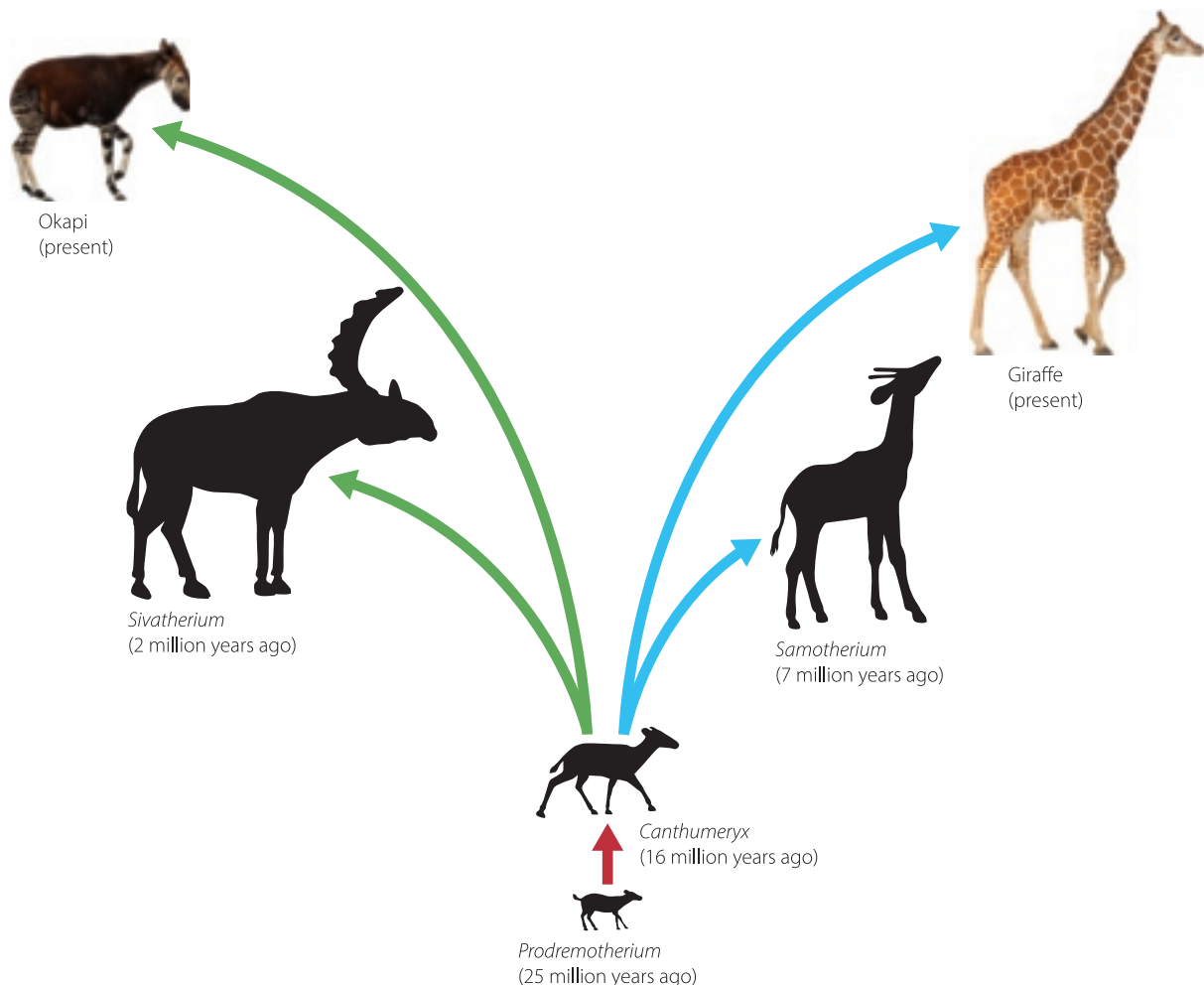


Unit 6

Natural Selection and Common Ancestry:

How could things living today be connected to the things that lived long ago?

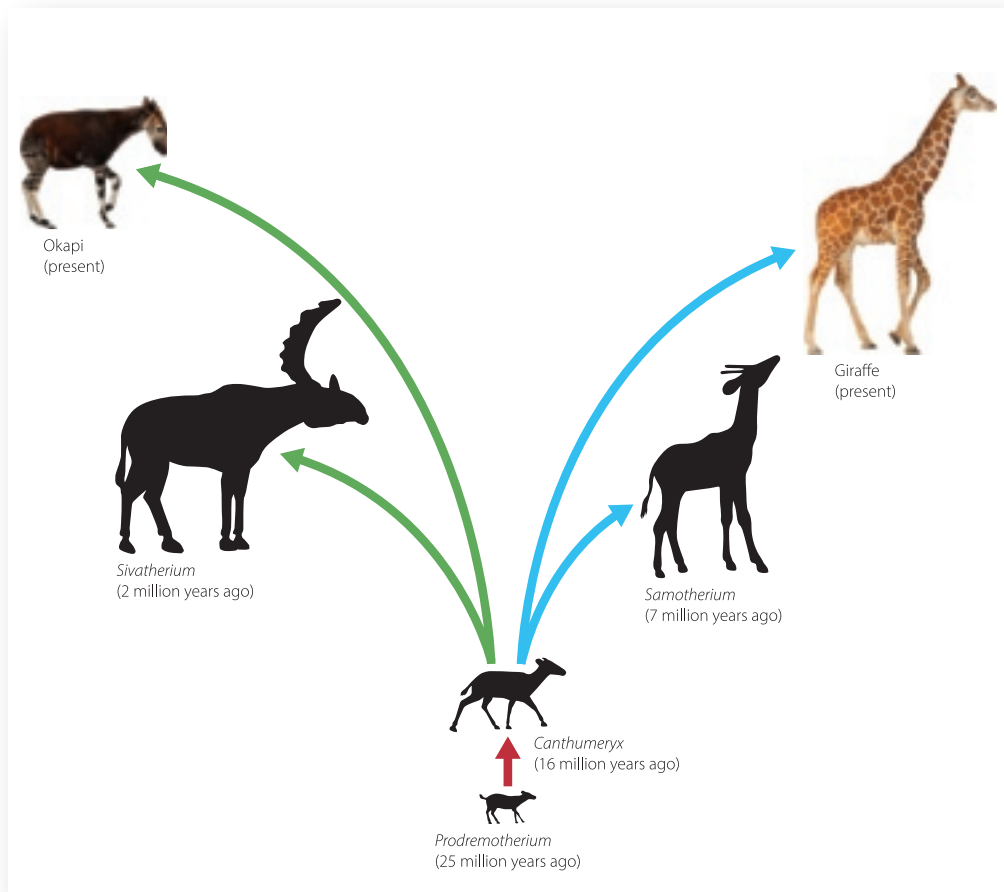
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Natural Selection and Common Ancestry:

How could things living today be connected
to the things that lived long ago?

Student Procedure Guide

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Natural Selection and Common Ancestry

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Lesson 1: How could penguins and other things living today be connected to the things that lived long ago?

Navigation

A giant penguin fossil that is 36 million years old was found in Peru.

With your class



1. Discuss the following questions with your class:

- What do you know about penguins?
- What kinds of experiences have you had with penguins?
- Where do they live today?

Meet Pedro, a human-sized penguin.

A team of researchers from Peru and the United States discovered a 36-million-year-old fossil of a giant penguin in Peru. We were able to talk with two members of the team, and they shared some photos of their discovery with us.

In your notebook



2. Listen to the recording of the story about Pedro's discovery and follow along in the transcript and photo journal.

3. Jot down the following and be ready to share your ideas with the class:

- a. any particularly interesting ideas you hear
- b. any questions that you have

Brainstorm types of evidence needed.

In the interview, this question was raised: How might penguins alive today be connected to the penguins that lived long ago, like Pedro?

With your class



4. Discuss the following questions with your class:

- What are different ways that living things could be connected to one another?
- What kinds of data would you need to determine whether penguins alive today are connected to Pedro?

Prepare to meet three species of penguins alive today.

In your notebook



5. Let's check out a few of the different species of penguins living today! We can keep track of what we notice using a data table.
- Tape *Penguin Comparison* into your notebook.
 - Keep track of the physical traits and behaviors you notice for each species of penguin.

Penguin Comparison	
Penguin Species	Physical characteristics

Meet three species of penguins alive today—emperor penguin.

With your class



6. Watch the video about the emperor penguin.
7. Examine the penguin card for the emperor penguin. Discuss observations with your partner.
8. Complete the data table on *Penguin Comparison* for the emperor penguin.

Meet three species of penguins alive today—southern rockhopper.

With your class



9. Watch the video about the southern rockhopper penguin.
10. Examine the penguin card for the southern rockhopper penguin. Discuss observations with your partner.
11. Complete the data table on *Penguin Comparison* for the southern rockhopper penguin.

Meet three species of penguins alive today—Adélie penguin.

With your class



12. Watch the video about the Adélie penguin.
13. Examine the penguin card for the Adélie penguin. Discuss observations with your partner.
14. Complete the data table on *Penguin Comparison* for the Adélie penguin.

Consider the connections among the penguins.

With your group



- 15.** Look back at our list of ways that living things could be connected to one another and the comparisons you made among the penguins. Discuss the following questions with your group and be ready to share your ideas with the class:
- What claims can you now make about how the emperor, Adélie, and southern rockhopper penguins are connected to one another?
 - What ideas do you have about how these 3 species of penguins might be connected to Pedro, but you would need additional evidence to support or refute?

Predict patterns in the penguins.

Last time, you made some claims about the ways that 3 species of penguins living today are connected to one another. You also considered how the 3 species of penguins might be connected to Pedro.

Turn and talk



- 16.** There are more than 3 species of penguins alive today. There are 18! Discuss the following questions with your partner and be ready to share your ideas with the class:
- What connections do you expect to find among the penguins alive today?
 - How might those patterns help us consider other possible connections between the penguins of today and Pedro?

Examine all eighteen species of penguins alive today.

Let's take a closer look at all the different species of penguins alive today and at Pedro to identify patterns in the data.

With your group



- 17.** Try grouping the cards in at least three different ways to help you see and talk about different patterns in the data. Be ready to share these patterns with the class.

Notice patterns in geographic data.

One type of pattern that we identified in the data was geographic location.

With your class



- 18.** Discuss the following questions with your class:
- What patterns did you notice in the geographic data across the different species of penguins?
 - What questions do you have?

Predict where other fossils would be found.

With your class



19. Discuss the following questions with your class:

- Where do you think we should dig to try to find more penguin fossils? Why?
- If we found penguin fossils there, what do you think the penguins would have looked like?

Draw and/or describe a penguin.

In your notebook



20. Follow your teacher's instructions and use *Predictions on Other Penguins That Lived Long Ago* to complete the following:

- Pick one of the places where you would want to hunt or dig for penguin fossils. Record this on the *Predictions on Other Penguins That Lived Long Ago* handout.
- Imagine you found a penguin fossil at your dig site. Make a prediction: Draw, list, or describe traits it would have had when it was alive. Predict whether they would be the same or different from those of penguins living today.
- Explain why you think this penguin would have looked like this.
- When the penguin you described above was alive, do you think it was the only species of penguin living on Earth? Why?

Compare predictions.

With a partner



21. Work with your partner to compare the ways your penguins might have been similar to or different from penguins living today.

Develop an initial model.

With your class



22. Work with your class to develop an initial consensus model to represent what you have figured out so far.

Navigation

Pedro is a species of ancient penguin that does not live on Earth today. We wondered if there were other species of ancient penguins that lived long ago. There are 18 different species of penguins that live on Earth today.

Turn and talk



23. Discuss the following questions with your partner and be prepared to share your ideas with the class.

- Where did all the ancient penguins go?
- Where did all the different species of modern penguins come from?

Write an initial explanation.

In your notebook



24. Use the *Initial Explanations* handout to organize your thinking.

Compare initial explanations.

With your group



25. Share your explanation with a small group, listening for similarities and differences among your explanations. Keep track of these ideas and be prepared to share the patterns you find with the whole class.

Similarities among our explanations	Differences among our explanations

Initial Class Consensus Explanation Discussion

Scientists Circle



26. Develop a whole-group record of what we agree on and where we have competing ideas across the initial explanations. Discuss the following questions with your class.

- What do we all seem to agree on?
- What do we disagree on?
- What are some new ideas that we may want to consider?

Where else have we seen this?

Turn and talk



27. Pedro is a bit different from the penguins of today. Discuss the following questions with a partner and be prepared to share your ideas with the class.

- What other organisms do you know of that lived in the past?
- What is a similar type(s) of organism alive today?

Organism from the past	Similar type of organism(s) alive today

Navigation

Turn and talk



28. We have shared many types of organisms that we think looked a bit different in the past than a similar organism alive today. Consider the reasons for why this might be and discuss the following questions with a partner.

- What are some possible reason(s) for these differences?
- What new questions does this raise for you?

What questions do you have?

In your notebook



29. Add a “Questions” section to your science notebook and jot down any questions you have that relate to what we have observed so far. To help you brainstorm your questions, look back at these resources:

- *Reference: Podcast Transcript and Photo Journal*
- penguin cards
- your sketch of a penguin fossil
- your initial explanation
- our list of similarities and differences in initial explanations
- your list of related phenomena

Revise our questions.

In your notebook



30. Review the questions you brainstormed. Use these question starters to create two revised or new questions to post to our Driving Question Board:

- Why ...?
- How ...?
- How would it be different if ...?
- What if ...?
- What is the purpose of ...?
- What causes ...?

31. Then write one question per sticky note.

- Write in marker—big and bold.
- Put your initials on the back in pencil.

