shown on your caliper. For example if your caliper says the length of the 10 mm scale bar is actually 25 mm, divide 10 mm/25 mm. This number can then be multiplied to all of your crown height and APL measurements to get the real life measurements.

Unknown	Crown Height (mm)			Anterior	Posterior Len	HI (actual crown	
FOSSII #	measured	conversion factor	actual	measured	conversion factor	actual	height/actual APL)
1		x			x		
2		x			x		
3		x			x		
4		x			x		
5		x			x		
6		x			x		
Average							

1. Based on your measurements, determine if these fossils are from the same species or different species? Justify your answer.

2. Calculate the average HI index of all 6 teeth. Record in the data chart above.

3. Using the data you collected in Lesson One identify what species the teeth came from. Explain how you arrived at your conclusion.

### **PART II**

 Examine the image that shows the top surface of the fossils. Draw what you see in the boxes below. Use the Horse Tooth Variation Guide below to assist you in identifying structures commonly used by vertebrate paleontologists. For each tooth write whether the protocone is connected, isolated, or somewhere in between and whether the plications are complex, simple, or intermediate.

# HORSE TOOTH VARIATION GUIDE

Use the two examples on the diagram below to identify variation in fossilized horse teeth samples.

- 1. Protocone Shape: Isolated or Connected
- 2. Complexity of Plicaiton: Simple or Complex



Image adapted from The Pony Express Florida Fossil Horse Newsletter, Volume 1, Number 3, 3rd Quarter—September 1992 https://www.flmnh.ufl.edu/ponyexpress/pony1\_3/Pe13.htm

Protocone is	Protocone is	Protocone is
Plications are	Plications are	Plications are
Fossil #	Fossil #	Fossil #
Protocone is Plications are	Protocone is Plications are	Protocone is Plications are
Fossil #	Fossil #	Fossil #

### STUDENT PAGE

- 2. Are all of the fossils exactly the same?
- 3. Describe some of the variation you observed.
- 4. What could be responsible for the variation in the teeth? List at least two factors. Which factors could be heritable?
- 5. Why would variation within a species be beneficial to long-term survival of the species?

### **CONCLUSION QUESTIONS**

1. If grasslands were becoming more prevalent which individual would have been able to live longer? Consider only food intake and ignore other survival factors such as predation. Explain.

2. In this changing environment with more grasses, which individual would have been more likely to produce more offspring throughout their lifetime? Which individual would have likely produced the fewest number of offspring? Explain your answers.

3. What might happen to the tooth morphology (shape) in future generations? Assuming tooth morphology is a trait coded for by genes, how would the composition of the gene pool change in future generations?

# LESSON 3 Proposing Changes to Orthogenesis and Communicating Evolution in Museums

# VOCABULARY

**ORTHOGENETIC:** the hypothesis that life has an innate tendency to evolve in a unilinear fashion due to some internal or external "driving force."

**PHYLOGENETIC TREE:** evolutionary tree; a branching diagram or "tree" showing the inferred evolutionary relationships among various biological species based upon similarities and differences in their physical or genetic characteristics

# **LESSON SUMMARY**

Students are presented a current problem observed in the majority of natural history museums in which orthogenesis is used to display the evolution of horses. The use of orthogenesis, rather than the widely accepted branching phylogenetic tree, often leads to misconceptions about evolution amongst visitors of the general public to such exhibits (MacFadden et al, 2012). Teachers can provide students with a fictional letter from the curator of a natural history museum requesting their help with this problem or have students complete a close read of the paper by MacFadden and colleagues (2012) to explore this issue. Students then use their fossil data graphs from Lesson One in addition to information about ancestral horse species presented on horse cards to complete a poster proposal to summarize how the fossil records clearly show a branching phylogenetic evolution of the horse.

# STUDENT LEARNING OBJECTIVES

- Students will be able to differentiate between orthogenetic and phylogenetic evolution and explain the flaws in orthogenesis.
- Students will be able to construct a phylogenetic tree based on measured fossil data.
- Students will be able analyze evolutionary relationships and determine common ancestors given a cladogram.

