13 *Embryology*

INVESTIGATION

2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students analyze and interpret skeletal and embryological images to identify patterns of similarities and differences across species that look very different as mature animals. Students identify patterns of similarities throughout developmental time to infer evolutionary relationships that are not obvious in the mature animals. This activity provides an opportunity to assess students' work related to Performance Expectation MS-LS4-3.

NGSS CORRELATIONS

Performance Expectations

MS-LS4-3: Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.

Applying MS-LS4-2: Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.

Disciplinary Core Ideas

MS-LS4.A Evidence of Common Ancestry and Diversity:

Comparison of the embryological development of different species also reveals similarities that show relationships not fully evident in the fully formed anatomy.

Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record, enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent.

Science and Engineering Practices

Analyzing and Interpreting Data: Analyze linear displays of data to identify linear and nonlinear relationships.

Crosscutting Concepts

Patterns: Graphs, charts, and images can be used to identify patterns in data.

Structure and Function: Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts, therefore complex natural structures/systems can be analyzed to determine how they function.

Common Core State Standards—ELA/Literacy

RST.6-8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

INVESTIGATIVE PHENOMENA AND SENSEMAKING

Evidence of species that no longer exist can be found in fossils.

Students compare and contrast data from adult skeletons and embryos to figure out that embryos can reveal information that is not apparent in adults. Students figure out that observations of embryos can provide further evidence of the evolutionary relationships of organisms.

WHAT STUDENTS DO

Students first examine forelimb skeletons of six species to identify bones with homologous structures and functions. Although the fully formed limbs appear different on the outside, students are able to identify similarities at the skeletal level. Students then examine the embryological development of limbs and notice many similarities between different species. Finally, students examine the development of whole embryos of different species to infer evolutionary relationships.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*

  1 Visual Aid 13.1, "Comparison of Vertebrate Forelimbs"
  1 Visual Aid 13.2, "Embryonic Limbs"
  1 Visual Aid 13.3, "Whole Embryo Sorting"
  1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID)
  * 64 envelopes (optional)
  * 64 paper clips (optional)

- *For each group of four students*

  colored pencils

- *For each pair of students*
  - 1 set of 12 Embryonic Limb Cards
  - 1 set of 20 Whole Embryo Cards

- *For each student*
  - 1 Student Sheet 13.1, "Comparison of Vertebrate Forelimbs"
  - 1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID) (optional)

* *not included in kit*

The ANALYZING AND INTERPRETING DATA (AID) Scoring Guide can be found in the Assessment tab in the back of this Teacher Edition.

You will distribute an entire set of Embryonic Limb Cards to each pair of students. It may be helpful to put these into envelopes or to paper-clip them together ahead of time.

You will distribute the Whole Embryo Cards to each pair of students based on the developmental stage. First, they will receive the animal names and the early-stage embryos. Second, they will receive the middle-stage embryos. And last, they will receive the late-stage embryos. To make it easier to hand out at the appropriate time, you may want to sort these into envelopes or paper-clip them together by developmental stage.

TEACHING SUMMARY

GET STARTED

1. Introduce this activity by connecting it to what students learned in "A Whale of a Tale."
   a. Ask students to describe how they used skeletons to determine evolutionary relationships.
   b. Review embryos.
   c. Direct students to read the introduction.
2. Let students know that they will investigate skeletons of adult animals and developing embryos.

DO THE ACTIVITY

3. Students complete Part A: comparing forelimb skeletons of three species.
   a. Distribute Student Sheet 13.1, "Comparison of Vertebrate Forelimbs."
   b. Show Visual Aid 13.1, "Comparison of Vertebrate Forelimbs," and allow students to compare and discuss their identifications.

   c. Have students discuss whether they think the animals are related, based on the structure and function of the forelimbs.

4. Students complete Part B: sorting and trying to identify embryonic limb images.
   a. Distribute a set of Embryonic Limb Cards to each pair of students.
   b. Explain why stages are given as early, middle, and late stage development rather than specific times.
   c. Have students compare and sort the cards and record the reasoning for their sorting in their science notebooks.
   d. Use Visual Aid 13.2, "Embryonic Limbs," to show students the correct sorting.
5. Students complete Part C: sorting and trying to identify whole embryo images.
   a. Distribute the first set of Whole Embryo Cards to each pair of students.
   b. Distribute the middle-stage set of Whole Embryo Cards to each pair of students.
   c. Distribute the late-stage set of Whole Embryo Cards to each pair of students.

BUILD UNDERSTANDING

6. Have pairs of students share their sorting and reasoning with each other.
   a. Have students discuss their rationale for sorting their embryo images.
   b. Use Visual Aid 13.3, "Whole Embryo Sorting," to show students the correct sorting.
7. Relate the crosscutting concepts of *patterns* and *structure and function* to this activity.
   a. Relate *patterns* to this activity.
   b. Relate *structure and function* to this activity.
8. Discuss the use of embryological and skeletal data as evidence for evolutionary relationships.
   a. Review how scientists are able to make inferences about how species are related, even if their mature forms look very different.
   b. (AID ASSESSMENT) Assess students' understanding of how patterns of similarities in embryological development can provide evidence for relationships between species.
9. Students revisit the driving question for this sequence of learning.

TEACHING STEPS

GET STARTED

1. Introduce this activity by connecting it to what students learned in "A Whale of a Tale."

   a. Ask students to describe how they used skeletons to determine evolutionary relationships.

      Review how students made observations of different whale skeletons to identify similarities and differences. More similarities suggested that the whales were more closely related.

   b. Review embryos.

      Students were introduced to the concept of embryos in the activity "A Whale of a Tale." Remind them that an *embryo* is the developing animal from fertilization through birth or hatching.

   c. Direct students to read the introduction.

      Students should recall from "A Whale of a Tale" that hair and hind limbs were present on the whale embryos but absent in the adults.

2. Let students know that they will investigate skeletons of adult animals and developing embryos.

   Explain that they will analyze images in order to make observations and develop explanations about evolutionary relationships.

DO THE ACTIVITY

3. Students complete Part A: comparing forelimb skeletons of three species.

   a. Distribute Student Sheet 13.1, "Comparison of Vertebrate Forelimbs."

      Students should start by making observations about the forelimbs and trying to identify specific structures, including the hand and foot, wrist, forearm, and upper arm. If necessary, you can guide students through identifying the structures in the human arm first; students are then likely to base their identifications on the structural similarities of the bones. The horse forelimb will likely cause some confusion. To help students figure out comparable structures, have them consider which part of the leg moves (or functions) much like a human arm.

      Emphasize that the color coding is to help students easily communicate their thinking and to visualize similar structures. They should not spend too much time trying to make beautiful artwork.

b. Show Visual Aid 13.1, "Comparison of Vertebrate Forelimbs," and allow students to compare and discuss their identifications.

Facilitate a discussion about the similarities and differences between the structure and function of the different forelimbs.

Although the external structure of the forelimbs is varied, the internal skeletal structure is very similar. Students should notice that animals that have a bigger "hand" tend to have more finger-like bones. This observation reinforces the crosscutting concept of *structure and function*. A horse's forelimb varies the most, especially in terms of the number of bones.

c. Have students discuss whether they think the animals are related, based on the structure and function of the forelimbs.