Driving Question Board (DQB)

Scientists Circle



32. Work with your class to build the DQB as follows.

- The first student reads their question aloud then posts it on the DQB.
- Students who are listening should raise their hand if they have a question that relates to the question that was just read aloud.
- The first student selects the next student whose hand is raised.
- The second student reads their question, says why or how it relates, and posts it near the question it most relates to on the DQB.
- That student selects the next student.
- We will continue until everyone has at least one question on the DQB.

Information and Data Needed

What kinds of investigations could we do and/or what additional data might we need to figure out the answers to our questions?

In your notebook



33. Add your ideas to a new notebook page titled “Ideas for Future Investigations and Data We Need”. Be prepared to share your ideas with the class.

Navigation

In your notebook



34. What should we investigate next to help us make sense of this phenomenon?

Lesson 2: How similar or different are different species of penguins?

Navigation

On your own



1. Open your science notebook to where we recorded ideas for future investigations in our last class. Complete the following and be prepared to share your ideas.
 - Visit our Driving Question Board, Ideas for Future Investigations and Data We Need poster, and Penguin Timeline model.
 - Look for connections between the questions we had and our ideas for investigation.
 - If you think of any other ideas, add them to your notebook.

Progress Tracker: What have you figured out?

In your notebook



2. Create a T-chart under the heading “Progress Tracker”. Write the questions we are working on in the left column: What do we know about different penguins? What do we know about how they are similar and different?
3. Use words and/or pictures to record in the column on the right what you saw or uncovered in the data so far.

Connection Between Penguins

With your class



4. Discuss the following questions:
 - What evidence would we want to collect to figure out which species of penguin an offspring is?
 - Would we want to look at characteristics that are mostly inherited, like those that could be passed on, or characteristics that are mostly impacted by the environment? Why?

Make connections.

With your class



5. Discuss the following question:
 - Which were some trait variations that we argued were mostly inherited genetically? (The environment played a relatively minor role in the variation we saw in the trait between individuals.)

Use published information from fellow scientists.

With your class



6. Scientists like Dr. Sara Bertelli have collected data on body structures and behaviors of penguins.
 - Dr. Sara Bertelli has published data on heritable body structures and behaviors in modern penguins and other birds.
 - Researchers like Sr. Ali Altimanaro and Dr. Julia Clarke have used data sets like the ones that Dr. Bertelli has published to try to figure out how modern penguins are connected to ancient penguins.

Some Heritable Body Structures and Behaviors in Penguins

With your class



7. Follow your teacher's instructions and examine
 - the subset of some of the heritable structures and behavior data Dr. Sara Bertelli collected for modern penguins,
 - some different possible variations found in the modern penguins, and
 - other external body structures and behaviors that may have more than two variations possible.

Analyze penguin character data to find patterns.

With a partner



8. Follow your teacher's instructions for using *Data Strips: External Structures in Modern Penguins and Pedro* and *Reference: External Structures and Behaviors Key* to complete the following with your partner:
 - Analyze the data strips that contain information about the body structures and behaviors of different penguins.
 - Sort them to see what patterns emerge. There is no right or wrong way to sort these data strips.

Record patterns.

In your notebook



9. Prepare a sheet of paper to record what patterns you notice, titled: **"Patterns in heritable external body structures and behaviors across all the modern penguins (and Pedro)."**
10. Record these patterns on your paper. Your teacher will provide you small stickers of the penguins to use to help do this in the last three minutes of this activity.
11. Be prepared to share these with the whole class.

Explain body structure and behavior variations.

With a partner



12. Discuss the following with your partner and be prepared to share your ideas with the whole class.

- What are two species of penguins that have the same variations for all the external body structures and behaviors you compared?
- What are two species of penguins that are pretty different?
- Do we feel better prepared to explain where modern penguins came from and where ancient penguins like Pedro went?

Orient to the bones in penguins.

With your class



13. Examine the following:

- the shape of the tip of a penguin's beak
- structures related to the shape of the shoulder blade of a penguin
- structures in the leg of a penguin
- the bone called the humerus in a penguin
- the different possible variations in traits

Record new questions.

- We have analyzed data of heritable external structures and behaviors and used them to group different species of penguins.
- We have looked at some images of internal body structure in modern penguins and Pedro.
- We will look at data of these internal structure variations in modern penguins and Pedro next.

On your own



14. Write what new questions you have on your sticky note.

Share new questions.

With your class



15. We have looked at some internal body structure variations in modern penguins and Pedro. Discuss these prompts with your class.

- What new questions did this investigation raise for you?
- How might examining bone structures across different species of penguins help us make progress on some of these questions?

Analyze penguin character data to find patterns.

In your notebook



- 16.** Prepare a new 2-page section of your notebook to record what patterns you notice. Title this section “Patterns in external & internal heritable body structures and behaviors across modern penguins (and Pedro)” and be prepared to share your ideas with the class.

With a partner



- 17.** Complete the following:
1. Analyze the data by comparing internal penguin structures.
 2. Sort them to see what kinds of patterns emerge.
 3. Unfold the data strips to also consider the external structures and behaviors.
 4. Record these patterns in your science notebook using the penguin stickers.

Reflect on patterns of body structures.

With a partner



- 18.** Discuss the following questions with your partner and be prepared to share your ideas with the whole class:
- What are two species of penguins that have the same variations in common for almost all the heritable body structures you compared?
 - Where did these penguins inherit their body structures from?
 - Why would they have so many heritable body structures in common?

Connection between Pedro and Modern Penguins

On your own



- 19.** On *New Questions and Ideas for Data We Need*, record your response to the questions: *Do you think Pedro could be an ancient ancestor of any of the modern penguins? Why or why not?*

Navigation

On your own



- 20.** On *New Questions and Ideas for Data We Need*, record the following and be prepared to share with the whole group next time:
- Record what new questions you now have.
 - Record any ideas for what data we need to analyze to begin to figure out some of these questions.

Lesson 3: How do the body structures of other ancient penguins compare to modern penguins?

Navigation

With your class



1. Share some of the questions you recorded last time on *New Questions and Ideas for Data We Need* on a sticky note after examining data.
2. Discuss the following question: How could analyzing these data from fossils of other ancient penguins help us make progress on some of our questions?

Analyze penguin bone data to find patterns.

With a partner



3. Complete the following with your partner and be prepared to share with the whole class:
 - Spread out the data strips for the ancient and the modern penguins.
 - Group and sort them based on their similarities and differences using the body structure variation key as needed.
 - Try sorting them multiple different ways.
 - Identify any connections you notice between the ancient penguins and the modern ones.

Share patterns.

With your class



4. Discuss this question with your class: What patterns did you and your partner notice as you sorted the penguin cards?

Make predictions.

On your own



5. Individually complete the following:
 - Pick one of the fossil data strips representing a penguin that you think might be more ancient (older) than Pedro. (lived more than 36 million years ago)
 - Pick one of the fossil data strips representing a penguin that you think might be less ancient (younger) than Pedro. (lived less than 36 million years ago)

With a partner



6. Share with a partner why you picked these two strips.

Prepare to compare the relative age of the fossils.

With your class



7. Follow your teacher's instructions and complete the following with your class.
 - Orient to the timescale on *Timeline Sections*. The ancient penguin data strips have a white box at the bottom that needs to be colored to correspond to that penguin's time period. See Pedro as an example.
 - Get colored pencils or color markers ready to add one of the colors shown on the timeline to the penguin fossil data strips.
8. Follow your teacher's instructions and color in the bottom white box of your penguin fossil data strips. Lodell's is shown as an example. You can also write in the names of the colors.

Compare the age of the fossils.

With your group



9. Complete the following with your new group:
 - Tape the timeline sections onto a piece of poster paper.
 - Organize the data strips by time period and look for connections to patterns in the body structure data.
 - Discuss different patterns you notice in the trait variation data between different penguins across time.
 - Tape your organization of these data strips above the timeline on your poster paper.
 - Using words, pictures, and/or drawings, annotate the paper with any connections your group saw in the trait variation data.
 - Roll up your poster and write your group members' names on the outside of it. Save the poster for a gallery walk in the next class.

Prepare for a silent gallery walk.

In your notebook



10. Add a section to your Progress Tracker with the question: **"How do the body structures of other ancient penguins compare to modern penguins?"**
11. Follow your teacher's instructions and carry out a silent gallery walk, comparing patterns on two posters (one of these can be your own).

12. Record in your Progress Tracker the patterns you notice across these two posters.
13. Be prepared to share these with the whole class.

Prepare to compare the relative age of the fossils.

With your class



14. View the slide and orient to the maps of Earth for two different points in the past.

Orient to ancient penguin cards.

With your class



15. Orient to the new types of data on *Ancient Penguin Data Cards*.

Compare the ancient penguins.

On your own



16. Organize your subset of cards in a way that is not only based on time period or bone structure variations. Repeat this task, trying out at least 2 other ways of organizing your cards.

With your group



17. Complete the following with your group:
 - Take turns having each group member suggest one possible way of organizing all the cards. Work together to do that.
 - Look for patterns in the penguins' structures now that they are in these new clusters. Discuss these as a group.
 - Repeat these last two steps until each person on the team has had a chance to facilitate at least one different way of organizing the cards.

Exit Ticket

On your own



18. Use the latest entry in your Progress Tracker and what you just figured out with the penguin fossil cards to answer the question: **How do the body structures of other ancient penguins compare to modern penguins?**
19. Be prepared to share these with the whole class.

Interpret the data.

With your class



20. Complete the following with your class:

- Share the patterns we noticed regarding connections among the characteristics of ancient penguins.
- Weigh in on whether we found similar patterns in our small groups.
- Identify areas of our Penguin Timeline model that we can start to fill in based on these patterns.

Navigation

Turn and talk



21. Discuss this question with a partner: How could measurements from only a few bones of a penguin fossil help a scientist estimate the penguin's overall size and height as well as its overall body structure?

Home Learning

Turn and talk



22. Discuss this question with a partner: How could measurements from only a few bones of a penguin fossil help a scientist estimate the penguin's overall size and height as well as its overall body structure?

Home Learning



23. Your reading will explore this question further: How do scientists know what an ancient penguin looked like from just its bones?

Lesson 4: Why are there similarities and differences in the body structures of modern and ancient penguins?

Navigation

Scientists Circle



1. Recall that we began our investigation by wondering if Pedro could be connected to modern penguins, and we identified these two important subquestions:
 - Where did all the ancient penguins go?
 - Where did all the different species of modern penguins come from?

Turn and talk



2. Look back in your notebook and discuss these questions with a partner: What evidence do we have for one or more of the updates we plan to make to our model?

Develop consensus representation of penguin groupings.

With your class



3. Repeat the following process with your class until all the penguins are grouped in a way that the class can agree on (for now):
 - Propose a potential penguin group. Justify the grouping decision with evidence.
 - “I think we should have a grouping for X, Y, and Z penguins here because (give evidence for why they go together).”
 - Agree, disagree, or propose a modification to the grouping (based on evidence).

Develop an explanation.

We are thinking about the question: Where did all the ancient penguins go?

In your notebook



4. Look back at your initial explanation from Lesson 1. Using evidence from our penguin groupings, make some notes about what we can add to or change about our explanation.

With your class



5. Work with your class to develop a consensus explanation based on evidence from the penguin groupings in response to the question: *Where did all the ancient penguins go?*

Develop an explanation.

We are thinking about the question: Where did all the different species of modern penguins come from?

In your notebook



6. Look back at your initial explanation from Lesson 1. Using evidence from our penguin groupings, make some notes about what we can add to or change about our explanation.

With your class



7. Work with your class to develop a consensus explanation based on evidence from the penguin groupings in response to the question: *Where did all the different species of the modern penguins come from?*

In your notebook



8. Develop an explanation in response to the question, *Why are there similarities and differences in the body structures we see between modern and ancient penguins?*

With your class



9. Work with your class to develop a consensus explanation to answer the question: *Why are there similarities and differences in the body structures we see between modern and ancient penguins?*

Analyze our explanations.

We have consensus explanations for these questions:

- *Where did all the ancient penguins go?*
- *Where did all the different species of modern penguins come from?*
- *Why are there similarities and differences in the traits we see between modern and ancient penguins?*

With your class



10. Review the three class consensus explanations by answering the following questions with your class:
 - Where are there gaps or missing evidence in our explanations?
 - What kind of evidence might make our explanations stronger?

Clarify traits.

With your class



11. Examine the images displayed by your teacher that show differences in key body structures of cattle and African buffalo.
12. Examine the images displayed by your teacher that show differences in penguin body structures.

Populations and Individuals

For some of our ancient penguin groupings, we used body structure variations such as similar humerus (a bone in the upper flipper) to group the penguins.

Turn and talk



13. Think back to one of the ancient penguins like the giant spear-billed. Do you think a body structure variation measured in a single penguin fossil was typical for the entire population of penguins that that individual belonged to when it was alive? Or, do you think the body structure variation was unique to that one individual that happened to be preserved as a fossil? Why?

- Discuss with a partner:
 - What do you think?
 - Why?
- Be ready to share your ideas with the class.

Analyze and interpret fossil data.

With your class



14. Follow your teacher's instructions and examine and discuss the fossil data on *Reference: Analyzing and Interpreting Fossil Data*.

Turn and talk



15. Look at the ancient penguins for which we have more than one fossil and discuss the following questions with a partner:

- Think back to the penguin cards. How would you describe what the data in the right column mean?
- What do you notice? What is the entire data table telling us?

Analyze and interpret trait variation.

With your class



16. Discuss the following with your class: If someone found another *Urbina* penguin fossil from the same place and the same time as the *Urbina* penguin fossils that have been found so far, what percent of body structure variations would you expect it to have in common with those already discovered?

Analyze and interpret body structures.

With your class



17. Discuss the following with your class: Which populations of modern penguins have variation for these bone structures?

Examine variation within and between populations.