# **MATERIALS**

- 1. "Email" from Dr. MacFadden
- 2. Close Reading Guide for MacFadden et al, 2012 Article: Fossil Horses Orthogenesis and Communicating Evolution in Museums
- 3. Horse Species Range Cards
- 4. Chart Paper (1 sheet per group)
- 5. Markers (1 pack per group)
- 6. Tape (1 roll per group)
- 7. Scissors (1 pair per group)
- 8. Evolution of the Horse Museum Display Proposal Grading Rubric
- 9. Student Page: Changing the Way We Think About Change

#### **KEY QUESTION(S):**

Why are phylogenic trees superior in depicting evolution, as opposed to orthogenetic displays?

#### **OVERALL TIME ESTIMATE:**

One 45 minute class period, with an optional presentation period

#### **LEARNING STYLES:**

Visual, Kinesthetic, Auditory, Cooperative



# **BACKGROUND INFORMATION**

After looking at evolution on the scale of many horse species over 55 million years and the process of natural selection as it acts on the variation within a single species, we wanted to use Lesson 3 to tackle misconceptions about how evolution actually works. The misconception we focus on most is that evolution is always beneficial and is always striving to make a species "better" in a linear fashion. In fact, evolution results in many species that go extinct and become dead-ends. In horses, the browsing anchitheriine horses (which includes the species Anchitherium clarencei from Lesson 1) survive alongside the many species of grazing horses until about 4 million years ago when they go extinct.

In MacFadden et al. (2012), the authors note a major problem with museum exhibits displaying horse evolution as a linear process (known to scientists as orthogenesis). Many museums contain exhibits (yes!, even including the American Museum of Natural History and the Smithsonian Institution, when this paper was published) that display the evolution of horses as a straight line and not as the complex, branching pattern in which we currently understand that horse evolution occurred. To put this a different way, we now know that horse evolution did not comprise of one ancestral species evolving into a descendant species all the way down the line from *Sifrhippus sandrae* to modern-day *Equus* sp. Instead, we know that many horse species lived at given time (some fossil localities in Florida have as many as 8! different species of horse) and that the "evolutionary tree of horses is bushy, with many species overlapping in time, multiple originations and frequent extinctions" (MacFadden et al., 2012). To help fight the misconception of orthogenesis in the evolution of horses, we ask the students to use the information they have learned in Lessons 1 and 2 to create their own museum exhibits that correctly display the evolution of horses as a branching, and not orthogenetic, pattern.

# **ADVANCE PREPARATION**

- Read background information
- · Print Copies of the MacFadden Email (1 per group or per student)
- (if using) Print Copies of the Close Reading Guide and MacFadden et al, 2012 Article Fossil Horses Orthogenesis and *Communicating Evolution in Museums* (1 per student)
- Print Horse Species Range Cards (1 set per group)
- Evolution of the Horse Museum Display Proposal Grading Rubric (1 per group)
- Print Student Page: Changing the Way We Think About Change (1 per student)

# PROCEDURE AND DISCUSSION QUESTIONS WITH TIME ESTIMATES

- 1. (Day before Lesson Three) **1-2 MINUTES** If using the Close Reading Guide, pass out with copies of the MacFadden et al, 2012 article for students to read and complete guide as homework.
- (If Close Reading Guide was used) 2-5 MINUTES Discuss questions and/or "surprising" things that students annotated on their article copies. Ensure the difference between orthogenetic and phylogenetic evolutionary patterns are clear to all students.
- 3. **1-3 MINUTES** Pass out ONE copy of the MacFadden email to each student group and read together as a class. Address questions as necessary.
- 4. 1-2 MINUTES Pass out one copy of the Evolution of the Horse Museum Proposal Grading Rubric, one set of Horse Species Range Cards and all other required materials (chart paper/poster board, markers, tape/glue, scissors) and instruct students to work with their group partners to construct a phylogenetic display of the evolution of the horse based on the data from Lesson One, the information on the species range cards and Dr. MacFadden's email request.

- 5. 25 MINUTES Circulate between groups, monitoring and supporting as necessary.
- 6. **15 MINUTES** Distribute one copy of the Student Page: Changing the Way We Think About Change to each student. Choose to have students work independently in class or for homework, work in small groups or complete as a whole class, depending on the level of your students.

(Implementation note: Have an interactive poster display as student groups hang their museum display posters. Discuss each as a class with the group sharing their proposal, calling attention to any misconceptions displayed and ensuring understanding of the entire class. This requires an extra day to accomplish, but combined with reviewing the Student Page: Changing the Way We Think About Change, it provides and excellent wrap up to the lesson and ties the curriculum together.)