Ask students if skeletal images provide any evidence that these animals might be related. Discuss (a) whether similar structures and functions would develop in different animals independently, or (b) whether those animals might be related and possibly have evolved from a common ancestor.

4. Students complete Part B: sorting and trying to identify embryonic limb images.

a. Distribute a set of Embryonic Limb Cards to each pair of students.

There are 12 total cards in each set: 3 cards that indicate the type of animal and limb, 3 early-stage embryonic limbs, 3 middle-stage embryonic limbs, and 3 late-stage embryonic limbs.

b. Explain why stages are given as early, middle, and late stage development rather than specific times.

The stages are identified as early, middle, and late, based on the total length of embryonic development for the animal. Since animals develop over various lengths of time, it is easier to compare stages as opposed to specific days of development. For example, a human embryo develops over 36 weeks, whereas a chicken develops over 3 weeks. This means that an early human embryo can be up to 12 weeks old, whereas an early chicken embryo would be only a few days old.

c. Have students compare and sort the cards and record the reasoning for their sorting in their science notebooks.

Students should find that the embryonic forelimbs of all three animals look very similar at each developmental stage, so much so that it is hard to know which animal they belong to. Emphasize the significant similarity of structure among the limbs in the early and middle stages. In fact, students might find it hard to distinguish between the limbs' owners until late in development. The bat wing is a good example of this. Although the embryonic limbs look different in the mature animals, the similar embryonic development suggests that these structures evolved from a common ancestor.

d. Use Visual Aid 13.2, "Embryonic Limbs," to show students correct sorting.

   Discuss why students found it easy or difficult to sort the limbs. For example, at the early and middle stages, all three limbs are almost indistinguishable, making it hard to attribute them to different animals.

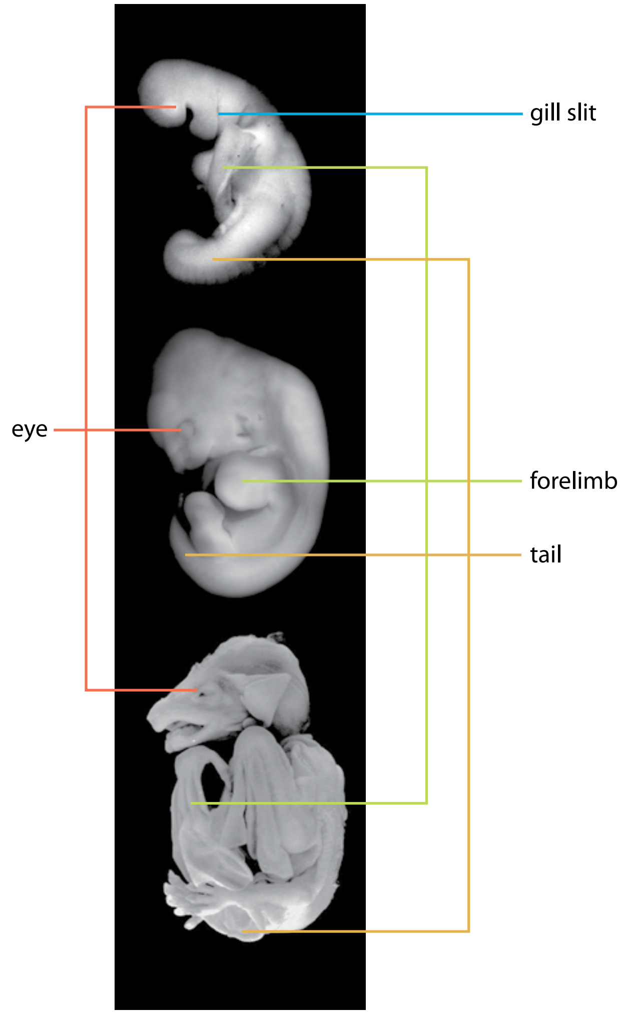
5. Students complete Part C: sorting and trying to identify whole embryo images.

   a. Distribute the first set of Whole Embryo Cards to each pair of students.

      This first set includes five animal name cards and five early-stage embryos.

      Students will find it difficult to identify which animal is which. Allow them to struggle with trying to identify which embryo matches which animal card. Tell them that they can change their sorting with the next set of cards.

      Make sure that students record their observations in their science notebooks. Their observations should include the structures they can identify, similarities and differences between the embryos, and the rationale for their sorting. At this stage of development, students may notice that each embryo has an end that resembles a head, while the other end looks like a tail. They might also notice where the eyes might form on the embryo later in development. Students might also notice gill slits in some of the embryos, most notably in the bat and the human. Make a point to identify the gill slits if students do not see them.



b. Distribute the middle-stage set of Whole Embryo Cards to each pair of students.

Students should try to identify which early-stage embryos these correspond to. In addition, they should look for similarities and differences between the middle-stage embryos and then between the early- and middle-stage embryos. Eyes are becoming more prominent, as are limb buds. Heads are also increasing in size.

Allow students to re-sort their cards if they think that they matched an early embryo to an animal incorrectly. Make sure that they record their new sorting and rationale.

c. Distribute the late-stage set of Whole Embryo Cards to each pair of students.

Final forms of the mature animals are evident in this last set of cards. Ears and limbs, including appendages, are fully developed. Tails have disappeared on the human (and possibly the bat).

Allow students to re-sort their cards if they think that they matched an early embryo to an animal incorrectly. Make sure that they record their new sorting and rationale.

BUILD UNDERSTANDING

6. Have pairs of students share their sorting and reasoning with each other.

    a. Have students discuss their rationale for sorting their embryo images.

    Students' sorting should reflect their comparison of the appearances (and sometimes disappearances) of various structures from early to late development. Based on their discussion, let students re-sort their images.

    b. Use Visual Aid 13.3, "Whole Embryo Sorting," to show students the correct sorting.

7. Relate the crosscutting concepts of *patterns* and *structure and function* to this activity.

    a. Relate *patterns* to this activity.

    Students should be able to identify patterns in the embryo images—structures that are similar and different, and structures that appear and/or disappear at the same time. Students will use the patterns they identified to answer Analysis items 1 and 2.

    Discuss why students found it easy or difficult to identify patterns and sort the embryo images. Students may find it difficult to identify developing structures. Structures also vary between different species. The presence or absence of a tail or head may be easier for students to identify than other features.

    b. Relate *structure and function* to this activity.

    Students should be able to explain that related but different structures in different organisms may have similar functions, and these structures likely form at a similar stage during development.

8. Discuss the use of embryological and skeletal data as evidence for evolutionary relationships.

    a. Review how scientists are able to make inferences about how species are related, even if their mature forms look very different.

    In "A Whale of a Tale," students used skeletal evidence to infer relatedness. In this activity, students used embryological data. If embryos have similarities (e.g., the presence or absence of structures), they are likely to be more closely related and to have evolved from a more recent common ancestor than less similar embryos. Embryos with fewer similar structures during development are likely to be more distantly related.