With your class



18. Examine the images of data cards on the slide and discuss the following with your class: What are some penguin structures and behaviors represented on these cards? For which of these structures or behaviors would you expect to see variation between individuals in the same population?

Investigate a specific trait variation character.

With your class



19. Discuss the following with your class:
- Can we say with certainty that *all adult king penguins are taller than all adult Galápagos penguins*?
 - What evidence from the cards supports your claim?

Analyze distribution in a population.

With your class



20. Examine the graph that shows the results of measuring the height of many Galapagos and king penguins.

Exit Ticket

On your own



21. Select another body structure or behavior that the Galápagos and king penguins share. Using information from the penguin cards, describe what you predict the variation in that body structure or behavior looks like **between** the Galápagos penguins and king penguins and **within** each population. Use *Exit Ticket - Trait Variation* to explain your thinking.

Revisit our related phenomena.

Turn and talk



22. Discuss the following with a partner and be ready to share your ideas with the class:
- How could we use our related phenomena to see if what we have figured out can apply to more than just penguins? *or*
 - How could we get more information about what was happening to penguins by looking at some other fossil records?

What questions can we answer?

On your own



- 23.** Visit the Driving Question Board and identify one question that you think we have answered or made progress on.
- 24.** Write your answer, based on evidence from Lessons 1-4, to a question on the Driving Question Board on a different-colored sticky note. Attach this sticky note to the original question.

Lesson 5: How might other living things be connected to ancient organisms?

Navigation

With a partner



1. Discuss this question with a partner: What did we figure out in our last lesson?

With your class



2. Discuss this question with your class: How could looking at data from other ancient and modern organisms help us answer our questions?

Organisms Character Sort

With your group



3. Follow your teacher's instructions and use *Day 1: Horseshoe Crab Data Cards*, *Day 1: Horse Data Cards*, and *Day 1: Whale Data Cards* to complete the following with your group:
 1. Identify in your set of organisms at least three body structures that show variation.
 2. Create a model by organizing the data cards on your table in a way that shows how similar or different you think your organisms might be to each other based on how similar or different their body structures seem to be.
 3. Use sticky notes to label your model and indicate what body structures and variations you used to sort the organisms.
 4. Leave your organized cards and labels out on your table.

Gallery Walk

In your notebook



4. Title a new page in your notebook: "Organizing (name of organism) by body structures."
5. Follow your teacher's instructions and do a gallery walk. Record similarities and differences in how other groups organized their data cards and be prepared to share your thinking with your group.

With your group



6. Discuss what you recorded and make any desired adjustments to your organizational model based on evidence.

What additional data do we need?

On your own



7. Complete the following in your notebook and be ready to share your thinking with the class.
 1. On 2 new pages of your notebook, use stickers and labeling to create a model showing your ideas about similarities and differences among your organisms.
 2. Now that we have some ideas about how closely connected our organisms are based on their body structures, ***what other information might help us better understand the patterns we noticed?*** Record your ideas on a clean page in your notebook.

Make predictions.

With your class



8. Follow your teacher's instructions and show a thumbs up, down, or sideways to indicate your response to the following questions:
 - **Where they live(d):** Do you think that how similar organisms are (based on their body structures) will be connected to *where* they live(d)?
 - **When they live(d):** Do you think that how similar organisms are (based on their body structures) will be connected to *when* they live(d) in time?

With a partner



9. Discuss the reasons for your predictions with a partner and be ready to share your thinking with the class.

Share predictions.

With your class



10. What were some of the reasons you and your partner gave for your predictions about the questions below?
 - **Where they live(d):** Do you think that how similar organisms are (based on their body structures) will be connected to where they live(d)?
 - **When they live(d):** Do you think that how similar organisms are (based on their body structures) will be connected to when they live(d) in time?

Prepare to analyze data to check our predictions.

With your class



11. We want to see if the data support or refute any of these predictions. You will work with the same group and organism as you did last time, but this time you will either focus on *where* or *when* the ancient and modern organisms live(d).

Sort by when or where they live(d).

With your group



12. Follow your teacher’s instructions to sort your organisms and see if the patterns in when or where they live(d) match patterns in their body structures. Complete the following with your group:

1. Sort your organisms by location or time.

Where they live(d)	When they live(d)
• where on Earth geographically • their local environment	• the order in which they appear in time • how close together they are in time

2. Discuss whether the patterns you discover match patterns in body structures.

Share your findings.

With your group



13. Prepare to discuss your findings with other groups. Write out how the patterns of body structures of your organisms are connected to either when or where they lived in the “How patterns of body structures are connected to my factor” section on *Patterns for My Organism*:_____

Scientists Circle



14. Get together with all the other groups that are working with the same organism.

15. Take turns sharing with the others in your circle the patterns you noticed, asking clarifying questions and recording their findings on *Patterns for My Organism*:_____.

Create a consensus model. Become an expert!

With your group



16. Based on everything you have learned, organize your data cards in a model that shows how you think the organisms might be connected.

In your notebook



17. Create a copy of that model in your science notebook using stickers. Record the reasons why you arranged the ancient and modern organisms that way.

Compare models in a jigsaw activity.

With your group



18. Follow your teacher's instructions and join a group of three (one person for each organism) and, **using good peer feedback practices**, complete the following:

- Share your model for your organism and listen to others as they describe their models.
- Share your answers to the questions on *Guiding Questions to Compare Our Models*.

Navigation: Where do we go from here?

On your own



19. Now that you have listened to the ideas of the others in your group, record your answers to the final two questions on *Guiding Questions to Compare Our Models*. We will pull the pieces together and organize all our ideas the next time we meet.

Lesson 6: How could organisms living today be connected to organisms that lived long ago?

Navigation

With your class



1. Discuss this question with your class: *What were some of the patterns we saw across all the different types of ancient and modern organisms we looked at in our last lesson (horses, whales, and horseshoe crabs)?*

With a partner



2. Discuss the following with a partner:
 - How do we think the similarities and differences we saw in the organisms preserved in the fossil record and modern-day whales, horses, and horseshoe crabs are connected?
 - Explain why you think that.

Take a poll.

With your class



3. Follow your teacher's instructions and when signaled, raise your hand if you agree that there is a connection between ancient and modern penguins.

Make and defend a claim.

On your own



4. Use "How are penguins today connected to penguins from long ago?" *Argument and Self-Assessment* to write a claim responding to the following question and defend your claim with evidence. Be prepared to share your ideas with the class. **How are penguins today connected to penguins from long ago?**

Share claims with a partner.

With a partner



5. Discuss the following question with a partner: How are penguins today connected to penguins from long ago?

Scientists Circle



6. Discuss the following question with your class: How are penguins today connected to penguins from long ago?

Discussion Self-Assessment

On your own



7. Complete part 2: "Discussion Self- Assessment" on "*How are penguins today connected to penguins from long ago?*" Argument and Self-Assessment.

Revisit our arguments.

With your class



8. Consider the following questions on your own and then with your class:
 - What was our argument for why there must be a line of descendants connecting one or more ancient penguin populations to modern ones?
 - Did we agree on what those lines of descent were?
 - Is there anything you want to revise from your previous argument?

On your own



Propose possible explanations.

On your own



9. Consider the following questions and list in your notebook possible causes and how they might contribute to this outcome:
 - What could be causing changes in the traits within a population?
 - How could that cause an entire population's trait distribution to change over time?

Stop and jot additional questions.

On your own



10. Jot down any questions you now have about this phenomenon as well as connections to similar things happening in other types of organisms.
 - Record each idea on a sticky note in **bold print so that everyone can see.**
 - Be ready to post your sticky note on the Driving Question Board.

Add questions to the DQB.

Scientists Circle



11. Follow the procedures for adding questions to the DQB:
 - The first student reads their question aloud then posts it on the DQB.
 - Students who are listening should raise their hand if they have a question that relates to the question that was just read aloud.
 - The first student selects the next student whose hand is raised.

- The second student reads their question, says why or how it relates, and posts it near the question it most relates to on the DQB.
- That student selects the next student.
- We will continue until everyone has at least one question on the DQB.

Navigation

With a partner



12. Discuss the following question with a partner:

- How could looking for whether such changes happen over a shorter timescale (fewer generations in any population) help us make progress on parts of our expanded DQB?

Lesson 7: How do traits found in a population change over a shorter amount of time?

A New Phenomenon

With your class



1. As we prepare for our next steps, discuss the following questions with your class:
 - How could investigating whether such changes happen over a shorter timescale (fewer generations in any population) help us make progress on our questions?
 - What data would we need in such cases in order to determine whether our ideas about what is happening in a line of descendants are supported or refuted?

Five Cases

With your group



2. With your group, familiarize yourself with the text and pictures on the slide.
3. Discuss what is similar and different among the five cases. Record these ideas in your science notebook.

Share your initial ideas.

Turn and talk



4. Discuss the following with a partner who is assigned a different case than yours:
 - Why do you think the changes may have occurred with your organism?
 - What do you think might have caused those changes to happen?

Prepare to analyze data about our cases.

With your group



5. Examine the data subset and case overview provided by your teacher.

Analyze the data for your case.

With your group



6. Work with your designated case group.
 - Read and understand the *Overview* section, using the color copy as a reference.
 - Annotate your personal copy as needed.

On your own



7. Independently work through your assigned data subset.

- Analyze the data in your data subset carefully.
- Record what they show and what they mean in the table at the end of your section.

A. Identify: What do I see in the data?	B. Interpret: What does this mean?

- Annotate the next data subset.

8. Be prepared to share your analysis with your group.

What if I do not finish my analysis and annotation?

Home Learning



9. You can finish your analysis and notation for home learning.

- Be sure to note any questions you have as you finish your analysis.
- You will share your findings with your group during the next class.

Navigation

With your class



10. Discuss the following questions with your class:

- Why are we looking at changes in a population of organisms over a few generations? How did we think this would help us make progress on the types of questions we had from our fossil-related cases?
- What is the goal of your group's analysis of your case? What are you working together to try to do?

Share your analysis.

With your group



11. Gather with your case study group. Share the results of your analysis using the instructions below.

- Start with data subset 1.
- Share what data were in the subset, what the data show, and what they mean.
- Share annotations (noticings and wonderings).
- Ask questions and discuss.

On your own



12. After each group member shares, complete the following on your own:

- Record a brief summary in the table at the end of the data subset.

A. Identify: What do I see in the data?	B. Interpret: What does this mean?
My summary:	My summary:

- Move to the next data subset.

13. Continue until all members of your group have had a chance to share and discuss their analysis.

Make a preliminary model.

On your own



14. Create an index card describing the meaning of your data subset for your organism.

With your group



15. Complete the following with your group:

- Create a model that explains what happens and how and why you think it happens that way.
- Use sticky notes to connect and explain.

Refine our thinking.

With your class



16. Prepare to discuss the crosscutting concepts.

We are going to use the crosscutting concepts to help us think about the complex natural systems of organisms and whole populations of organisms, their survival and reproduction, as well as their environment and what happens to them over time.

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter
- Structure and Function
- Stability and Change

Think together using a CCC Lens—Structure and Function.

With a partner



17. Work with a partner in your group to record your responses to the questions in the “Structure and Function” section of the *Using the CCC Lens* handout.

Think together using a CCC Lens—Cause and Effect.

With a partner



18. Working with a new partner, record your responses to the questions in the “Cause and Effect” sections of the *Using the CCC Lens* handout.

What if I do not finish my CCC thinking?

Home Learning



19. You can finish your CCC thinking for home learning.
- Be sure to note any questions you have as you think about your case using the CCC lenses.

Think about probability.

With your class



20. Think about your answers to these questions:
- Would the specific trait variation you are investigating always affect an individual the same way?
 - Does the trait variation affect how likely the individual would be to produce offspring?
21. Be ready to share your thinking with your class.

Make a preliminary model.

On your own



22. On your own, work on the “CCC: Systems and System Models” section of *Develop a System Model*. When you finish, go on to complete the second page of the handout.

Five Cases

With your group



Now that you have had the chance to think individually about the system model for your case, your group needs to come to a consensus in order to tell the story of the cause(s) for the changes in your population.

A Chain of Cause and Effect

With your group



- 23.** Examine the two different chain of cause and effect models shown on the slide.

Resources for a Chain of Cause and Effect

With your group



- 24.** Follow your teacher's instructions for building a chain of cause and effect to tell the story of what caused the changes in your population to happen for your group's case.
- 25.** Use the following resources to build your chain of cause and effect:
- Data packet for your case
 - Index cards for the data subsets
 - Preliminary model
 - CCC: Structure and Function
 - CCC: Cause and Effect
 - Your individual thinking about Systems and System Models and what happens over a few generations
- 26.** You may want to sketch or write ideas in your science notebook.

Create a system model poster.

With your group



- 27.** Follow your teacher's instructions and create a poster to communicate to others the story of what caused the changes in your population to happen for your group's case.

Next Steps

We have developed system models that tell the story of what caused the changes in a population in multiple cases.

With your class



- 28.** Discuss with your class the reason for investigating these cases.

Lesson 8: How can we model what is causing the changes in the populations happening across all our case studies?

Navigation

With your class



1. Discuss this question with your class: How could developing a general model for explaining all five of our cases help us answer some of the questions we had about ancient and modern penguins, horses, and so forth?

Discussion Protocol #1: Share case system models.

With a partner



2. Prepare to share your case with someone who has a different case. Review the discussion protocol:
 - Each person has equal time (4 minutes) to share the story of what their population change was and what caused their population to change.
 - The person who is not presenting is actively listening for any similar cause, mechanism, or relationship to one in their own system model.
 - Signal these similarities by snapping fingers a few times. This will allow the person presenting to continue on with their explanation without pausing yet for questions.
3. Using the protocol above, carry out a poster walk and talk with the partner you have been assigned from a different case study.

Create a system model poster.