### ASSESSMENT SUGGESTIONS

- · Collect Close Reading Guide Reflective Writing
- Infographic Proposal to Museum
- · Collect Student Page: Changing the Way We Think About Change

# **EXTENSIONS**

Consider having students create an electronic infographic using a Web 2.0 tool such as: http://www.easel.ly/

# **RESOURCES/REFERENCES**

MacFadden, Bruce J. "Fossil Horses-Evidence for Evolution." Science 307 (2005): 1728-729.

MacFadden, Bruce J., Luz Helena Oviedo, Grace M. Seymour, and Shari Ellis. "Fossil Horses, Orthogenesis, and Communicating Evolution in Museums." *Evolution: Education and Outreach* 5.1 (2012): 29-37. Springerlink.com. Web.





# Close Reading Guide for Fossil Horses Orthogenesis and Communicating Evolution in Museums

# HOW TO CLOSE READ

- 1. FIRST READING: Read the article in completion, to determine the gist of the article.
- **2. SECOND READING:** Carefully re-read the article writing a 2-3 word summary to the left of each paragraph and annotating other details to the right of each paragraph, using the guide below. We will discuss the questions and things that surprised you as a group during our next whole class meeting.



# A NOTE TO STUDENTS ABOUT ANNOTATING:

You might not find it necessary to complete every one of the suggested annotations on the guide for each paragraph.

Remember, you are using the annotations to draw out the key points of the article, as well as focus on your interests and possible areas of confusion, which you will discuss with your teacher and your classmates before your final reflection on the article.

**3. REFLECTIVE WRITING:** Using evidence from the article and your knowledge of phylogenetics and evolution, respond to the following prompt, using formal paragraph structure:

What is an orthogenetic (based on orthogenesis) display? Why do the authors of the paper argue that orthogenesis is major contributor to "general misconceptions about evolution"? Why is a phylogenetic representation a more accurate display for visual understanding of the evolution of an organism, such as the horse? If it is so well known that branching phylogenetic trees are a better representation of horse evolution, why are orthogenetic displays prevalent nationally in natural history museums?

#### STUDENT PAGE



Florida Museum of Natural History Dickinson Hall 1659 Museum Road University of Florida Gainesville, FL 32611

To: Biology Students From: Dr. MacFadden Date: Today Re: Help Please! Evolution of the Horse Displays in Museums are Misleading!

#### Hello all,

I hope you have been enjoying working with the fossilized horse teeth from my collection at the Florida Museum of Natural History. Now that you have a handle on how horses evolved in response to the evolution of plants and climate change, I need your help with a problem I have observed at many natural history museums across the country. Over 55% of natural history museums that my lab surveyed in 2012 (including the American Museum of Natural History in NYC and the Smithsonian in Washington, DC) use a straight line graphic to represent the evolution of the modern horse, suggesting a progression from the oldest ancestor at the bottom to the youngest/most modern individual at the top. This misleading evolution representation is referred to as orthogenesis. As far back as the beginning of the 20th century paleontologists realized that the evolutionary pattern of horses is a branching, phylogenetic tree, not straight orthogenesis!

This image might help you differentiate between orthogenic and phylogenic:





Here is where I need your help! Below is an image of the current Evolution of the Horse Exhibit at a museum I'm helping to remodel. As you can see it is orthogenetic which we know is incorrect and misleading.

Using the data from the different species of horse teeth you measured, can you help me create a branching phylogenetic display of the evolution of the modern horse? Please send me a picture of your proposed exhibit! I cannot wait to see them!

Good luck!

Dr. MacFadden

# EVOLUTION OF THE HORSE MUSEUM DISPLAY PROPOSAL

**DIRECTIONS:** Using the data from Lesson One and the supplied Horse Species Range Cards create a poster display of the evolution of the modern horse as per Dr. MacFadden's email. You have seen the fossil teeth of most of these species, but there are a few additional ones to add to the display.