To emphasize this point, have students discuss the similarities and differences between the mature animals and their developing embryos. Have students identify structures that may have been present that are no longer present in the mature form, such as gill slits in humans.

b. (AID ASSESSMENT) Assess students' understanding of how patterns of similarities in embryological development can provide evidence for relationships between species.

Teacher Resources
Learning Pathways

You can use the AID Scoring Guide to assess students' work on Analysis item 3, which also assesses Performance Expectation MS-LS4-3. Optionally project or distribute the Scoring Guide, and point out the different descriptions for each level. Review the levels as needed.

9. Students revisit the driving question for this sequence of learning.

This activity concludes a sequence of learning around the third driving question: What information can we learn from fossils? Revisit the Driving Questions Board for this learning sequence, and identify any lingering questions.

EXTENSION

Encourage students to watch the video of a developing chick embryo on the *SEPUP Third Edition Evolution* website at **www.sepuplhs.org/middle/third-edition**. Students can identify which points in the movie correspond to the images of the early-, middle-, and late-stage embryos in Part C.

STRATEGIES FOR TEACHING DIVERSE LEARNERS

Below are suggestions for differentiating instruction and assessment in this activity for diverse learners in your classroom:

- Students with learning disabilities: After giving groups some time to do the activity on their own, work through it as a whole class.

SAMPLE RESPONSES TO ANALYSIS

1. Was it easy to identify the animal when looking at the embryological images? Why or why not?

It was hard to identify the species for the early- and middle-stage embryos because they looked very similar. When we got the late-stage embryo cards, the pictures looked closer to what the mature animals looked like, so it was easier to identify them.

2. Review the observations you recorded in your science notebook.

   a. What patterns did you observe?

   Hint: A **pattern** is something that happens in a repeated and predictable way.

   There is a pattern in how they look more similar at the beginning and then over time begin to look more like the mature animal. They all looked pretty similar at the early stage, with a rounder-looking head on one end and a tail on the other end. Another pattern is that some of the structures appeared at the same stage in the different animals. By the middle stage, they all had what looked like eyes and some sort of limbs.

   b. What structures appeared and when?

   They all had heads and tails in the early stage, and you could also see where the eyes might form. By the middle stage, you could see eyes in all of the embryos, and the limb buds were forming. By the late stage, you could see all the formed structures—the head, ears, eyes, limbs, mouths.

   c. What structures disappeared and when?

   Between the middle and late stages, the tail disappeared from the human. It was hard to tell in the picture if the bat also lost its tail. The gill slits also disappeared by the late stage in all the animals except the salmon.

3. (AID ASSESSMENT, MS-LS4-3) What relationships across different animal species can you see in embryological data that you cannot observe by comparing mature animals? Use data from your investigation to support your answer.

   SAMPLE LEVEL 4 RESPONSE

   I can see that early human embryos had gills and tails, just like fish. This means that we are related to fish! Other animals like the snake and bat also have gills as early embryos, so they must be related to fish, too. I also saw that all five of the animals started with a tail, but humans lost it somewhere after the middle stage. When looking at the early-stage embryos, it was really hard to tell them all apart because they looked so similar, except the fish.

4. **Revisit the issue:** How do you think analyzing and interpreting many kinds of evidence helps people understand how they affect and are affecting evolution?

   All these pieces of evidence help us understand what species existed in the past, what species went extinct, and what species might go extinct in the future. We can look at which species probably went extinct due to people in the past, and the effect that we are having on species now. We might be able to predict which species will go extinct, or how species might evolve because of our activities.

REVISIT THE GUIDING QUESTION

How can embryos provide evidence about evolutionary relationships?

Students should be able to identify patterns of similarities and differences between embryological images from different species and explain that similarities often provide evidence of relatively closer evolutionary relationships. For example, a human hand, a mouse hind limb, and a bat wing are almost indistinguishable early in development, suggesting a similar structure and function and a common ancestor. In another example, early human and snake embryos have gill slits that disappear through development. The presence of these gill slits early in development suggests that humans and snakes are evolutionarily related to fish and other species with gills.

ACTIVITY RESOURCES

KEY VOCABULARY

embryo

pattern

BACKGROUND INFORMATION

EMBRYOS

Ever since Darwin, scientists have looked at embryos and wondered what they might reveal about evolution. Some have wondered whether the sequence of embryonic development revealed the actual evolutionary history of the organism. That is, they wondered whether "ontogeny recapitulates phylogeny." This line of inquiry reached its peak in the late 1800s with the work of Ernst Haeckel, who championed this idea, naming it the *biogenetic law*. Essentially, Haeckel maintained that evolution is unidirectional, with organisms moving along a single trajectory toward "higher" life forms. While numerous examples could be found to support Haeckel's idea, a growing number of cases refuted it. With the discovery of genes and their mechanism of action, scientists discovered that mutations can cause organisms to move along many paths, not just one leading to an ever "higher" form. Haeckel's "law" was eventually dismissed. Nevertheless, as seen in this activity, embryos do indicate evolutionary relationships and can reveal relationships that are not apparent in adult forms. As scientists learn more about genetics, especially Hox genes, which control the development of major body parts and segments, we gain greater insight into evolutionary history and relationships.