Scientists Circle



4. With your science notebook, regroup as a whole class in a Scientists Circle around the General Model for Natural Selection poster.
5. Open up to the next blank page in your science notebook and title it as follows:
 - Our General Model for explaining: How and why is the population changing in all our cases?
6. Together as a class, start building parts of a general model for explaining all the cases.
7. Add the corresponding model ideas to your notebook page using the sticky notes provided to you.

Discussion Protocol #2: Create General Model ideas.

With a partner



8. Working with your partner from the poster talk, develop additional model ideas to explain multiple cases. Add these ideas to the general model in your notebook:
 1. Figure out general statements describing Survival and Reproduction for the pink paper and Offspring and Inheritance for the blue paper.
 2. Decide the order they go in and connect them with arrows.
 3. Write out what is going on in the arrows by finishing the statement "Because of this"

Reflect on our discourse contributions.

On your own



9. Reflect on the discourse you participated in today. Complete the *Argumentation Self-Assessment* handout and turn it in to your teacher as you leave class.

Discussion Protocol #3: Test the General Model ideas.

With a partner



10. Compare your previously created model ideas with a new partner. Following the protocol below, modify your general model statements as needed.
 1. Share one of the general model ideas you recorded in your notebook last time.
 2. Ask your partner if it applies to their own case and if it needs to be modified in any way to be a better fit for their case, too.
 3. As needed, work together to figure out how to revise the wording of that general model idea.
 4. Then switch to the other partner and have them share one of their model ideas they recorded and repeat the steps above.
 5. Continue doing this until you have gone through the entire set of both of your model ideas or the time is up.

Develop our General Model.

Scientists Circle



11. Gather your science notebook (with the sticky notes that describe your general model ideas) and something to write with and prepare to move to our Scientists Circle.

12. Work with your class to develop the remaining parts of a general model for explaining all these cases.

Connection to Environmental Interactions

Turn and talk



13. Turn and talk with a shoulder partner about what part of our model you think is caused by the environmental interactions and how it is connected.

What comes next?

Turn and talk



14. Turn and talk with your other shoulder partner about what part comes next, blue or purple.
- What part should the arrow coming from the pink paper connect with and what “Because of this . . .” statement connects them?

Use our model to make predictions.

On your own



15. On your *How can we use our model to make predictions?* handout, use our model of natural selection to make predictions about what would happen
- to any population,
 - in any environment, and
 - over a different number of generations.

Lesson 9: How well does our General Model predict and explain the changes happening over time in a different population?

Navigation

In your notebook



1. Add your copy of the General Model for Natural Selection to your Progress Tracker.
2. Circle the question on the top of the model that the model is answering: How and why is the population changing in all our cases?

Test our model and predictions.

With your class



3. Review how we used our model to make predictions about what would happen
 - to any population,
 - in any environment, and
 - over a different number of generations.

Consider that there are two types of experimental systems scientists typically use to test such predictions:

- a population of live organisms
- a simulation of a system that has a population in it

What We Need in a Simulation

On your own



4. Make a T-chart in your science notebook and title the page "Simulation Needs".

Parts of the system that need to be included	Parts we need to be able to change

5. Brainstorm what needs to be a part of the system in the simulation in order to test our model and the things we need to be able to change or control in the simulation.
6. Be prepared to share these ideas with a partner.

Compare organisms.

With your class



7. Examine the list of organisms on the slide and discuss the following question with your class: Why do you think these are some of the more-commonly used organisms for studying traits in offspring over many generations?

Compare reproductive rates.

With your class



8. Discuss the following questions with your class:
 - Some organisms can reproduce asexually. How is this different than sexual reproduction?
 - What happens to a bacterium cell when it reproduces asexually?
 - Why might it be easier to determine if a trait is heritable using an organism that reproduces asexually instead of sexually?

Compare salmonella bacteria.

Examine the image on the slide. The structures seen sticking out of some of the individual salmonella bacteria are called flagella. They use these structures to move around.

With your class



9. Discuss the following questions with your class:
 - What variation do you notice among them?
 - Do you think any of these variations would give some individuals an advantage for surviving in certain environments? Why?

Brainstorm

With your class



10. First, take a minute on your own to brainstorm some specific risks and resources for bacteria:
 - Risks in the environment
 - that can kill off bacteria outside our bodies
 - that can kill off bacteria inside our bodies
 - Resources in these environments that bacteria need to live, grow, and/or reproduce
11. Then after a minute, share your ideas with the whole class.

Orient to the structures that fight off an infection.

With your class



- 12.** Follow your teacher's instructions and watch the video to see an example of how a white blood cell fights off a bacterial infection.

Orient to the simulation.

With your class



- 13.** Follow your teacher's instructions and watch the screencast which explains how variables can be changed in the simulation model.

Carry out investigation 1: neutrophil in the environment.

With a partner



- 14.** Follow the steps below to carry out investigation 1:
- Access the simulation using this URL: <https://www.openscienced.org/general/salmonella-hunt/>
 - Check that the settings match the image on the slide.
 - Press "setup" and then "go/pause".
 - Hunt bacteria by chasing them around and clicking on them. See if you can catch more than your partner does in the same amount of time.
 - When the simulation automatically stops, compare your results with your partner. Discuss the following questions:
 - What happened to the distribution of the traits in your populations?
 - Why might you and your partner have gotten similar shifts but not exactly the same results?

Make sense of the investigation.

On your own



- 15.** Complete part B of your *Investigation 1* handout by answering the questions about how and why the population changed in this environment.
- 16.** Be prepared to share these ideas with a partner.

Compare our results: neutrophil in the environment.

With your class



17. Look back at the discoveries you summarized on your *Investigation 1* handout from last time.
18. Discuss the following questions with your class:
 - How did the bacteria population change in the simulated environment?
 - How can we explain this outcome in terms of competitive advantage?
 - Why might you and your partner have gotten similar shifts in the distribution of trait variations but not exactly the same results?

Make predictions.

Turn and talk



19. With a partner, make predictions about the following questions:
 - What do you think will happen to the population if we change the simulation environment so that it has only nonmoving white blood cells (monocytes) in it? Why do you think this?
 - Would anything change if you ran the simulation under those conditions for a longer length of time?
20. Be prepared to share your predictions with the whole class.

Carry out investigation 2: monocyte in the environment.

With a partner



21. Follow the steps below to carry out investigation 2:
 - Access the simulation using this URL: <https://www.openscienced.org/general/salmonella-hunt/>
 - Check that the settings match the image on the slide.
 - Press “setup” and then “go/pause”.
 - Hunt bacteria by keeping your cursor in one place and letting the bacteria run into it. See if you can catch more than your partner does in the same amount of time.
 - When the simulation automatically stops, compare your results with your partner. Discuss the following questions:
 - What happened to the distribution of the traits in your populations?
 - Why might you and your partner have gotten similar shifts but not exactly the same results?

With a partner



22. Discuss the following with your partner:

- At the start of the model run there were 6 different trait variations in your bacteria population. With your partner, compare how many different trait variations there are in each of your populations now.

23. Follow the steps below to carry out investigation 2 for a longer period of time:

- To continue running the simulation for a longer length of time, adjust the “auto-stop” setting to “at time = **4000**”.
- The model will resume running again once you click on “go/pause”.
- Hunt bacteria by leaving your mouse cursor in one part of the environment and let go of it so that bacteria start running into it.
- When the simulation stops, discuss the following question with your partner:
- Did the number of trait variations in the population remain stable or did it change?

Compare our findings.

With your class



24. Discuss the following questions with your class:

- How did the bacteria population change in this different environment?
- How can we explain this outcome in terms of competitive advantage?
- How did running for a longer length of time affect the results?
- Why might you and your partner have gotten similar shifts in the distribution of traits but not exactly the same results?

Revisit our General Model.

With your class



25. Let's revisit our General Model for Natural Selection and see if there are any new ideas that we should add to it to more fully explain our results.

Prepare for our next investigation.

Home Learning



26. Consider the following tasks as you complete the *Refining and Applying Our General Model for Natural Selection* handout:

- Brainstorm how the simulation could be changed to include resources bacteria need in order to survive and/or reproduce.

- Make predictions about whether the number of flagella for a bacterium will give it a competitive advantage in environments with different resources.
- Consider how what we are figuring out could explain some of the characteristics found in penguins.

27. Be prepared to share these ideas with the whole class.

Lesson 10: Why does our General Model tend to produce different outcomes in different environmental conditions?

Navigation

For home learning, you brainstormed resources bacteria would need from their environment in order to survive and reproduce.

Turn and talk



1. Share with a partner your ideas from the *Refining and Applying Our General Model for Natural Selection* handout. Be prepared to share with the whole class.

Orient to the bacteria in the simulation.

- There are many different types of bacteria in the world, besides *Salmonella*, that have variations in their flagella.
- *Salmonella* consume food in our bodies (e.g., our blood) as fuel to move and as building blocks for making new cells. Other types of bacteria, like *Bacillus*, consume other living things, like algae, as food sources.

Orient to the simulation.

With your class



2. Follow your teacher's directions and watch the screencast which explains how variables can be changed in the simulation model.

Make predictions.

Turn and talk



3. Discuss the following with a partner: Predict what will happen to the number of bacteria in each of these populations over time. Explain your reasoning.
4. Be prepared to share your ideas with the whole class.

Prepare for the investigation.

This next test of our model can serve as an assessment for ourselves to see how far we have come in explaining how and why different environments can cause different types of population changes.

With your class



5. Discuss the following with your class:

- Before we get to explaining our ideas, we need to explore the simulation, running multiple trials, until we find the following:
- one kind of environment that repeatedly selects for certain trait variations in bacteria
- at least one additional kind of environment that repeatedly selects for different trait variations in bacteria

Investigate changes in trait variations in a population.

On your own



6. Individually explore the simulation following the prompts below:

- Access the simulation using this URL: <https://www.openscienced.org/general/bacteria-environments/>
- Try to find two environmental conditions that result in very different results in trait variation distribution.
- Run multiple trials to confirm the general trend holds for these environmental conditions.

Plan for data collection.

With your class



7. Review the *Different Environmental Conditions and Results* handout and plan for the types of data you will need to collect and your investigation strategy.

Investigate changes in trait variations in a population.

On your own



8. Individually collect data following the prompts below:

- Access the simulation using this URL: <https://www.openscienced.org/general/bacteria-environments/>
- Use your two environmental conditions and run multiple trials to confirm the trends.
- Record your data on the *Different Environmental Conditions and Results* handout.

Navigation

Turn and talk



9. Complete the following with a partner:
 1. Share your investigation setup and findings with a partner.
 2. Discuss these questions for both your and your partner's investigations:
 - Did the population change over many generations?
 - Did different environments cause this change?
10. Be prepared to share your ideas with the whole class.

Orient to the General Model and handout.

On your own



11. Using your *Progress Tracker Copy of Our General Model* and the handout *My Model for Changes in Bacteria Populations*, locate the major headings (e.g., Survival and Reproduction, Environment).

Write an explanation for each case.

On your own



12. Write explanations for what is causing changes you observed in the population. Start with Environment 1 and then move on to Environment 2.
13. Cross-reference both of your explanations with the General Model by placing a check mark next to the ideas on your *Progress Tracker Copy of Our General Model* when you have included them in your explanation.

Make predictions.

Turn and talk



14. Discuss the following with a partner: What do you think will happen to the trait variations in the bacteria population if you run the model for really long periods of time?
15. Be prepared to share your ideas with the whole class.

Lesson 11: Can we use our General Model for Natural Selection to explain changes over time in green anole lizards?

Navigation

With your class



1. Discuss the following questions:

- Do you think the General Model for Natural Selection could help us explain differences in populations of other organisms?
- If so, what would we be looking for in those populations?:

Individual Assessment: A New Phenomenon

On your own



2. Use your *Progress Tracker Copy of Our General Model* (updated in Lesson 10) to complete the *Green Anole Lizard Explanation*.

Provide and receive feedback.

With a partner



3. Prepare to share and receive feedback with a partner.

- Share your *Green Anole Lizard Explanation* with a partner and provide feedback.
- Remember that feedback needs to be specific and actionable.
- After giving feedback, you will revisit your own explanation with the feedback you receive and revise your thinking in a different color.

Receive peer feedback.

On your own



5. Use the feedback you received to revise your explanation, making it clearer, more accurate, and better supported by evidence. Take these steps:
 - Review your notes about the feedback your partner provided.
 - Decide if you agree or disagree with the feedback.
 - Revise your work to address the feedback.
6. Reflect on your progress in giving and receiving feedback by completing the *Peer Feedback Self-Assessment* handout.
7. Turn in the *Green Anole Lizard Explanation* to your teacher.

Navigation

Turn and talk



8. With a partner, select one of the three questions below and begin to brainstorm your response to it.
- Can our model explain how penguins are living and reproducing in certain environments and not others? Why?
 - Can our model explain why there are differences in some body structures for penguins that live in some environments compared to others (e.g., Humboldt vs. emperor)?
 - Can our model explain why penguins living long ago had trait variations that were typical in their population but are different from those of modern penguins?

Lesson 12: Can our model explain changes over really long periods of time?

Navigation

With your class



1. Discuss the following questions with your class:

- Can our model explain how penguins are living and reproducing in certain environments and not others? Why?
- Can our model explain why there are differences in some body structures for penguins that live in some environments compared to others (e.g., Humboldt vs. emperor)?
- Can our model explain why penguins living long ago had trait variations that were typical in their population but are different from those of modern penguins?

Recall what caused variation in cattle muscles.

With your class



2. Examine the image shown by your teacher of the two chromosomes with structural differences for the gene for myostatin. The different forms of the gene are called alleles.

How common are mutations?

A mutation is any small change that happens to the structure of a chromosome that can be passed on to future offspring but was not there before. Mutations may lead to new alleles for a gene.