# RUBRIC

CATEGORY	1 POINT	3 POINTS	5 POINTS	SCORE
Proposal is clearly phylogenetic in nature	Proposal includes all species from the study set, but is straight line, orthogenic	Proposal is branching, but does not include all the species from the study set	Proposal is clearly branching and includes all the species from the study set	
Proposal is clearly based on data measured in lesson one	Proposal does not take into consideration all the data points from lesson one	Proposal includes all the data from lesson one but neglects to consider overlapping time of existence between species	Proposal includes all data from lesson one and clearly shows overlapping times of existence between species	
Proposal timeline is accurately scaled	Epochs are either not included or are inconsistent	Epochs are identified, but not clearly or consistently scaled	Epochs are clearly identified and scaled accurately and consistently	
Plant life during each epoch is clearly indicated as: a) Mainly forests, b) Forests and grasslands (not savannas) c) primarily grasslands and savannas	Plant life is not described in the display or is incorrectly categorized in two or more epochs	Plant life is identified in only some of the epochs or is incorrectly categorized in one epoch	Plant life is clearly and correctly identified in each epoch	
			TOTAL	

# STUDENT PAGE

# Changing the Way We Think About Change



# PART I

The above figure from a 2005 paper in the journal Science shows the evolution of the Family Equidae over the past 55 million years.

- 1. Does this graphic support or refute your proposal? Cite specific evidence/measurements to support your answer.
- 2. How many species were extant (alive) 10 million years ago?
- 3. Does your answer to question 2 support an orthogenetic or a phylogenetic pattern of evolution in horses? Include a definition of both orthogenetic and phylogenetic in your answer.
- 4. According to the figure, which horse species is the oldest and the ancestor of all of the other horse species on the tree?

#### **PART II**

In the 2012 paper Fossil Horses, Orthogenetics, and Communicating Evolution in Museums, Dr. MacFadden writes about his concern that some people who do not understand evolution say "Don't tell me I'm descended from a monkey." This type of thinking may be the result of viewing human evolution as an orthogenetic process in which humans evolved directly from apes. The figure below shows a more accurate representation of primate evolution.



#### Answer the following questions based on the figure above:

1. Does the figure show that primate evolution is orthogenetic or phylogenetic? Explain.

- 2. How many years ago did the ancestral primate evolve?
- 3. How many million years ago did old world monkeys evolve?
- 4. Which primates on the given figure are classified as apes (hominoids)?
- 5. What primate do we share the most recent common ancestor with?
- 6. Based on what you learned about horse evolution and the primate phylogenic tree above, write a one-paragraph response to someone who says, "Don't tell me, I'm descended from a monkey." In your answer please include the following terms: <u>common ancestor</u>, <u>phylogenetic</u>, <u>orthogenetic</u>, <u>shared characteristics</u>, <u>genetic variation</u> and <u>speciation</u>.

# **CONTENT ASSESSMENT**

Identifier given by your teacher: \_\_\_\_

1. (T or F) Horses did not live in the Americas until the Spanish explorers introduced them about 500 years ago.

Date:

- 2. (T or F) Horses have always been grazers (feeding on grass).
- 3. (T or F) Multiple species of horses existed in North America at the same time.
- 4. (T or F) If there was no change in the type of available food resources the length of horse teeth would likely increase over time.
- 5. (T or F) A species with high genetic diversity would be more likely to adapt to a sudden change in climate or environment than a species with low genetic diversity.
- 6. Evidence from the fossil record indicates that horses have existed for
  - a) five hundred years (500).
  - b) fifty-five thousand years (55,000).
  - c) fifty-five million years (55,000,000).
  - d) five billion years (5,000,000,000).

7. Which of the following is not a geological time period when horses lived?

- a) Mesozoic (252-66 Ma)
- b) Eocene (55.8-33.9 Ma)
- c) Miocene (23-5.3 Ma)
- d) Pleistocene (2.6-0.01 Ma)

8. From the Eocene to the Pleistocene the habitats where horses lived generally changed from \_\_\_\_\_\_ to \_\_\_\_\_.

- a) Coastal, savannah
- b) Forests, grasslands
- c) Grasslands, forests
- d) Savannah, coastal

9. Geologic time is divided into different spans of time called epochs. Epochs are generally distinct from each due to

- a) Differences in the Earth's climate
- b) Differences in the number of fossils collected by paleontologists
- c) Differences in Earth's distance from the sun
- d) Differences in mating behaviors of organisms

10. One way to characterize taxa is by their food choice. A browsing animal consumes primarily

- a) Fruits
- b) Grasses
- c) Leaves
- d) Nuts

11. Which is an example of an evolved character NOT found throughout the evolution of horses?

- a) Complex plications
- b) Decreased limb proportions
- c) Increased hypsodonty
- d) Isolated protocone

12. Feeding on leaves would result in rates \_\_\_\_\_\_ of tooth wear than grass.

a) Higher

b) Lower

Explain your answer:

13. Which representation best describes our current understanding of horse evolution?

- a) Orthogeneic
- b) Phylogenic

Explain your answer:

Use the following data to answer questions 15-16.