REFERENCES

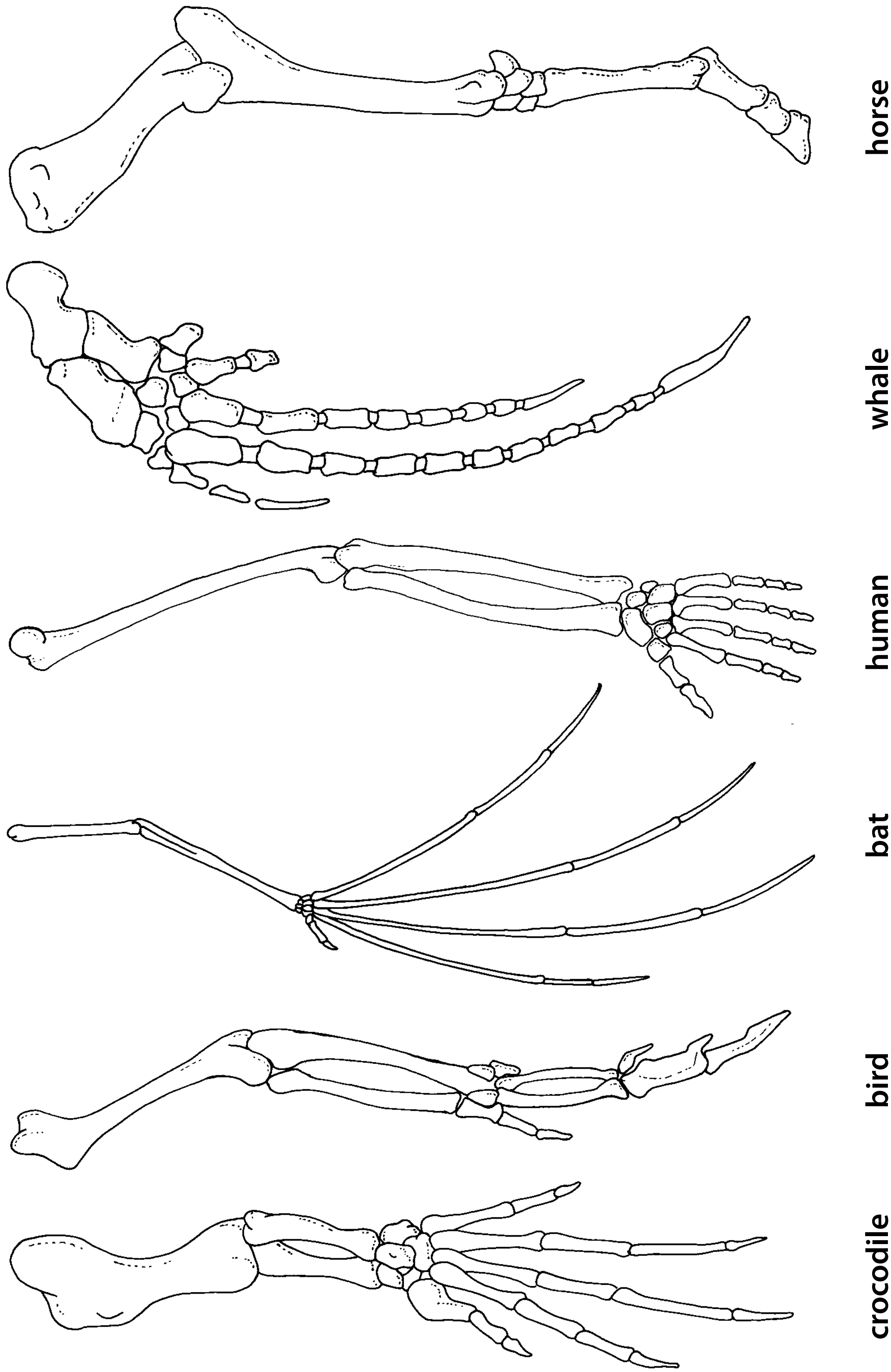
Richardson, M. K., Hanken, J., Selwood, L., Wright, G. M., Richards, R. J., & Raynaud, A. (1998). Haeckel, embryos, and evolution. *Science, 280*(5366), 983, 985–986. 10.1126/science.280.5366.983c

Wang, Z., Dai, M., Wang, Y., Cooper, K. L., Zhu, T., Dong, D., Zhang, J., & Zhang, S. (2014, May). Unique expression patterns of multiple key genes associated with the evolution of mammalian flight. *Proceedings of the Royal Society B, 281*(1783), 20133133. 10.1098/rspb.2013.3133