With a partner



3. Discuss the following with a partner:

- What role do you think mutation plays with regard to how the animals we are studying have changed over long periods of time?
- Do you think mutations are common or rare? Why?

With your class



4. Examine the data showing rates of mutations for different organisms and discuss this question with your class: How common do you think mutations are in horses, whales, horseshoe crabs, and penguins?

How should we update our model?

With your class



5. Discuss this question with your class: Where is the best place to add mutation to our General Model for Natural Selection?

Ancient and modern organisms.

With your class



6. Recall the organisms we looked at over long periods of time with both ancient and modern types.

Examine traits of some ancient and modern horses.

With your class



7. Discuss some of the interesting traits in horses that you saw were different over time.
8. Discuss how the number of toes changed from the most ancient to modern horses.

Does the General Model for Natural Selection work for horses' toes?

On your own



9. Read the article about ancient and modern horses.

Turn and talk



10. Follow your teacher's instructions in order to describe the information that is important for the model and be prepared to share your ideas with your class.

Use the General Model for Natural Selection.

With your class



11. Discuss this question with your class: Where else should we add specific details to the model to use it to explain what happened with the horses' toes?

Examine traits of ancient and modern horseshoe crabs.

With your class



12. Examine the ancient and modern horseshoe crabs, where we do not see such obvious changes in traits.
13. Discuss some of the interesting body structures observed in horseshoe crabs.

Use the General Model for Natural Selection to explain horseshoe crabs.

With your group



14. Complete the following with your group:

- You may want to assign roles in your group.
- Gather all the information you need and discuss how to show that on your copy of the model.
- Come to a consensus on each part of your explanation, based on the model.
- Cover each part of the model with a sticky note explaining that detail for horseshoe crabs.
- Prepare to share your explanation. Be sure your notes are carefully thought out and easy to read.

Share horseshoe crab explanations with another group.

With your group



15. Compare another group's explanation with yours. Record the elements you notice are similar or different. What do you wonder?

In your notebook



16. Add your noticings and wonderings to a chart on a new page in your notebook titled: **Explaining Horseshoe Crab Traits Using the Natural Selection Model.**

17. Be prepared to share these with the whole class.

Update progress tracker: What have you figured out?

In your notebook



18. Write in the left column the question we are working on: **How does mutation help our model explain the comparisons in body structures we observe in ancient and modern organisms?**

19. Write in the column on the right what you have figured out so far. You can use pictures and/or words. Take as much space as you need to record your thoughts.

Examine traits of ancient and modern whales.

With your class



- 20.** Examine the images shown to see some of the large-scale differences among ancient and modern whales.
- 21.** Examine the images shown and focus on the differences in the type of teeth whales have.

Examine traits of some ancient and modern penguins.

With your class



- 22.** Consider the many species of modern penguins and how we might use the General Model for Natural Selection to explain how there are so many different species.

Lesson 13: Can we apply the General Model for Natural Selection over millions of years to explain how all the ancient and modern penguins are connected?

Navigation

With your class



1. Discuss with your class: What did we add to our model that helped us support our explanations of how traits in ancient species could have changed over time and resulted in the trait variations we now see in modern species?

Examine two species of penguins.

With your group



2. Compare the two rockhopper penguin species cards and data strips and discuss the following with a partner: What do you notice about the similarities and differences between these penguins?

Show connections between modern penguins.

Scientists Circle



3. Gather near your group members around the Scientists Circle.

Create a model to show modern penguin connections.

With your group



4. With your group, use the information on the data strips for all **18** species of modern penguins to create a model that represents how they are all connected to one another.

Analyze ancient penguin data to add to the model.

With your class



5. Discuss this question with your class: Do you think ancient penguins like Pedro can be connected to this model?

Introduce the next task.

With your class



6. Discuss this question with your class: How do you think the data strips with information about ancient penguin structures can help us figure out how Pedro and the other ancient penguins might be connected to the modern penguins?

Analyze ancient penguin data and add to the model.

With your group



7. Work with your small group to add to your model:
 - Work with your small group to organize your data strips.
 - Use sticky notes and pencil to draft possibilities for extending your existing model. Try several arrangements.
 - Take photos or make quick sketches of the arrangements you try so you can keep a record of the alternates you considered.
 - Come to consensus in your small group about the arrangement you want to record on your Penguin Ancestry Model.
8. Be prepared to share your ideas with the class.

Share about our models.

With your class



9. Discuss this question with your class: What were some parts of the Penguin Ancestry Model that you were more certain about than others?

Write an explanation.

On your own



10. Follow your teacher's instructions and complete the *Version 1: Ancient and Modern Penguin Explanation* handout.

Gallery Walk

In your notebook



11. Title a new page of your notebook: "Explaining Connections between Modern and Ancient Penguins".
12. Create a Similarities and Differences chart in your notebook.
13. While doing the gallery walk, discuss with your group:
 - Are these competing models equally valid in light of what we know about how natural selection and mutation can result in population changes over time?
 - How could additional fossils and genetic information about these organisms help us decide which model(s) is more likely to be the closest representation to reality?
14. Be prepared to share these ideas with the whole class.

Share ideas with your class.

With your class



15. Discuss the following with your class:

- What were the similarities and differences in the models you saw?
- Are these competing models equally valid in light of what we know about how natural selection and mutation can result in population changes over time?
- How could additional fossils and genetic information about these organisms help us decide which model(s) is more likely to be the closest representation to reality?

Navigation: Related Phenomena

With your class



16. Discuss the following with your class:

- What other types of organisms are you wondering about that we might be able to trace back to their ancestors?
- What kind of evidence would you want to help you figure out how other organisms trace back to their ancestors?

Lesson 14: What do the patterns in embryo development tell us about how things living today could be connected to the things that lived long ago?

Navigation

With your class



1. Discuss the following questions with your class:
 - What are some types of organisms we have on our Related Phenomena poster that we have not yet investigated to look for the kind of connections we discovered in penguins, whales, horses, and horseshoe crabs?
 - If we had sufficient data about some of these modern and ancient organisms listed on our Related Phenomena poster, do you think we might find similar connections between them?

Use a model.

With your class



2. Follow your teacher's instructions and examine the images and information about different embryos and newborn animals on the slide.
3. Take a few minutes to look through the embryo-related data on the slide.

Make a prediction.

Turn and talk



4. Examine the information on the slide about chicken embryos and discuss the following with a partner:
 - What physical similarities and differences would you expect to see between a newly hatched chicken and a chicken embryo midway through its development (**10** days after fertilization)?

Turn and talk



5. Examine the information on the slide about chicken and salamander embryos and discuss the following with a partner:
 - What physical similarities and differences would you expect to see between a newly hatched salamander and a salamander embryo midway through its development (**60-75** after fertilization)?

With your class



6. Respond to the following question. Share your prediction with the class:
 - How do you think the embryos of these organisms would compare to each other midway through their development?
 - A. They would have just as many physical structures in common as embryos as they do when they are born.

- B. They would have more physical structures in common as embryos than when they are born.
- C. They would have fewer physical structures in common as embryos than when they are born

Prepare for an investigation.

With your class



7. Record on a new notebook page the question your class identified to investigate.
8. Create a chart below it to record how embryos of egg-layers compare at different stages of development.

Egg-layer embryos	Similarities	Differences

9. Follow your teacher's instructions and examine the sketches on *Egg-Laying Embryos*.

Analyze data.

On your own



10. Individually analyze and annotate the different sketches on *Egg-Laying Embryos*.
 - Compare the physical structures in all four egg-layers.
 - Use colored pencils or crayons to identify and annotate any similarities and differences in physical structures you notice between organisms at each stage of development.

Analyze and interpret data.

With a partner



11. With a partner, compare the similarities and differences in physical structures you noticed between organisms at each stage of development.

On your own



12. Record these similarities and differences in your notebook.

With your class



13. Discuss the following question with your class:
 - What were some similarities and differences you discovered in their physical structures at different stages of development?

Prepare for an investigation.

In your notebook



14. Set up another chart in your notebook to record how embryos of live-birth organisms compare at different stages of development.

Live-birth embryos	Similarities	Differences

Analyze data.

On your own



15. Individually analyze and annotate the different sketches on *Live Birth Embryos*.
- Compare the physical structures in all the live-birth embryos.
 - Use colored pencils or crayons to identify and annotate any similarities and differences in physical structures you notice between organisms at each stage of development.

Analyze and interpret data.

With a partner



16. With a partner, compare the similarities and differences in physical structures you noticed between organisms at each stage of development.

In your notebook



17. Record these similarities and differences in your notebook.

Construct explanations and ask questions.

On your own



18. Review your notebook and the colored and annotated embryo drawings.
19. On the *New Ideas and Questions Connected to Embryo Comparisons* handout record the following;
- A. Any new ideas you now have about how to answer our lesson question.
 - B. Any new questions you now have.
 - C. A summary of how the data you analyzed in this lesson helped you develop these new ideas and/or questions.

Share explanations and questions.

Scientists Circle



20. Bring your completed *New Ideas and Questions Connected to Embryo Comparisons* and meet in a Scientists Circle. Discuss the following with your class:

- Share new ideas you now have about how to answer our lesson question and/or any new questions you now have.

Lesson 15: What can we explain now, and what questions do we still have?

Evaluate our DQB questions.

With a partner



1. Using all we have figured out in the unit, decide together how you think we have answered questions on our DQB using *Unknown material with identifier: ns./15.ho1* and the following symbols:
 - We did not answer this question or any parts of it yet: **O** or **?**
 - Our class answered some parts of this question, or I think I could answer *some parts* of this question: **✓**
 - Our class answered this question, or using the ideas we have developed, I could now answer this question: **✓✓**
2. Pick three questions and write an answer to them.

What questions have we made progress on?

On your own



3. Follow your teacher's instructions for marking questions on the DQB that you think we have made progress on and complete the following:
 - Take *Reviewing Our Driving Question Board* and **10** sticky dots to the DQB.
 - Place your sticky dots on the sticky notes that match questions you think we have made progress on.
 - Once you have placed your **10** dots, move to the Scientists Circle.
 - As you are waiting for others to place their sticky dots
 - finish writing answers to the three questions you chose.
 - notice and wonder about which questions have the most sticky dots.

Revisit our Driving Question Board.

Scientists Circle



4. Discuss the following with your class:
 - Which questions have we made the most progress on?
 - What have we figured out?
 - What can we say now about the big question on our DQB: How could things living today be connected to the things that lived long ago?

Add to our progress trackers: What have you figured out?

In your notebook



5. Add a new entry to your Progress Tracker and write in the left column the big question we have been working on: **How could things living today be connected to the things that lived long ago?**
6. Write in the right column what you have figured out about this question.

Tweet Blizzard

On your own



7. Follow your teacher's instructions and complete the following:
 1. On a piece of scrap paper, write a tweet with your own hashtags. The tweet may share
 - a big idea you learned in this unit or school year that will always be with you,
 - a challenge you faced in this unit or school year that you overcame, or
 - a rewarding thing about this unit or school year that you want to share.
 2. Crumple up the paper into a "snowball."
 3. When everyone is ready, toss the snowball in the air.
 4. Pick up a new snowball and be prepared to share.

Generate new Driving Question Board.

Scientists Circle



8. Discuss the following with your class:
 - What questions did we pose this year that we did not answer, but we want to carry forward into future science learning?
 - What other questions are you interested in figuring out answers for in high school?
 - How can we go about answering these new questions?

Podcast Transcript and Photo Journal

Narrator: Hi, my name is Sergio Salgado and I'm part of a team called OpenSciEd that provides freely available, high-quality science instructional materials. We recently spoke with two paleontologists from the United States and Peru who discovered a fossil of a giant penguin in Peru. We wanted to better understand the impact of their research and findings.

Señor Altamirano: The site where Pedro was found is called the Yumaque Peninsula, which is in the Paracas National Reserve at the southern coast of Peru. It's around four hours south of Lima. It's a completely arid region; it's a whole desert. The only source of life, or discernible life, is actually in the sea. Much of the rest is a complete desert.

Narrator: That was Ali Altamirano, a researcher at the Natural History Museum in Lima, Peru, in the department of Vertebrate Paleontology. In 2006, as an intern, he found the remains of a fossilized penguin that came to be known as Pedro. He worked with his mentor and leader of the lab, Dr. Rodolfo Salas, on the excavation of Pedro. We asked him to describe their initial excitement of the discovery.



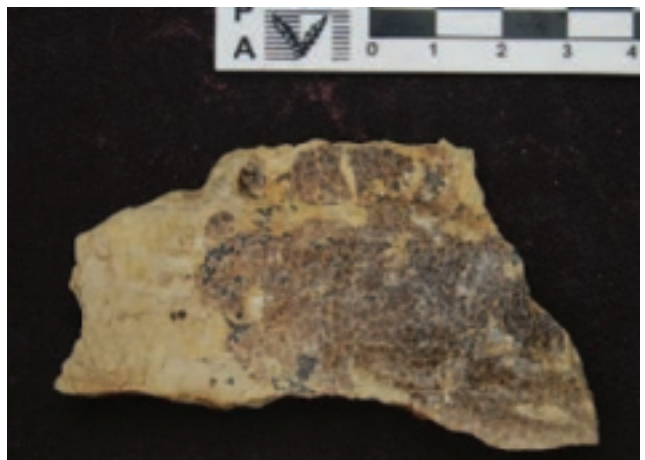
Señor Ali Altamirano. ClarkeLab



Señor Altamirano: And it was amazing because it was very well preserved. We start excavating, and when it came out, it was the set of scales of this fossilized penguin foot. At that moment



A fossilized foot bone from Pedro. ClarkeLab



Fossilized scales from Pedro. ClarkeLab

we were yelling out of our own amazement that we have discovered these fossilized penguin remains. We took this very small sample, just to make sure that anybody believed us that the discovery was as amazing as we thought it was. And we urgently contacted Dr. Clarke so we can do more research in the same area.