Fossil	Crown Height (mm)	Anterior-Posterior Length (APL) (mm)
А	2.9	6.1
В	9.2	13.8
С	12.6	19.9
D	76.1	29.3



14. Which fossil tooth is likely from a grazer?

- a) A
- b) B
- c) C
- d) D

15. What is the hypsodonty index for Fossil C?

- a) -7.3
- b) 0.63
- c) 1.58
- d) 7.3

#### 16. Evolution is:

- a) One animal turning into a completely different animal
- b) Change in a habitat over time
- c) Trait that enhances survival
- d) Gradual change in a species over a long time

17. Which of the following is a correct statement about the relationship between natural selection and evolution?

- a) Natural selection results from evolution.
- b) Natural selection includes evolution as a part of it.
- c) Natural selection is one mechanism of evolution.
- d) Natural selection and evolution are the same thing.
- 18. How do fossils demonstrate evidence of evolution?
  - a) They show that ancient species share similarities with species now on Earth.
  - b) They show evidence of species that are now extinct.
  - c) They are the primary source of evidence of natural selection.
  - d) Fossils reveal that many species have remained unchanged for millions of years.
- 19. A certain species has little genetic variation. The rapid extinction of this species would most likely result from the effect of
  - a) environmental change
  - b) gene cloning
  - c) genetic recombination
  - d) successful cloning

- 20. Coevolution is a process in which species
  - a) Become extinct and are lost permanently
  - b) Become increasingly different from each other
  - c) Evolve in response to changes in each other
  - d) Evolve similar characteristics in different habitats

21. What is the term for a feature that allows an organism to survive better in its environment?

- a) Adaptation
- b) Homologous structure
- c) Variation
- d) Vestigial structure



- 22. One possible conclusion that can be drawn regarding ancestral horses A and B is that
  - a) A was better adapted to changes that occurred during the Pliocene Epoch than was B.
  - b) The areas that B migrated to contained fewer varieties of producers than did the areas that A migrated to
  - c) Competition between A and B led to the extinction of Pliohippus
  - d) The adaptive characteristics present in both A and B were insufficient for survival
- 23. *Miohippus* has been classified as a browser (an animal that feeds on shrubs and trees) while *Merychippus* has been classified as a grazer (an animal that feeds on grasses). One valid inference that can be made regarding the evolution of modern horses based on this information is that
  - a) Eohippus inhabited grassland areas throughout the world
  - b) Pliohippus had teeth adapted for grazing
  - c) Equus evolved as a result of the migration of Pliohippus into forested areas due to increased competition
  - d) Ecological succession led to changes in tooth structure during the Eocene Epoch.

# **CONTENT ASSESSMENT**

- 1. F
- 2. F
- 3. T
- 4. F
- 5. T
- 6. C
- 7. A
- 8. B 9. A
- 10. C
- 11. B
- 12. B (EXPLAIN)

13. B (EXPLAIN)

- 14. D
- 15. B
- 16. D
- 17. C
- 18. A
- 19. A

20. C

21. A

22. D

23. B

# MATE

Identifier	aiven	bv	vour	teacher:	
achterier	green	~y	your	couciici.	

\_\_\_\_\_ Date: \_\_\_\_\_

Please respond to the statements below by marking Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), or Strongly Disagree (SD).

	SA	А	U	D	SD
Organisms existing today are the result of evolutionary processes that have occurred over millions of years. (1)					
The theory of evolution is incapable of being scientifically tested. (2)					
Modern humans are the product of evolutionary processes which have occurred over millions of years. (3)					
The theory of evolution is based on speculation and not valid scientific observation and testing. (4)					
Most scientists accept evolutionary theory to be a scientifically valid theory. (5)					
The available data are ambiguous as to whether evolution actually occurs. (6)					
The age of the earth is less than 20,000 years. (7)					
There is a significant body of data which supports evolutionary theory. (8)					
Organisms exist today in essentially the same form in which they always have. (9)					
Evolution is not a scientifically valid theory. (10)					
The age of the earth is at least 4 billion years. (11)					
Current evolutionary theory is the result of sound scientific research and methodology. (12)					
Evolutionary theory generates testable predictions with respect to the characteristics of life. (13)					
The theory of evolution cannot be correct since it disagrees with the Biblical account of creation. (14)					
Humans exist today in essentially the same form in which they always have. (15)					
Evolutionary theory is supported by factual, historical, and laboratory data. (16)					
Much of the scientific community doubts if evolution occurs. (22)					
The theory of evolution brings meaning to the diverse characteristics and behaviors observed in living forms. (18)					
With few exceptions, organisms on earth came into existence at about the same time. (19)					
Evolution is a scientifically valid theory. (20)					