Name____ Date__________

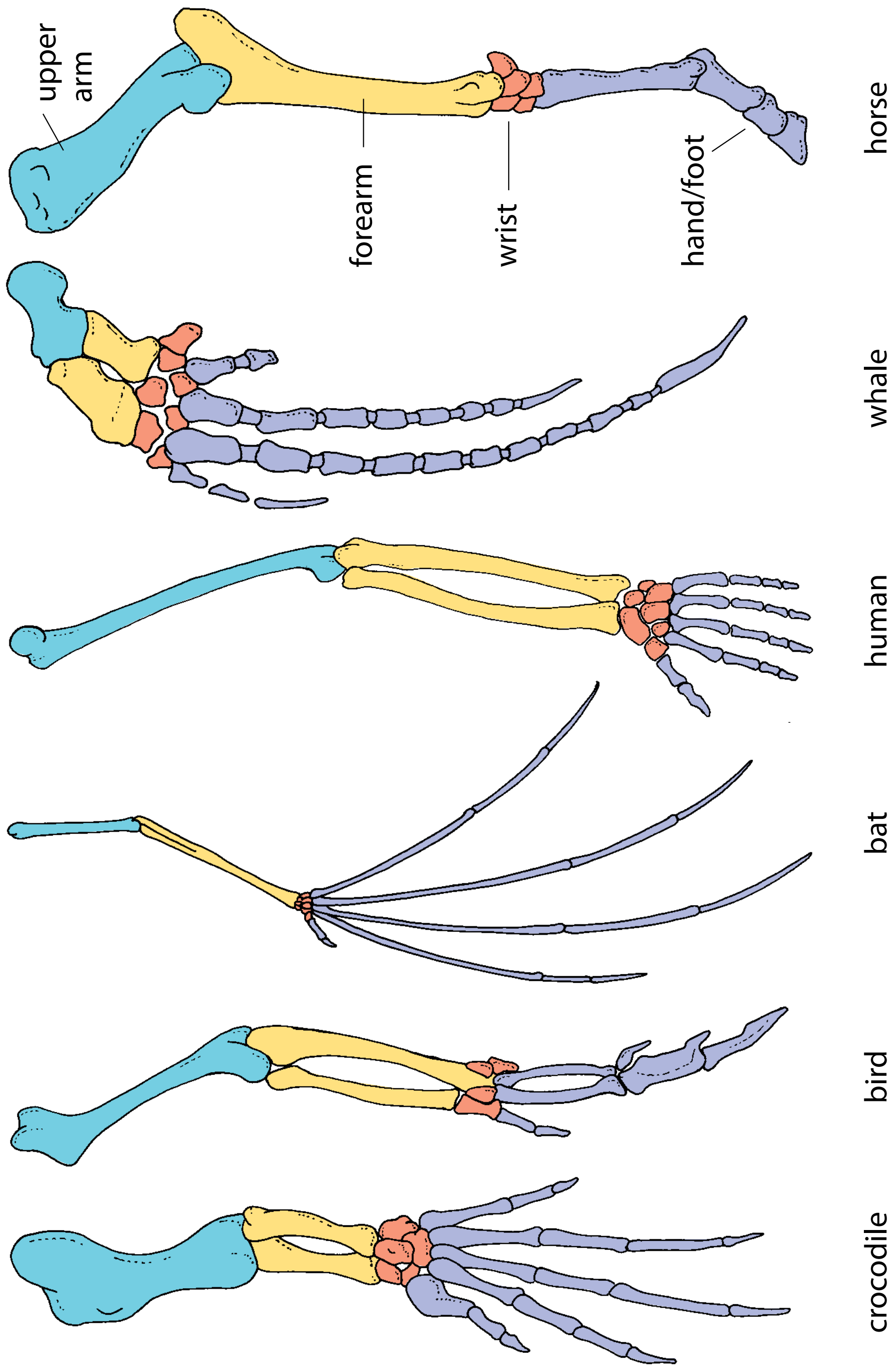
STUDENT SHEET 13.1

COMPARISON OF VERTEBRATE FORELIMBS



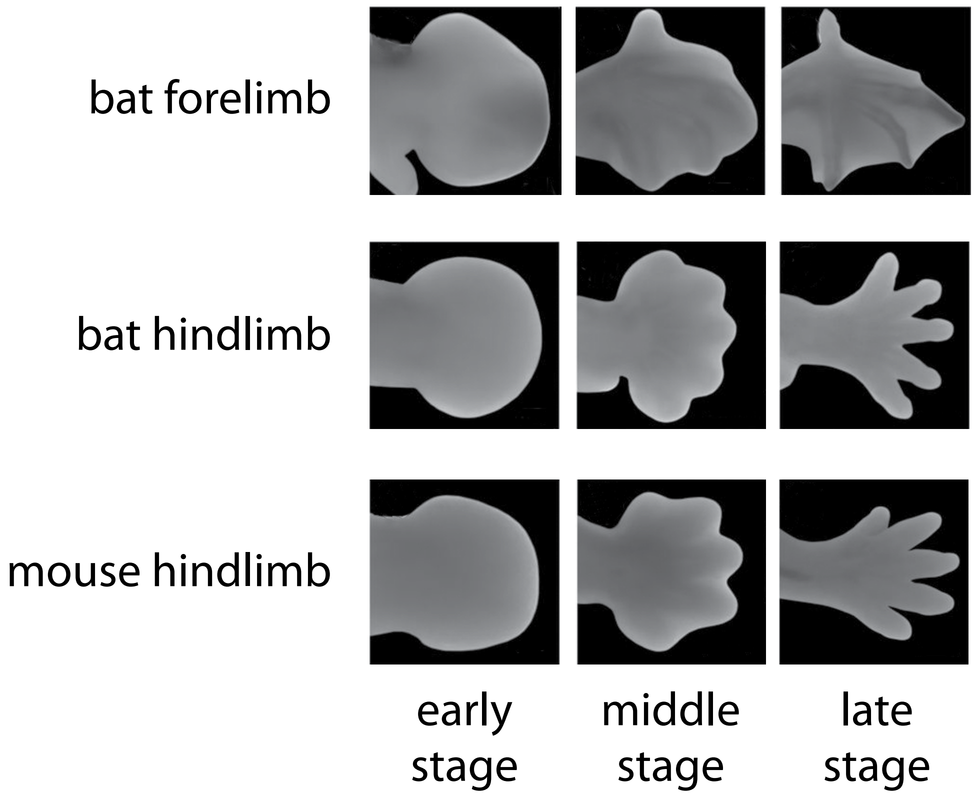
VISUAL AID 13.1

COMPARISON OF VERTEBRATE FORELIMBS



VISUAL AID 13.2

EMBRYONIC LIMBS



VISUAL AID 13.3

WHOLE EMBRYO SORTING

snake
human
salmon
chicken
bat

early stage
middle stage
late stage

ANALYZING AND INTERPRETING DATA (AID)

When to use this Scoring Guide:
This Scoring Guide is used when students analyze and interpret data that they have collected or that has been provided to them.

What to look for:

- Response describes patterns and trends in data.
- Response interprets patterns and trends, using relevant crosscutting concepts and disciplinary core ideas, to describe possible causal, relationships.

Level	Description
Level 4 Complete and correct	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data, and interprets them completely and correctly to identify and describe relationships. When appropriate, the student • makes distinctions between causation and correlation. • states how biases and errors may affect interpretation of the data.
Level 3 Almost there	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes patterns in the data BUT incorrectly and/or incompletely interprets them to identify and describe relationships.
Level 2 On the way	The student analyzes the data with appropriate tools, techniques, and reasoning. The student identifies and describes, BUT does not interpret, patterns and relationships.
Level 1 Getting started	The student attempts to analyze the data BUT does not use appropriate tools, techniques and/or reasoning to identify and describe patterns and relationships.
Level 0	The student's analysis is missing, illegible, or irrelevant to the goal of the investigation.
x	The student had no opportunity to respond.

NGSS OVERVIEW

EVOLUTION

Performance Expectation MS-LS4-1: Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.

Performance Expectation MS-LS4-2: Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.

Performance Expectation MS-LS4-3: Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.

Performance Expectation MS-LS4-4: Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.

Performance Expectation MS-LS4-5: Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.

Performance Expectation MS-LS4-6: Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.

Performance Expectation MS-LS3-1: Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
1. **Investigation: The Full Course** Students use a model to explore the cause-and-effect relationship between inappropriate use of antibiotics and the phenomenon of the evolution of antibiotic resistance. As they use the model, students use mathematical representations to support their analysis of patterns and trends in the results and to develop explanations for how and why the population of bacteria is changing. These explanations are based on the differential survival and reproduction of resistant bacteria when antibiotics are present in their environment (the human body they are infecting).	MS-LS4.B MS-LS4.C	Analyzing and Interpreting Data Developing and Using Models Using Mathematics and Computational Thinking	Patterns Cause and Effect	Mathematics: 6.SP.B.5 6.RP.A.1 ELA/Literacy: RST.6-8.3
2. **Modeling: Hiding in the Background** Students use a model to explain how a change in the environment—a change in predation—can cause changes in trait frequency within a population of prey. Students analyze and interpret data from their model using mathematical representations in their explanations.	MS-LS4.B MS-LS4.C MS-LS2.A	Analyzing and Interpreting Data Developing and Using Models Constructing Explanations and Designing Solutions Using Mathematics and Computational Thinking	Cause and Effect Patterns	Mathematics: 6.SP.B.5 6.RP.A.1 ELA/Literacy: RST.6-8.3

EVOLUTION (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
3. **Role Play: A Meeting of Minds** Students develop an understanding of Darwin's Theory of Natural Selection and use it to explain why species change over time. They learn why this explanation has prevailed by listening to arguments supporting Darwin vs. Lamarck. They use the theory to explain how a change in the environment causes a change in trait frequency from one generation to the next.	MS-LS4.B MS-LS4.C MS-LS3.B	Constructing Explanations and Designing Solutions Engaging in Argument from Evidence	Cause and Effect Patterns	ELA/Literacy: RST.6-8.2 WHST.6-8.2
4. **Modeling: Battling Beaks** Students use a model to simulate the role of genetic mutations in natural selection. They discover that mutations provide the variation on which natural selection acts. Some mutations cause traits that have the effect of enhancing an organism's survival in its current environment. Students explain that individuals possessing these adaptive traits survive to have relatively more offspring. Thus, these traits become proportionally more common in the next generation. This activity provides an opportunity to assess student work related to Performance Expectation MS-LS4-4.	MS-LS4.B MS-LS4.C MS-LS2.A MS-LS3.B MS-LS3.A	Constructing Explanations and Designing Solutions Using Mathematics and Computational Thinking Developing and Using Models Analyzing and Interpreting Data	Cause and Effect Patterns Structure and Function	Mathematics: 6.SP.B.5 6.RP.A.1 ELA/Literacy: RST.6-8.3 WHST.6-8.2
5. **Modeling: Mutations: Good or Bad?** Students follow the inheritance of a hemoglobin mutation through two generations. Students identify patterns in their data and investigate the cause-and- effect relationship between environmental conditions and the frequency of a trait in a population. Based on their data collection and analysis, students construct explanations for how changes to a gene influence an organism's ability to survive and reproduce. Specifically, students use the example of hemoglobin to explain how structural changes to genes, or mutations, lead to changes in protein structure and function, and how this can lead to changes in the function of red blood cells, which, in turn, can affect survival of individuals with the mutation. This activity provides an opportunity to assess student work related to Performance Expectation MS-LS3-1.	MS-LS4.B MS-LS3.A MS-LS3.B MS-LS4.C	Developing and Using Models Using Mathematics and Computational Thinking Constructing Explanations and Designing Solutions	Structure and Function Cause and Effect Patterns Scale, Proportion, and Quantity	Mathematics: 6.RP.A.1 6.SP.B.5 ELA/Literacy: SL.8.1 SL.8.4