Narrator: Mr. Altamirano and Dr. Salas are part of an international, collaborative research group that worked on excavating and researching fossils like Pedro. Research on Pedro was led by Dr. Julia Clarke.

Dr. Clarke: When Ali and Rodolfo contacted me, I was in the US, and they sent me an email, and I believe it was pictures of the scales. And I got super-duper excited because we have no fossil penguins with any kind of soft tissue remains that had been previously known. That was just exciting, even if there were just scales, but somehow having seen other fossils from around the world that preserved some soft tissue, like scales, they often also preserve others that are related in terms of their chemistry and being skin structures. So I was like, I bet there are feathers in that fossil. So we got to work.

Narrator: And she was right. They did find intact feathers on Pedro. Dr. Julia Clarke is a professor of paleontology at the University of Texas at Austin, and she is an expert on birds. She tells us more about the excavation of Pedro.

Dr. Clarke: First, this fossil would need to be excavated, and then it would need to be moved to Lima, and then it would need to be soaked to remove the salt from the specimen before we could even start looking at the structures that Ali had glimpsed in the field—the scales. And I could be there to look and check, the way I had been familiar with from looking at other fossils with feathers from around the world.

Narrator: Dr. Clarke saw similarities to living penguins early on, so we asked her and Mr. Altamirano to tell us more about how they knew that Pedro was a penguin.

Dr. Clarke: We had a wing of feathering—all of the organization of the feathers of the wing that were these identical popsicle stick-shaped feathers that made up this wing.

And then we also had these body feathers that showed this flattening and this color gradient from white to dark



Dr. Julia Clarke (left) and Señor Altamirano (right) working carefully to chip away rock to uncover Pedro's feathers. ClarkeLab



Señor Altamirano and members of the research team chiselling out a slab of rock containing the fossil. Rodolfo Salas-Gismondi



Fossilized feathers from the wing of Pedro. ClarkeLab

near the tips that was identical to what we see in living penguins. I was in the lab and starting to find the first evidence of fossil feathers in the wing area.

What you see is these really flat, flat bones, the hand, the tip of the wing bones, and the proximal arm bone, called the humerus, is really stout.

And in these giant penguins, like Pedro, these are essentially nearly solid bones, and what that density of the bone is related to is resisting buoyancy. We see these nearly solid bones in parts of animals that are deep divers.

Señor Altamirano: These bones were actually very peculiar, because they were very stout. He was really built, he was amazingly heavy. It's like seeing the modern penguin toe bones, only ten times the size. And it was amazing because there is nothing, in my mind, that can match such size.

Dr. Clarke: Pedro is, you know, a giant penguin. So it's, it's somewhere in the five-foot range. The foot was almost the size of a human hand.

Narrator: Though Pedro shares a lot of similarities with living penguins, there are some distinct differences.

Dr. Clarke: What Pedro had was a long and pointed beak, very different from living penguins today, which in general, the beak is just about the same length or a little longer than the back of the skull.

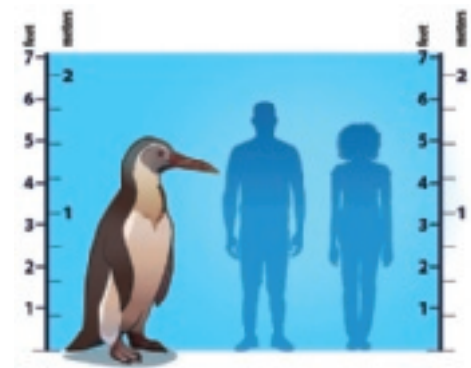
Narrator: These fascinating findings helped us understand what Pedro was like, but we wanted to know more about the region and time period Pedro would have lived in.

Dr. Clarke: The ecosystem around this time period, about 36 million years ago, you have these enormous whales, very different looking from living whales today, with teeth. And then you have these long body shapes and sharks, that Ali's an expert in, that range from tiny to giant. And you have an archipelago, maybe some small islands, maybe less-abrupt cliffs along this coastline.

And we're able to date fossil remains like Pedro by looking, not just at what we know about the distribution and ages of animals from the site where Pedro was found itself, but we can also, in this case, we dated an ash layer that's just above the rocks that contain Pedro. In this case, we got an age of around 36 million years.



Photographs of the bones recovered from the specimen with reconstruction of Pedro showing recovered elements in white and missing elements in gray. J.A. Clarke



Pedro



Fossilized skull and beak of Pedro held in place with four pieces of red clay. ClarkeLab

Señor Altamirano: Well, it's amazing that this very strange-looking penguin, huge in size, have thrived in this arid coast, which, even now, the modern Humboldt penguin is still alive.

Penguins have thrived for millions of years, in the entire Peruvian coast, and it has to tell us, in some way, that this long-lived bird has been here for way longer than us, the humans.

Narrator: As penguins still live in the area where Pedro was found, it got us wondering how those alive today might be connected to the penguins that lived long ago, like Pedro.

Finding a fossil specimen as intact as Pedro is rare. Dr. Clarke, Mr. Altamirano, and the rest of their team have been able to examine and contribute meaningful data on this question thanks to their work on Pedro.

We wanted to close by asking them about their approach to and motivations in paleontology.

Dr. Clarke: When I was a kid, I loved art. I loved building things and making things. And what I truly believe is that creativity and the sense of optimism are embedded at the center of doing science. And the creativity can be in where you look, where you choose to go, but also, more so, how you bring what we know of living animals together with data from fossils in new ways.

And so there's always new things to discover because each one of us is going to approach that question or any questions like that in different ways.

To be a paleontologist, you have to be incredibly optimistic. You have to believe that the next time that you're walking in the desert, be it in Peru or Mongolia or Antarctica, you have to believe that you're going to potentially find something new to science. But, we don't always realize it in that moment.

Señor Altamirano: When I was walking in this desert area at the Paracas Reserve, I was around 12, 13, I came out with some pointed reddish thing. And I look into it, it look exactly like a shark tooth. And I was jumping out of happiness because I never found myself one shark tooth all by myself. And I went back to my teacher and said, "Well, look, I just found these shark teeth. It means that there may be more shark teeth and maybe some other more things." And that was the first time that I ever get to find one of these amazing fossils.

After the years have passed, my interest in animals, in biodiversity in the area, has never stopped.

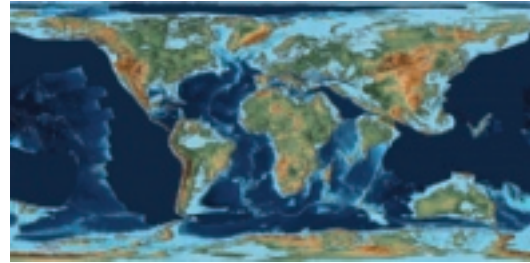
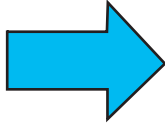
And one day, I actually found these fossils at the Yumaque area, where one of them turned out to be Pedro, the giant penguin.



Señor Altamirano (left) and Dr. Clarke (right) at the fossil site from which Pedro was removed. ClarkeLab

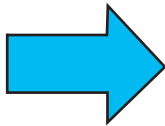
Maps of Earth's Surface Over the Last 50 Million Years

Earth's surface
50 million years
ago (mya)



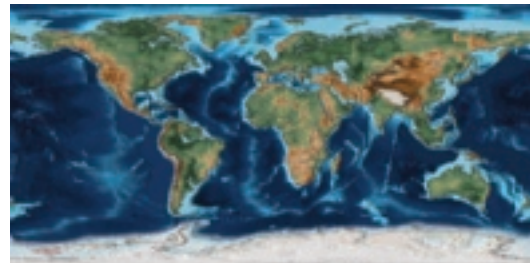
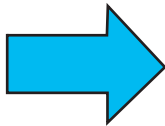
Paleogeographic maps by C.R. Scotese, PALEOMAP Project

Earth's surface
30 mya



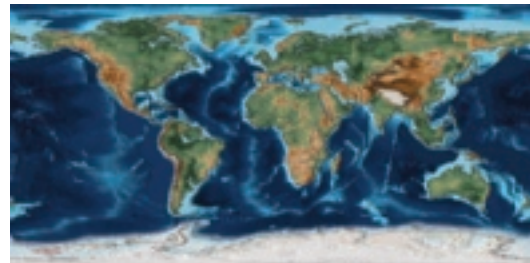
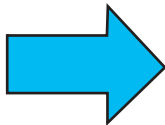
Paleogeographic maps by C.R. Scotese, PALEOMAP Project

Earth's surface
15 mya



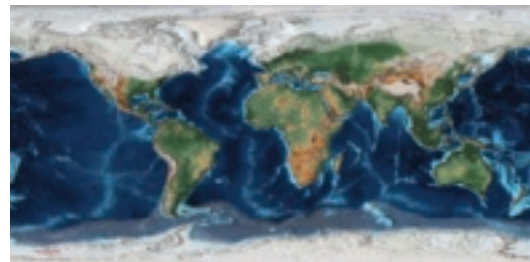
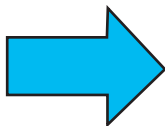
Paleogeographic maps by C.R. Scotese, PALEOMAP Project

Earth's surface
2.5 mya



Paleogeographic maps by C.R. Scotese, PALEOMAP Project

Earth's surface 21,500
years ago during
the last ice age
(which ended 11,700
years ago)



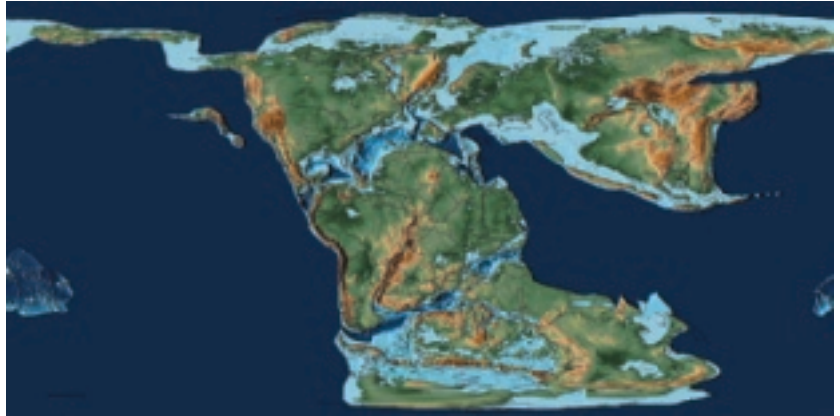
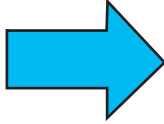
Analyzing and Interpreting Fossil Data

Ancient penguin	Number of fossils discovered so far	Percent of fossils discovered with the same variation in the structure of the humerus bone
Water King/Pedro	1	n/a
<i>P. devriesi</i>	1	n/a
Harris'	1	n/a
Simpson's	1	n/a
Lowe's	1	n/a
Lopdell's	1	n/a
Giant spear-billed	1	n/a
Slender-footed	2	100
Tiny rower	3	100
<i>S. urbinai</i>	4	100
<i>W. tuatahi</i>	4	100
Colossus	7	100
<i>Gunnari</i>	11	100

Data from Paleobiology Database (2021). The Paleobiology Database. Checklist dataset <https://doi.org/10.15468/zzoyxi> accessed via GBIF.org on 2022-02-21.

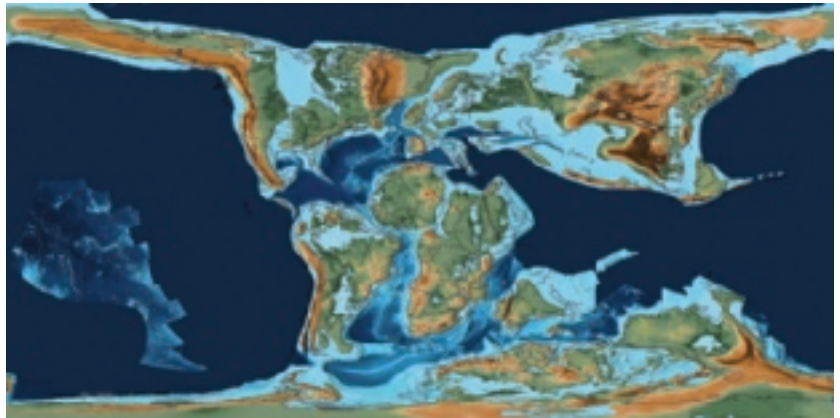
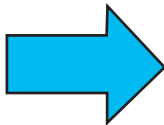
Maps of Earth's Surface 150 and 100 Million Years Ago

Earth's surface
150 million
years ago (mya)



Paleogeographic maps by C.R. Scotese, PALEOMAP Project

Earth's surface
100 mya



Paleogeographic maps by C.R. Scotese, PALEOMAP Project

Peer Feedback Guidelines

This tool was inspired by the Sticky Note Feedback resource originally developed by Ambitious Science Teaching at <https://ambitioussciencelearning.org/sticky-note-student-feedback/>

Feedback needs to be specific and actionable.

That means it needs to be related to science ideas and have your own suggestions for improvement. Productive examples are the following:

- “Your model shows that the sound source changes position when it is hit. I think you should add details about how the sound source moves back and forth after it is hit.”
- “Your explanation said that plants are not able to live through the winter when they have no leaves, but we saw in the video of the maple tree that they can grow new leaves in the spring. We disagree and suggest reviewing the carbon dioxide data from the seedlings in the bag investigation.”

Unproductive examples of feedback that do not help other students improve are the following:

- “I like your drawing.”
- “Your poster is really pretty.”
- “I agree with everything you said.”

How to Give Feedback

Your feedback should give ideas for specific changes or additions the person or group can make. Use the sentence starters below if you need help writing feedback.