# STUDENT FEEDBACK FORM: CHEWING ON CHANGE

Student code:	Date:	Student grade level:	Circle one:	Male	Female
School:		Teacher Name:	Subject:		

# PART I: EVALUATION OF INDIVIDUAL ACTIVITIES

**SECTION A:** For each question below, please indicate your response for each **specific activity** by marking High, Moderate, Low, or Not Applicable (NA).

	Activity 1		Activity 2			Activity 3						
	High	Mod	Low	N/A	High	Mod	Low	N/A	High	Mod	Low	N/A
<ol> <li>Is the amount of background information sufficient?</li> </ol>												
2. Were you provided enough time to perform the activity?												
3. Is the procedure clearly written?												
4. Does the data collection/analysis section assist documentation of your observations?												
5. Do the review questions help clarify thinking?												
6. Are the assessment instructions clearly stated?												
7. Are the illustrations/charts/tables helpful?												

**SECTION B:** Please provide additional comments pertaining to each specific experiment.

	ACTIVITY 1	ACTIVITY 2	ACTIVITY 3
<ol> <li>Are there any topics/ sections that should be added or deleted? If so, please explain.</li> </ol>			
2. Additional comments?			

# PART II. PLEASE EVALUATE THE CHEWING ON CHANGE CURRICULUM OVERALL.

For each item below, indicate your personal response by marking Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), or Strongly Disagree (SD).

	SA	А	U	D	SD
1. Do you think evolution is an interesting topic?					
2. Do you think evolution is relevant to your own life?					
3. Did you enjoy the activities?					
4. Did performing the activities increase your knowledge of evolution?					
5. Do you feel the activities reflect actual research practice?					

# PART III.

Do you have any questions or is there anything you do not understand related to the activities you performed?

#### PART IV.

Do you have any additional comments related to the activities you performed that you would like to share?

### STUDENT DEMOGRAPHIC FORM

School:

\_\_\_\_\_ Teacher Name: \_\_\_\_\_\_ Subject: \_\_\_\_\_

For our reporting purposes, we need to identify the following information. Please help us provide complete and accurate data! This form is to be used for collecting data about class(es) that participate in the field testing of the Chewing on Change curriculum. If you implemented the curriculum with different subjects and/or levels, please complete a form for each (for example, one form for AP Biology and another form for Biology I Standard Level).

1. Number (not percentage) of students in your class only by RACE and GENDER in the current school year. Please fill these categories out to the best of your ability and please do not create new categories.

TABLE 1	Nu	Number of Students       Male     Female     Total       Image: State of Students     Image: State of				
Ethnicity	Male	Female	Total			
Asian						
Black						
Hispanic						
Native Alaskan						
Native American						
Native Pacific Islander						
White, not Hispanic						
Table 1 Totals						

2. Number of students in your class by GRADE LEVEL in the current school year.

Grade	Number
6	
7	
8	
9	
10	
11	
12	
TOTAL	

(Must equal total from Table 1)

3. How many of your students indicated above are considered special education?

4. How many of your students indicated above are eligible for free or reduced lunch?

# TEACHER IMPLEMENTATION FEEDBACK FORM: CHEWING ON CHANGE

Thank you for implementing the Chewing on Change curriculum in your classroom! We are very interested in how you actually used the lessons with your students to better understand different strategies and outcomes in diverse school settings. Please answer the items below, if possible reflecting on each lesson as you move through implementation to capture as many nuances as possible.