EVOLUTION (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
6. **Computer Simulation: Mutations and Evolution** Students continue investigating the inheritance and selection for the hemoglobin mutation using a computer simulation. Students use mathematical representations and analyze graphs to determine the distribution of the mutation in their population over time. Students manipulate different parameters to investigate multiple cause-and-effect relationships between environmental conditions and natural selection in their population. This activity provides an opportunity to assess student work related to Performance Expectation MS-LS4-6.	MS-LS4.C MS-LS4.B MS-LS3.A MS-LS3.B	Using Mathematics and Computational Thinking Constructing Explanations and Designing Solutions Asking Questions and Defining Problems Developing and Using Models	Cause and Effect Patterns Structure and Function	Mathematics: 6.RP.A.1 6.SP.B.5 ELA/Literacy: SL.8.1 SL.8.4
7. **View and Reflect: Origins of Species** Students explore and explain how one species of finch arriving on the Galapagos Islands 3 million years ago evolved into the current 13 species. They also explore how recent changes in the environment have selected for different beak shapes and sizes within a species, reinforcing cause-and-effect relationships. Students learn that evidence from the Galapagos finches supports scientists' assumptions that the same processes that operated in the past are operating today; thus, the same cause-and-effect relationships happening in Galapagos finches today also happened in the past.	MS-LS4.A MS-LS3.B MS-LS4.B MS-LS4.C	Constructing Explanations and Designing Solutions	Cause and Effect Patterns Connections to Nature of Science: Science Is a Human Endeavor	ELA/Literacy: RST.6-8.9 WHST.6-8.2
8. **Reading: History and Diversity of Life** Students obtain information through text and graphics about the history and diversity of life. They learn how life forms have evolved over time, with all organisms sharing a common ancestor. They build un their understanding of speciation and evolutionary trees as a way to represent evolutionary relationships, and they are introduced to the process of extinction.	MS-LS4.A	Constructing Explanations and Designing Solutions Obtaining, Evaluating, and Communicating Information	Patterns	ELA/Literacy: RST.6-8.7 WHST.6-8.2

EVOLUTION (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
9. **Laboratory: Fossil Evidence** Students examine actual fossils of four species representing a diversity of life forms that existed at different points in the past. Then they examine simulated stratigraphic data to detect patterns in the fossil record. They analyze and interpret these patterns to place the four species in chronological order and, thus, determine their relative ages.	MS-LS4.A MS-ESS1.C	Analyzing and Interpreting Data Constructing Explanations and Designing Solutions Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns Cause and Effect Connections to Nature of Science: Scientific Knowledge Assumes an Order and Consistency in Natural Systems	ELA/Literacy: RST.6-8.3
10. **Investigation: Fossilized Footprints** Students look for patterns in a set of fossilized footprints, a kind of trace fossil. They analyze the patterns to draw inferences about the organisms that left these traces, including the behavior and size of the organisms. They argue for the most plausible explanation for these patterns.	MS-LS4.A	Analyzing and Interpreting Data Engaging in Argument from Evidence Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns Cause and Effect Connections to Nature of Science: Scientific Knowledge Assumes an Order and Consistency in Natural Systems	ELA/Literacy: RST.6-8.3
11. **Investigation: Family Histories** Students analyze and interpret data to look for patterns in the evolution and extinction of families from three classes of vertebrates. They summarize how life forms have evolved over time, assuming that the same natural laws have always operated and will continue to operate in the future. This activity provides an opportunity to assess student work related to Performance Expectation MS-LS4-1.	MS-LS4.A	Analyzing and Interpreting Data Constructing Explanations and Designing Solutions Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns Connections to Nature of Science: Scientific Knowledge Assumes an Order and Consistency in Natural Systems	Mathematics: 6.SP.B.5 ELA/Literacy: RST.6-8.7
12. **Investigation:** A Whale of a Tale Students compare anatomical structures in modern adult whales and embryos with fossil whales to construct an explanation about the evolutionary history and relationships of whales. The activity provides an opportunity to assess student work related to Performance Expectation MS-LS4-2.	MS-LS4.A MS-ESS1.C	Constructing Explanations and Designing Solutions Analyzing and Interpreting Data Engaging in Argument from Evidence	Patterns Connections to Nature of Science: Scientific Knowledge Assumes an Order and Consistency in Natural Systems	Mathematics: 6.SP.B.5 ELA/Literacy: RST.6-8.7

EVOLUTION (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
13. **Investigation: Embryology** Students analyze and interpret skeletal and embryological images to identify patterns of similarities and differences across species that look very different as mature animals. Students identify patterns of similarities throughout developmental time to infer evolutionary relationships not obvious in the mature animals. This activity provides an opportunity to assess student work related to Performance Expectation MS-LS4-3.	MS-LS4.A	Analyzing and Interpreting Data	Patterns Structure and Function	ELA/Literacy: RST.6-8.7
14. **Talking it Over: The Sixth Extinction?** Students analyze and interpret patterns of large-scale extinctions over the entire history of Earth, and identify the five mass extinctions detected by scientists. Students compare the possible causes of those extinctions, and learn that there may be multiple causes. They analyze data on the current rate of extinction and engage in argument based on evidence about whether there is currently a sixth mass extinction caused by human activity.	MS-LS4.A MS-ESS3.C MS-LS4.D MS-LS4.B	Analyzing and Interpreting Data Engaging in Argument from Evidence Asking Questions and Defining Problems	Patterns Cause and Effect Stability and Change Connections to Nature of Science: Science Knowledge Assumes an Order and Consistency in Natural Systems Connections to Nature of Science: Science Addresses Questions About the Natural and Material World	ELA/Literacy: RST.6-8.7 WHST.6-8.9
15. **Reading: Bacteria and Bugs: Evolution of Resistance** Students obtain information about four types of organisms that have evolved resistance to chemical control methods. Students identify the cause-and-effect relationship between human activity and the evolution of resistance to chemical controls, and they consider whether this pattern is likely to continue in the future. They conclude by using the principles of natural selection to explain the phenomenon of the evolution of antibiotic resistance.	MS-LS4.B MS-LS4.C	Obtaining, Evaluating, and Communicating Information Constructing Explanations and Designing Solutions	Cause and Effect Patterns	ELA/Literacy: RST.6-8.1 WHST.6-8.9

EVOLUTION (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
16. **Investigation: Manipulating Genes** Students obtain and synthesize information from multiple sources about technologies that people have used over time to change the traits of organisms to make them more useful or desirable to people. They evaluate this information for its accuracy, reliability, and bias. They consider the impact of this technology on people and other organisms. The activity provides an opportunity to assess student work related to Performance Expectation MS-LS4-5.	MS-LS4.B MS-LS4.D	Obtaining, Evaluating, and Communicating Information	Cause and Effect Connections to Engineering, Technology, and Applications of Science: Interdependence of Science, Engineering, and Technology Connections to Nature of Science: Science Addresses Questions About the Natural and Material World	ELA/Literacy: WHST.6-8.2 WHST.6-8.8
17. **Project: Superbugs and Other Ways Humans are Affecting Evolution** Students synthesize their understanding of evolution by natural selection to communicate to an audience of peers and community members one important thing they have learned about how evolution has shaped and continues to shape life on Earth.	MS-LS4.B MS-LS4.C MS-LS3.B	Obtaining, Evaluating, and Communicating Information	Cause and Effect	ELA/Literacy: WHST.6-8.2

PHENOMENA, DRIVING QUESTIONS AND SEPUP STORYLINE

EVOLUTION

EVOLUTION

Unit Issue: How people can affect and be affected by evolution.