- The poster said _____. We disagree because _____. We think you should change _____.
- I like how you _____. It would be more complete if you added _____.
- We agree that _____. We think you should add more evidence from the _____ investigation.
- We agree/disagree with your claim that _____. However, we do not think the _____ (evidence) you used matches your claim.

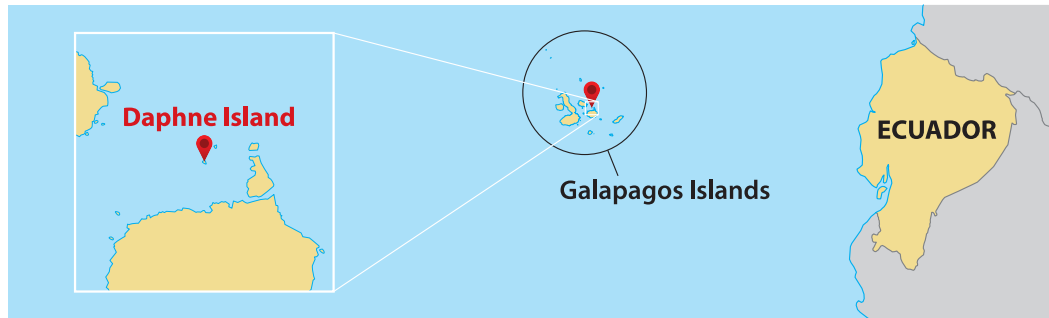
Receiving Feedback from Peers

The purpose of feedback is to get ideas from your peers about things you might improve or change to make your work more clear, more accurate, or better supported by evidence you have collected. It can also help you to communicate your ideas more effectively to others. When you receive feedback, you should take these steps:

- Read it carefully. Ask someone else to help you understand it, if necessary.
- Decide if you agree or disagree with the feedback and say why you agree or disagree.
- Revise your work to address the feedback.

Overview: Finch Beaks

The medium ground finches are one of 14 different types of finches that live on the Galápagos Islands off the coast of Ecuador. They typically live their entire lives on a single island. Where this population of ground finches lives is a desert-like island with sparse vegetation that is called Daphne Major. It is only about a half mile across at its widest point. No people have ever lived there.



Created with ArcGIS: Earthstar Geographics, Esri, DGIAR, USGS, HERE, Garmin, METI/NASA, National Geographic, Imagery

On Daphne Major the ground finches, as their name suggests, forage for food that they find on the ground. They occasionally catch and eat insects, but they mostly survive by eating the seeds of the few plants that grow on the island.

Here are the three types of plants that are the sources of these seeds:

chamaesyce



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portulaca



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tribulus



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Each year, these finches start to look for mates as soon as the rainy season begins. This behavior increases their odds of reproducing. They mate, lay eggs, and produce offspring called fledglings during the wet, rainy season that typically lasts from January through May. The fledglings grow to adulthood during the dry season that typically lasts from June through December. These young birds can mate and reproduce during the following wet season. The adult female ground finches and the fledglings are speckled brown in color. The adult males are black.



David Cook, CC BY-NC 2.0

The finches on the Galápagos Islands have been studied for more than 160 years, starting with research done by Charles Darwin. Modern researchers Peter Grant and Rosemary Grant were interested in finding out whether they could observe any differences among the populations of finches on some of these small islands. So starting in 1973, they set out to collect as much data as they could about the finches and the islands they live on.

In their studies, the Grants traveled to the isolated Daphne Major island each year during the wet season and during the dry season. While there, they caught and banded as many of the finches that lived on the island as possible. Then, when they returned each year, they collected, counted, observed, and measured all the finches they could find, recording data about the ones they had banded in earlier years and banding new ones they found. They also collected data on other organisms living on Daphne Major. They kept records of the number and kind of plants on the island and how many seeds they produced each year. They recorded information about more than 1,000 individual finches over the course of their study from 1973 to 1978. During the years 1976-1978 they saw the average length of the beaks of the population of finches on Daphne Major change.

This document shares some of the data that Peter Grant and Rosemary Grant found in their study of the finches. The data in this packet is simplified from their actual data to make it easier for you to work with. The graphs and tables that follow show a smaller subset of the finches that is based on the larger sample of finches the Grants actually studied.

Overview: Peppered Moth

There is a type of moth that is common in England and in parts of North America that is called the peppered moth. It is called that because many of the moths have a distinctive black and white pattern on their wings. Scientists refer to the lighter-colored peppered moths as the “typical” form. Like



many other types of organisms, the peppered moth occurs in more than one color. Some of the peppered moths are almost entirely black in color. The darker peppered moths are referred to as the “carbonaria” form. These two different forms of the peppered moth are able to breed with each other and produce offspring (much like dogs, cats, or horses of different colors can breed together). Besides their color differences, however, the lighter- and the darker-colored moths do not show a lot of other trait variation.

The moths all live in wooded areas both far away from and close to where people live.

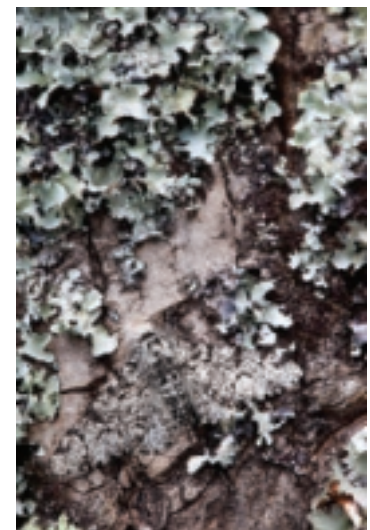
The moths start out as caterpillars in the summer months, then spend the winter underground as pupae. They all emerge as mature moths at about the same time in the spring. This increases the odds that they will find mates. They fly around at night looking for food and mates. During the day they hide from predators by sitting still on the branches and trunks of trees. Since the peppered moths are pretty common, many different kinds of woodland birds prey on the peppered moths.



The birds pick the moths off the trees where they find them during the day.

Some of the trees where the moths hide have dark-colored bark, but many are partly covered with growths of lichen (a plant-like organism that often grows on trees), which give the tree trunk and branches a lighter-colored, mottled appearance. The mottled areas of the tree bark are covered with lichen. The darker areas have no lichen on them.

In the 1800s, people began to notice more and more of the carbonaria form of the moth. At the same time that this was occurring, the industrial revolution was taking place in England. Many factories were being built, and a lot of people began heating their homes with coal. There was suddenly much more



Can you find the typical-form moth on this tree bark?

pollution in England. Scientists at the time wondered whether the change in the moths' color might have something to do with the increasing pollution in the area where the moths were living which darkened the trees where they rested. But it took until the 1950s before people actually did the research to test these ideas. Their research showed that between 1973 and 1997 the predominant color of a population of moths in England changed over 24 generations.

Overview: Cliff Swallow Wings

Cliff swallows are songbirds that gather in large colonies and build nests out of mud that they attach to hard or rocky vertical areas with overhanging surfaces, like those found on many cliffs. Sometimes there are thousands of nests in one colony.

Cliff swallows spend half the year in South America and migrate north in large flocks to nest and produce young during the summer months. This behavior of staying with the flock and returning to their colonies makes it more likely that each bird will find a mate and be able to reproduce. Their colonies are established near muddy areas close to water sources which provide them sufficient mud for nest building as well as sufficient food sources. Their diet is made up of flying insects.

As the number of highways expanded throughout much of the United States, large populations of cliff swallows left their original nesting sites on natural cliffs and began nesting in highway overpasses and culverts and beneath bridges.

Soon there were huge colonies nesting under highways.

These man-made areas were more protected than the cliffs where the birds had been nesting before, and they had the same kinds of hard, vertical surfaces with overhangs that the swallows needed in order to build their nests. In addition, since many of these overpasses and bridges were built over rivers and other waterways, there were plenty of muddy areas and a lot of flying insects near the highways.

Researchers Charles Brown and Mary Bomberger Brown were interested in whether there would be any change in the birds themselves when they changed the locations where they nested from cliffs to under highways. Starting in the mid-1980s and continuing for many years, they studied large numbers of colonies of these birds that nested near highways in Nebraska, collecting specimens and banding, counting, measuring, and keeping track of birds over time.

From 1983 to 2012, the researchers observed that the average length of the wings of the population of cliff swallows in Nebraska changed.

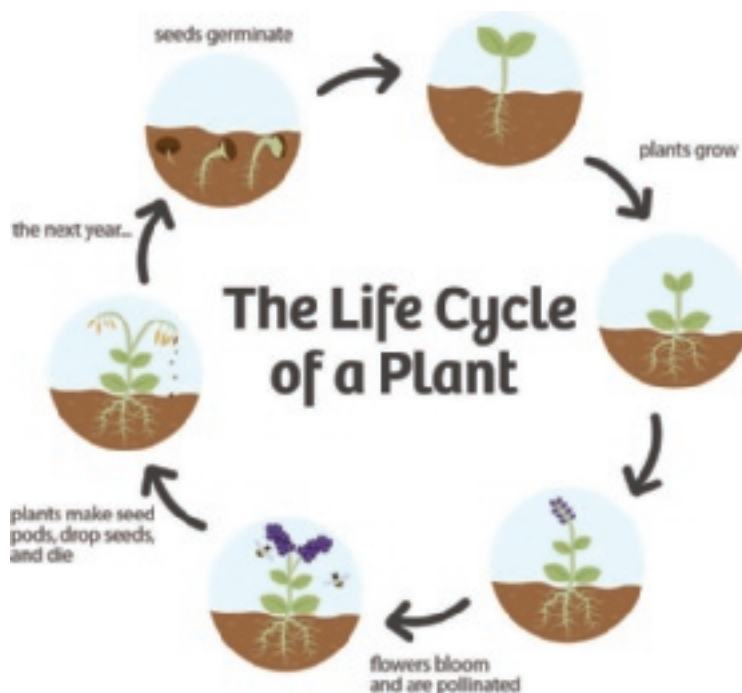


Overview: Mustard Plant Time to Flowering

The mustard plant is known as *Brassica rapa* by scientists. Selective breeding of mustard plants over long periods of time has resulted in the production of vegetables as diverse as turnips, napa cabbage, and bok choy. The mustard plant is commonly used in genetic experiments in laboratories because it is easy to grow, grows quickly, and has many different traits that are easy to see and measure. However, mustard plants also grow in the wild throughout much of coastal California, where they are considered weeds. Wild mustard plants were probably introduced to California about 300 years ago from Asia or Europe, where the mustard plant also grows in the wild.



The wild mustard plants in California are an annual plant, meaning that they sprout—or germinate—from seeds, grow to full size, bloom, produce seeds, and die all in one year. The following year, the new seeds sprout and the cycle starts again. No individual plant grows for more than one year.



In California, wild mustard plants typically sprout and begin to grow sometime between October and January, right after the first rain of the season. They continue to grow as long as they have enough rain. When they are fully grown, they produce flowers, typically sometime between January and April. The flowers of one plant pollinate the flowers of neighboring plants,

fertilizing them so that seeds are produced. When neighboring plants bloom close to the same time, it increases the likelihood that pollination will occur. Each fertilized flower produces several seeds in a pod which falls to the ground. These seeds will then sprout at the start of the next year's growing season and produce the next generation of plants. The length of time that it takes for a plant to become fully grown and produce its first flower is referred to as the "time to flowering" or "flowering time".

Scientists working in Southern California were interested in whether the wild mustard plants growing near them would show the same variety of different traits as the mustard plants they grew in the lab. Wild mustard plants grew in several, different locations near the scientists. They had noticed that in some of those populations, the plants seemed to bloom earlier in the year than in others. Because the climate in Southern California is changing, they wanted to know what the effect of that might be on the wild mustard plants. They collected seeds from plants that grew in the same place in 1997 and in 2004 and made observations about how they grew. Between 1997 and 2004 they saw a change in the flowering time of the mustard plants.



Overview: Stickleback Armor

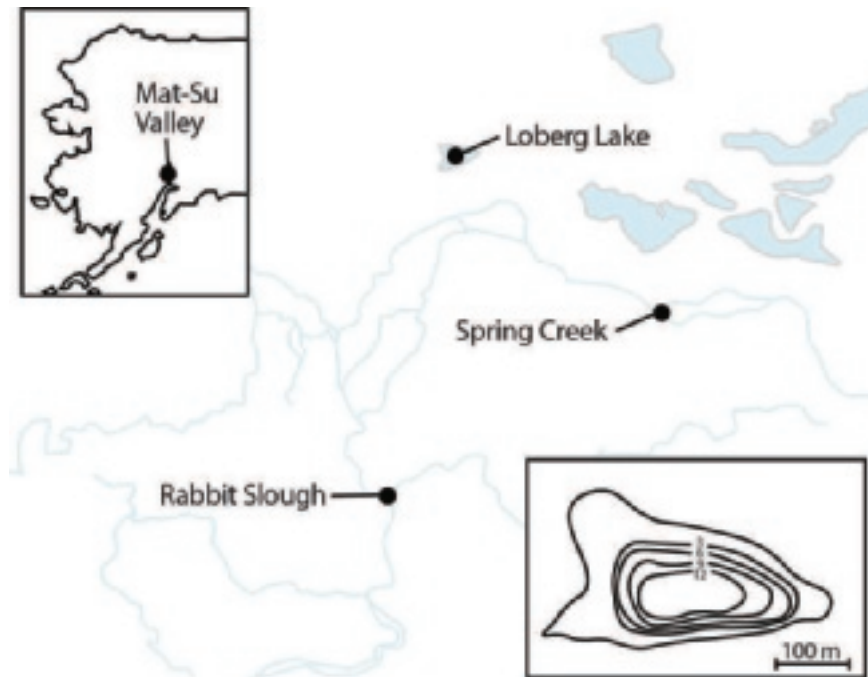
Sticklebacks are a type of small fish, usually no more than about 3 inches (8 cm) long, that are found in most bodies of freshwater as well as in the ocean along the coasts in the Northern Hemisphere. Because they are small and numerous, they have a lot of predators wherever they live. The stickleback fish have a number of different types of “armor” that help protect them from predators. Most have a row of 2-16 sharp spines on their back. Many have spiny fins on their bellies. Some types of sticklebacks also have bony plates along their sides, extending from behind their gills to their tails on both sides, sort of like a suit of armor.