School:	Teacher Name:	Subject:
Email:		

### **ACTIVITY ONE**

1. Briefly describe your implementation of Activity One, noting any modifications you made.

2. Did you or your students have any particular challenges with this activity?

3. Were there particular successes or "ah-ha" moments with this activity for you or your students?

4. What modifications would you made to this activity prior to using it again?

### **ACTIVITY TWO**

1. Briefly describe your implementation of Activity Two, noting any modifications you made.

2. Did you or your students have any particular challenges with this activity?

3. Were there particular successes or "ah-ha" moments with this activity for you or your students?

4. What modifications would you made to this activity prior to using it again?

## **ACTIVITY THREE**

1. Briefly describe your implementation of Activity Three, noting any modifications you made.

2. Did you or your students have any particular challenges with this activity?

3. Were there particular successes or "ah-ha" moments with this activity for you or your students?

4. What modifications would you made to this activity prior to using it again?

### OVERALL

1. Where did you situate the horse curriculum within your course sequence? What unit/lessons did you teach immediately before and after the horse curriculum?

2. Are there any topics/sections that should be added to/deleted from the curriculum? If so, please explain.

3. Would you use this curriculum again? Why or why not?

# TEACHER FEEDBACK FORM: CHEWING ON CHANGE

Teacher name:	
Subjects taught:	_Grade levels taught:
School:	_Email:

Thank you for reviewing the Chewing on Change curriculum. Please review the entire curriculum and then complete the questions below. You are welcome to insert comments directly in the manual as well as in the section provided below. Comments and suggestions are greatly appreciated!

# PART I: EVALUATION OF THE ENTIRE CURRICULUM

**SECTION A:** For each item below, please indicate your response to each question as it relates to the curriculum overall by marking Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), or Strongly Disagree (SD).

	SA	А	U	D	SD
1. Are the experimental procedures appropriate for your students?					
2. Are the topics addressed important for your course objectives?					
3. Are the topics addressed relevant to your students' lives?					
4. Are the topics addressed interesting to your students?					
5. Is the depth of coverage of topics appropriate?					
6. Is the overall quality of the curriculum satisfactory?					
7. Is the content in the manual properly sequenced?					
8. Is the content in the manual adaptable for a range of student ability levels?					

**SECTION B:** Please provide additional comments pertaining to the curriculum overall.

1. Are there any topics/sections that should be added to/deleted from the curriculum? If so, please explain.

2. Additional comments

## PART II: EVALUATION OF INDIVIDUAL EXPERIMENTS

**SECTION A:** For each question below, please indicate your response for each specific experiment by marking High, Moderate (Mod), Low, or Not Applicable (N/A).

	Activity 1		Activity 2				Activity 3					
	High	Mod	Low	N/A	High	Mod	Low	N/A	High	Mod	Low	N/A
1. Is the amount of teacher background information sufficient?												
2. Do the time estimates seem reasonable?												
3. Is the advance preparation reasonable?												
4. Is the student procedure clearly stated?												
5. Do the review questions help students clarify their thinking?												
6. Does the data collection/analysis section help students organize their thoughts?												
7. Is the suggested assessment of sufficient quality?												
8. Are the illustrations/charts/tables helpful?												

#### **SECTION B:** Please provide additional comments pertaining to each specific activity.

	Activity 1	Activity 2	Activity 3
1. Are there any topics/ sections that should be added or deleted? If so, please explain.			
2. Additional comments?			

# CONTENT AREA EXPERT EVALUATION: CHEWING ON CHANGE CURRICULUM

Please review the entire manual and then complete the questions below. Comments may be inserted directly in the manual as well as in the section provided below. Comments and suggestions are greatly appreciated!

Reviewer name:	Date reviewed:
Email:	Employer:
Department/Division:	Job title:

**PART I:** For each item below, please indicate your response to each question as it relates to the curriculum overall by checking Yes (Y), No (N), or Undecided (U).

	Y	Ν	U
1. Is the science content in the curriculum accurate?			
2. Is the science content in the curriculum current?			
3. Is the science content in the curriculum important for science literacy?			
4. Is the content in the manual related to major biological concepts? (e.g., evolution)			
5. Is the content coverage in the curriculum thorough and complete?			
6. Are potential misconceptions adequately addressed?			
7. Is the content in the lesson properly sequenced for a novice?			
8. Do the experiments model authentic research?			
9. Are there additional concepts that should be included? (If yes, please elaborate below.)			

**PART II:** Please include below any comments or suggestions about the curriculum.

1. General comments about the overall curriculum

### 2. Comments regarding individual experiments



Notes:	

Notes:	