Anchoring Phenomenon: Populations change over time. Some changes take place over very long time periods, while others take place over observable time periods. People can cause and be affected by these changes. Examples include: there are more life forms now than there were in the past; some kinds of organisms have gone extinct, like large dinosaurs; organisms that are harmful, like some bacteria and pests, have developed resistance to our methods of eliminating them. Students generate and answer questions such as: How have populations changed over time? What caused these changes? How are people affected by and affecting evolution? Are people causing a mass extinction?

Investigative Phenomena	Driving Questions	Guiding Questions	Activities	PE	Storyline
Humans can change the way species, including bacteria, look or behave.	How are humans affecting evolution?	What happens when a person does not take antibiotics as prescribed? (Activity 1)	1 [14, 15, 16, 17]	MS-LS4-4 MS-LS4-6	Some bacteria are more resistant to antibiotics than others, and because of that, can become more abundant over time.
Populations change over time.	How do populations change over time?	How does the environment affect an individual's probability of survival and successful reproduction? (Activity 2)	1, 2, 3, 4, 5, 6	MS-LS4-4 MS-LS4-6 MS-LS3-1	Some traits increase an individual's chance of survival in a specific type of environment.
		How does natural selection happen? (Activity 3)			Natural selection is the process by which some traits become relatively more common in a population over time.
		What role does genetic variation play in the process of natural selection? (Activity 4)			Variation in traits is caused by mutations, and mutations are passed on to offspring; the frequency of the trait in the population depends on the environment.
		How do mutations affect survival? (Activity 5)			The sickle cell mutation is harmful when a person has two copies because it affects the structure and function of red blood cells; it is beneficial when a person has one copy in an environment with malaria.
		Why does sickle cell trait frequency vary across the world? (Activity 6)			The frequency of the sickle cell trait depends on two environmental variables—the frequency of malaria and the availability of health care.

PHENOMENA, DRIVING QUESTIONS AND SEPUP STORYLINE

EVOLUTION (continued)

Investigative Phenomena	Driving Questions	Guiding Questions	Activities	PE	Storyline
Evidence of species that no longer exist can be found in fossils.	What information can we learn from fossils?	How do new species evolve? (Activity 7)	7, 8, 9, 10, 11, 12, 13	MS-LS4-1 MS-LS4-2 MS-LS4-3	Natural selection happening over a short period of time leads to changes in trait frequency in a population; when it happens over a long period of time, populations with different traits may evolve into separate species.
		How are the diverse species living today related to one another and to the species that once lived on Earth? (Activity 8)			Speciation is a continual process that has resulted in many life forms and billions of species, most of which have gone extinct; all species are related to one another, sharing either a recent or distant ancestor.
		What kind of evidence do fossils provide about evolution? (Activity 9)			Fossils provide evidence for evolutionary relationships of organisms that lived in the distant and recent past.
		What other kinds of information can we get from fossils? (Activity 10)			Fossils can also provide information about the habits, traits, and environments of extinct organisms.
		What can you learn about evolution by comparing the fossil records of fish, mammals, and reptiles? (Activity 11)			Life forms have evolved over time, with some life forms having been relatively more abundant in the past, and other life forms becoming relatively more abundant more recently.

PHENOMENA, DRIVING QUESTIONS AND STORYLINE

EVOLUTION (continued)

Investigative Phenomena	Driving Questions	Guiding Questions	Activities	PE	Storyline
		How did whales evolve? (Activity 12)			Whales, despite sharing superficial similarities with fish, are aquatic mammals that evolved from terrestrial relatives; this evolutionary history is informed by fossil evidence and evidence from embryos.
		How can embryos provide evidence about evolutionary relationships? (Activity 13)			Embryos can reveal evolutionary relationships that are not apparent in the adult organisms.
Humans can change the way species look or behave, including bacteria.	How are humans affecting evolution?	Is the current rate of extinction typical? (Activity 14)	1, 14, 15, 16, 17	MS-LS4-4 MS-LS4-5	People are affecting evolution by causing a significantly higher rate of extinction than in the past.
		What is the evidence that resistance to chemical controls is evolving in other types of organisms? (Activity 15)			People are affecting evolution by changing selection pressure on organisms that cause problems for us; the evolutionary respons-es of these organisms can lead to additional problems for us.
		How have humans manipulated genes in other organisms? (Activity 16)			People have manipulated genes and, therefore, evolution of organisms for thousands of years, most recently through genetic engineering.
		How are humans affecting and affected by evolution? (Activity 17)			There are many ways humans are affected by and affecting evolution, and understanding evolution by natural selection is important for understanding and anticipating these processes.

UNIT OVERVIEW

EVOLUTION

Unit Issue: How people can affect and be affected by evolution.

Anchoring Phenomenon: Populations change over time. Some changes take place over very long time periods, while others take place over observable time periods.

Listed below is a summary of the activities in this unit. Note that the total teaching time is listed as 29–34 periods of approximately 45–50 minutes (approximately 6-7 weeks). There are no suggested activities to skip in this unit as skipping an activity in this case would mean losing key NGSS elements of the unit, e.g. the opportunity to practice elements of the PE prior to the activity that assesses it.

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
1. **Investigation: The Full Course** Students model the effects of antibiotics on a population of disease-causing bacteria during an infection. Students toss number cubes to determine whether an infected individual remembers to take the prescribed daily dose of antibiotics, which in turn affects the size and antibiotic resistance of the bacterial population in the patient. Students keep track of and graph the population size of the remaining bacteria depending on their resistance to antibiotics. Students consider the effect of changing the chemical environment on the survival of bacteria with varying levels of antibiotic resistance.	Antibiotic resistance, changing environment LITERACY MATHEMATICS	Prepare Student Sheet(s).	ODA QUICK CHECK Proc.	2
2. **Modeling: Hiding in the Background** Using toothpicks of two colors, students simulate the effect of prey coloration on predation rates by birds. They calculate and graph the changing frequencies of worm colors over successive generations. Students consider how this model is similar to the antibiotic scenario in the previous activity.	Traits, variation, population MATHEMATICS	Prepare Student Sheet.	ODA PROC. AID A1	2
3. **Role Play: A Meeting of Minds** Students role-play an imaginary meeting between Charles Darwin, Jean-Baptiste Lamarck, a modern-day science reporter, and a middle school student. In the role play, Darwin and Lamarck present and compare their explanations for how a change in a species occurs. Students learn that Darwin's explanation has been accepted as the Theory of Natural Selection and that this theory is essential to our understanding of evolution.	Natural selection, trait, variation, populations, evolution LITERACY	Prepare Student Sheet	EXP A3	1–2

EVOLUTION (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
4. **Modeling: Battling Beaks** Students simulate the effect of natural selection on an imaginary forkbird species. Genetic mutations, represented by tosses of a number cube, introduce variation into the population. Differential survival and reproduction of particular types of forkbirds changes the composition of the population over time. At the close of the activity, the class discusses the role of variation in the process of natural selection.	Natural selection, evolution, trait, variation, mutation, genes	Buy any dry O-shape cereal, prepare plastic forks (break off tines)	MOD QUICK CHECK A4 EXP A5 (Assessment of PE MS-LS4-4)	2
5. **Modeling: Mutations: Good or Bad?** Students follow the inheritance of a hemoglobin mutation through two generations. They investigate the effects of environmental conditions (incidence of malaria, survival rates, and resource availability) on the increase or decrease of the trait.	Natural selection, trait, variation, mutation, genes evolution, genes, structure/ function	Prepare Student Sheets.	MOD A3 (Assessment of PE MS-LS3-1)	2
6. **Computer Simulation: Mutations and Evolution** Students use a computer simulation to extend their investigation around the inheritance of the hemoglobin mutation. The simulation first extends their data from the previous activity through 30 generations. Then students are able to adjust the environmental conditions to see how access to resources and the prevalence of malaria influence the distribution of the hemoglobin gene over time.	Evolution, natural selection, population, trait, variation, cause and effect, computer simulation	Arrange access to computers with Internet access.	EXP A2 (Assessment of PE MS-LS4-6)	2
7. **View and Reflect: Origins of Species** Students watch a video segment on the evolution of Galapagos finches. They learn about Darwin's original discovery of the finches and how the birds contributed to his ideas about natural selection. They also learn about recent research done by Peter and Rosemary Grant over several decades, who documented the phenomenon of evolving beak size. They use a viewing guide to help them understand speciation and natural selection in the Galapagos finches.	Evolution, speciation, diversity LITERACY	View video, prepare Student Sheet.	EXP A1	1–2

EVOLUTION (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
8. **Reading: History and Diversity of Life** Students read text and examine graphs and charts to obtain information about both a brief history of life on Earth and a glimpse at the diversity of life on Earth today, as well as in the past. Stop to Think questions guide them through the reading to develop an understanding of the dynamic nature of life on Earth.	Evolution, speciation, diversity, extinction LITERACY	Prepare Student Sheet.	COM QUICK CHECK A4	1–2
9. **Laboratory: Fossil Evidence** Students examine and describe four types of fossils from various localities and geologic time periods. Students then examine four simulated drill cores, representing a fictional series of rock layers found in different parts of the world. The fossils in the drill cores are the same four fossils they examined. Based on the fossils contained within the layers, students are asked to determine how the layers in each locality correlate to the layers from the other localities. They are then challenged to use this fossil evidence to construct a timeline showing the relative timespans of each species represented by the actual fossils.	Fossils, paleontology, geologic time scale, evolution	Prepare Student Sheet.	AID A2	2
10. **Investigation: Fossilized Footprints** Students interpret fossilized footprint evidence that is presented to them in stages. Through this process, they develop their skills at distinguishing observations from inferences, and at modifying hypotheses in light of new evidence. They also learn about other kinds of evidence that can be gathered from fossils, such as behavior.	Trace fossils, paleontology, evidence versus inference, evolution LITERACY		ARG PROC. QUICK CHECK A3	1–2
11. **Investigation: Family Histories** Students draw and compare double bar graphs showing changes in the numbers of fossil families in the fish, reptile, and mammal classes over geologic time. From this evidence, they can conclude that both speciation and extinction have occurred in all classes of vertebrates for as long as each class has existed. Students discuss how this evidence provides further support for a branching model for evolution.	Evolution, speciation, extinction, classes, evolutionary tree		AID A1 (Assessment of PE MS-LS4-1)	2

EVOLUTION (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
12. **Investigation: A Whale of a Tale** Students investigate how fossil history provides another line of evidence for evolution. They compare the skeleton of a living whale to fossils of its extinct ancestors and use anatomical differences to arrange the skeletons in order. Students apply the theory of natural selection to whale evolution, using anatomical adaptations to infer the habitats and lifestyles of extinct species.	Evolution, speciation	Prepare Student Sheet.	EXP A4 (Assessment of PE MS-LS4-2)	2
13. **Investigation: Embryology** Students first examine six species to identify bones with homologous structures and functions. Although the fully formed limbs appear different on the outside, students are able to identify similarities at the skeletal level. Students then examine embryological development of limbs and notice many similarities between different species. Finally, students then examine development of whole embryos of different species to infer evolutionary relationships.	Evolution, embryos, embryology	Prepare Student Sheet, organize cards.	AID A3 (Assessment of PE MS-LS4-3)	2
14. **Talking it Over: The Sixth Extinction?** Students examine a graph showing rates of extinction over time and identify episodes where rates of extinction were well above the background rate of extinction. They match information on cards about the five major extinction events identified by scientists to the graph. They also summarize the possible causes for these extinctions. Students then read about rates of extinction since 1500 and examine possible causes for those extinctions. Students consider whether there is currently a sixth mass extinction due to humans and, if so, whether people should do anything to prevent it.	Extinction, extinction events, evidence and trade- offs	Copy Student Sheet.	ARG A2 E&T QUICK CHECK A4	2

EVOLUTION (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
15. **Reading: Bacteria and Bugs: Evolution of Resistance** Students read about four types of organisms that cause problems for people, the use of chemicals to control those organisms, and how the organisms ultimately develop resistance to these chemicals. Students draw connections to the evolution of antibiotic resistance introduced at the start of the unit.	Evolution, natural selection, resistance LITERACY	Prepare Student Sheet.	EXP A2	1
16. **Investigation: Manipulating Genes** Students search a collection of websites for information about one or more technologies that people have developed to affect traits of organisms. They summarize the key points from at least two sources and synthesize the information. They evaluate each source according to a set of criteria. Students share the results of their research with their peers. Finally, students consider the possible trade- offs of using these technologies.	Genetic engineering, genetically modified organism, selective breeding, artificial selection	Arrange Internet access; prepare Student Sheet.	COM A2 (Assessment of PE MS-LS4-5) E&T A3	2–3
17. **Project: Evolution and Us** Students develop a presentation or visual display to help scientists convince the public that learning about and understanding evolution is directly relevant to people's lives. They share this presentation or visual display within the classroom (and may also share it outside of the classroom).	Evolution, natural selection	Gather supplies for presentations/visual displays.	COM PROC.	2