Sticklebacks are known for being found almost everywhere along coasts in the Northern Hemisphere. Some of the sticklebacks live in the ocean but breed in freshwater streams and lakes, so they travel back and forth between saltwater and freshwater. Some of the sticklebacks live and breed only in the ocean or only in freshwater. Wherever they breed, male sticklebacks build nests and perform characteristic mating dances to attract females. The males with the best dances are more likely to breed and reproduce.

Oceanic sticklebacks can be identified because they usually have a lot of bony plates along their sides. Freshwater sticklebacks almost always have very few of these bony plates. Having few of the bony plates allows the fish to swim quickly and hide in small spaces so that they are harder for predator fish to find and catch. Having a lot of the plates makes it harder to swim and hide to avoid predators, but it helps the fish to escape from predators that do catch them because the plates make it difficult for the predators to bite down and hang onto the sticklebacks.

Some of the freshwater sticklebacks lived in Loberg Lake in Alaska. When Loberg Lake was being developed as a recreational area for fishermen and boaters, the sticklebacks were eliminated from Loberg Lake so that the salmon and rainbow trout that often preyed on the sticklebacks would be more likely to take the bait of fishermen. The sticklebacks were removed from Loberg Lake in October 1982. After that time, the lake was examined each year to assess how the salmon and trout populations were doing. No sticklebacks were observed for many years. Then in 1990, a few heavily armored sticklebacks were observed in the lake.



Scientists were interested in where these new sticklebacks had come from and how their population might expand in the lake. So each year from 1991 to 2001, they caught and measured sticklebacks from Loberg Lake. During that time, the number of bony armor plates on the fish in the population changed significantly.

Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?

As scientists, if we want to know something about modern penguins, we can observe them. We can also take measurements of their bodies, watch their behaviors, and investigate their environments. We cannot do all those things with penguins, or any other organisms, that lived millions of years ago! Yet, scientists often try to visualize what organisms from long ago looked like based on measurements of the size and shape of a fossil. **How do scientists know all this just from looking at fossils?**

Think about the question in bold as you read further. As you develop an answer to that question, also think about what limitations there are on the conclusions we come to.

We know how fossils are formed. The process that turns the solid parts of organisms like bones, teeth, hooves, and shells into fossils develops a pretty accurate re-creation of the shapes and sizes of those original parts. Fossils can be directly observed and measured. Fossils are a good source of evidence about what those parts of organisms that lived millions of years ago looked like. But very few fossils represent complete skeletons. The bones are almost always disorganized in the rocks, and usually several pieces are missing.



To figure out what a whole skeleton of a fossilized organism would have looked like, scientists make comparisons with similar living, modern organisms. They know a lot about how skeletons are organized from observing and measuring modern organisms. The bone structures have certain specific shapes, and they fit together in certain specific ways. For example, all birds' wings have similar bones that fit together in similar ways, even though there may be minor differences in the sizes or shapes of the bone structures in different species of birds.

Some animals also have a backbone made up of vertebrae that fit together in a long column with each bone matching the shape of the bones next to it, sort of like a puzzle.



The segments of shells of many organisms like beetles and lobsters fit together in predictable ways based on their size and shape too.



If someone gave you a puzzle with some of the pieces missing, you would probably be able to put most of the puzzle together and then make predictions about what the missing pieces would likely look like and how they would be shaped. The more pieces of the puzzle you have, the better your predictions about the missing pieces would be. Based on our knowledge of skeletons of living organisms, we can figure out what bones are missing in a skeleton of a fossil and what they are likely to have looked like. As with a puzzle, this is easier to do if there are only a few pieces missing. This is why scientists are always very excited to find almost-complete skeletons in fossils (like Pedro!).

But this is still only bones. How do scientists know what size ancient penguins were based on only their bones? Again, they can make some predictions based on what they know about organisms alive today. For example, from a simple measurement of a femur (upper leg) bone we can make a pretty accurate prediction of the overall height of an organism.

For example, a mathematical model used in forensic medicine by scientists as far back as 1899 shows that there is strong linear association between femur length and a person's height. These are the equations that are used to predict the height of an individual in inches (y) based on just the length of their femur (x):

For men: $y = 0.2610x + 44.201$

For women: $y = 0.2019x + 67.579$

Similar mathematical models exist for other organisms too, like penguins and horses. So if we know that a particular ancient penguin's femur is a certain length, we can use that to make predictions about its overall height. We can also do this for weight. This is based on having a mathematical model that describes the relationship between how much weight the bones of modern penguins support compared to the length and thickness of their bones. We also know that scientific principles like those that describe the relationship between weight and gravity or forces and distance were the same millions of years ago as they are today. So scientists can use those scientific principles to support their models for ancient penguins.

Fossil bones can also tell us how muscles might have been attached to those bones and how the overall limb functioned. For example, modern penguins with larger rib cages tend to have larger lungs. They also tend to have larger bone structures and more muscular bodies that enable them to hold their breath longer and to dive more deeply than smaller penguins. Scientists can use this relationship to make predictions that penguins with larger bones in certain parts of their bodies would have been able to hunt for food longer before coming up for air and would have been able to dive deeper into the sea when they did so.

Scientific artists use all this information to create reconstructions of what an ancient penguin probably looked like. However, we cannot always be sure about the shapes of the soft parts of an organism's body or the color of its fur or plumage (except in some cases, like Pedro's). Artists make decisions about these surface details based on the best scientific evidence they have, but they are still only guesses based on what we know about penguins living today. So not every artist's reconstruction of the same penguin fossil will look exactly the same:



Combining what is known about the structures of ancient penguins with other information about their fossils, we can even make some predictions about their interactions with their local environment when they were alive. We can learn what their local environment was like from the chemical content of the rocks where their fossils were found, the known climate that existed at the time they died, and the fossils that are found near them in the same layer of rocks they were found in. Fossils of plants, plankton, or microorganisms are especially helpful in determining what kind of environment they lived in. Putting all this information together, scientists can make predictions about what ancient organisms might have eaten and whether there were predators in the environments they bred or hunted in.

In your science notebook, summarize what you figured out related to these two questions:

- How can scientists determine some of the characteristics of an ancient organism since they cannot directly observe what that organism looked like when it was alive?
- What are some limitations on the conclusions scientists can make based on the data they have?

Reading: Version 1: Horses—Ancient and Modern

Both the global climate and local environments have changed significantly in the 50 million years between the multi-toed ancient horses and the modern Przewalski's horse and plains zebra that have only a single, large toe or hoof. Over that time, Earth has become cooler and drier. Fifty million years ago, much of the land where horses lived was similar to tropical rainforests—warm and damp with many plants and trees. Over time, as the planet cooled and got drier, those rainforests disappeared and more-open forests took their place, with grasslands and just some trees. In modern times, the environments where horses are found are wide-open grasslands.



Those ancient tropical rainforests where the multi-toed horses lived were rich in resources. There were many different types of plants that could be used as food by the herbivorous animals. The terrain was crowded with trees and vines growing in all directions. A lot of different kinds of animals lived in those rainforests. Like the horses, some ate only plants. Some small predators thrived on insects. Larger predators were ambush hunters, lying in wait for smaller animals to come by and then pouncing on them.

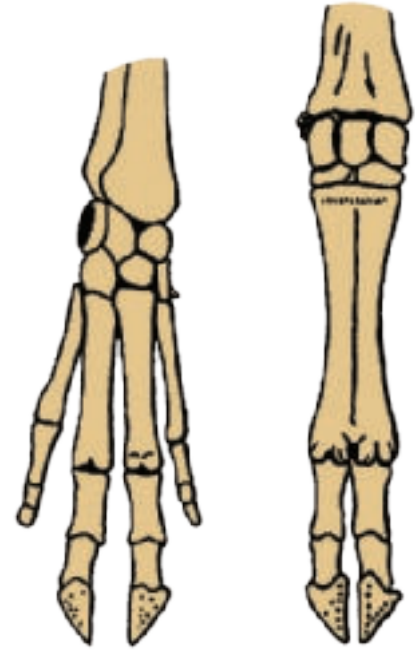
In open grasslands where modern horses live, there are also rich resources. Grass grows in abundance and is the primary source of food for animals that live there. The terrain is mostly flat and firm and covered with grasses and a few other kinds of plants. The grass grows in wide-open expanses that sometimes go on for miles with nothing to interrupt the view. The grasses provide food for many insects and other herbivores, including the horses. Small predators catch and eat insects and some small mammals, like mice. Larger predators in the grasslands, like lions and cheetahs, typically hide in the grass and stalk their prey, then chase them down in order to catch them.



Nothing is known from the fossil record about how long ancient horses lived or how often they reproduced. Modern horses live for about 30 years. They are first able to reproduce when

they are 3-5 years old. They generally give birth to one offspring (called a foal) every two years.

Just like you, many scientists are interested in the toes of horses. They want to know more about the multiple toes that ancient horses had. However, there are no ancient horses alive to be studied. So scientists study other ungulates (hooved animals), such as deer, goats, boar, cattle, and camels, in order to understand how the multiple toes work. These ungulates are animals that are similar to horses in many ways except they have two toes, called cloven hooves. Scientists found that with two toes, the animals are able to spread their toes as they step forward and then close their toes when they place them down. This allows them to grasp and hold onto rocks and uneven surfaces very well. Animals with single, flattened hooves like zebras or Przewalski's horses cannot grasp the ground their feet land on. However, they are able to lift and place their feet quickly, which allows them to run very fast.



Forelegs of boar (left) and cattle (right).

References

- Cothran, E. G., & Podhajsky, A. W. (2018). *Evolution of the horse*. Encyclopædia Britannica. Retrieved from <https://www.britannica.com/animal/horse/Evolution-of-the-horse>
- American Museum of Natural History. (n.d.). *The evolution of horses*. Retrieved from <https://www.amnh.org/exhibitions/horse/the-evolution-of-horses>
- Ginsberg, J. R. (2013). Biodiversity of Mammals. In S. A. Levin (Ed.), *Encyclopedia of Biodiversity* (second edition) (pp. 681–707). Elsevier, Inc. <https://doi.org/10.1016/B978-0-12-384719-5.00089-7>
- McHorse, B. K., Biewener, A. A., & Pierce, S. E. (2019). The evolution of a single toe in horses: Causes, consequences, and the way forward. *Integrative and Comparative Biology*, 59(3), 638–655. <https://doi.org/10.1093/icb/icz050>
- *On your toes: AMNH*. American Museum of Natural History. (2021). Retrieved from <https://www.amnh.org/exhibitions/horse/the-evolution-of-horses/on-your-toes>
- Williams, P. (2016). *The remarkable comeback of Przewalski's Horse*. Retrieved from <https://www.smithsonianmag.com/science-nature/remarkable-comeback-przewalski-horse-180961142/>

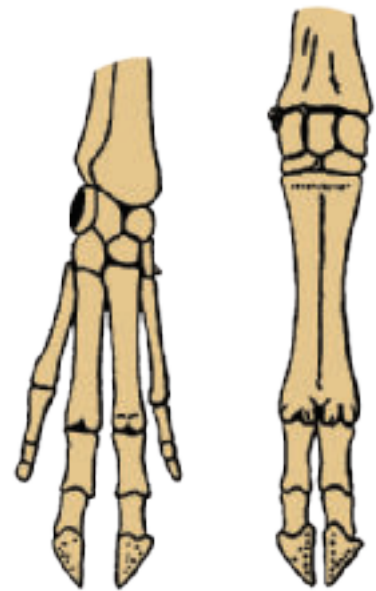
Reading: Version 2: Horses—Ancient and Modern

Both the global climate and local environments have changed significantly in the 50 million years between ancient and modern horses. Over that time, Earth has become cooler and drier. When ancient multi-toed horses lived on Earth 50 million years ago, their environment was similar to tropical rainforests. It was warm and damp with many plants and trees. Over time, as the planet cooled and got drier, those rainforests disappeared. Open forests with grasslands and just a few trees became common. In modern times, the environments where horses live are wide-open grasslands.

Those ancient tropical rainforests where the multitoed horses lived were rich in resources. There were many different types of plants that could be used as food by these herbivores. The land was crowded with trees and vines. Many different animals lived in those rainforests. Some of these animals ate only plants, and others ate insects. Larger predators were ambush hunters, which means they waited for animals to come by and then pounced on them.

The open grasslands where modern horses live also contain rich resources. There is plenty of grass and other plants for the horses and other herbivores to eat. The land is mostly flat and firm. The grass grows in wide-open spaces that can go on for miles. Small predators catch and eat insects and some small mammals, like mice. Larger predators in the grasslands include lions and cheetahs. These predators usually chase their prey to catch them. Nothing is known from the fossil record about how long ancient horses lived or how often they reproduced. Modern horses live for about 30 years. They are first able to reproduce when they are 3-5 years old. They generally give birth to one offspring (called a foal) every two years.

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References

- Cothran, E. G., & Podhajsky, A. W. (2018). *Evolution of the horse*. Encyclopædia Britannica. Retrieved from <https://www.britannica.com/animal/horse/Evolution-of-the-horse>
- American Museum of Natural History. (n.d.). *The evolution of horses*. Retrieved from <https://www.amnh.org/exhibitions/horse/the-evolution-of-horses>
- Ginsberg, J. R. (2013). Biodiversity of Mammals. In S. A. Levin (Ed.), *Encyclopedia of Biodiversity* (second edition) (pp. 681–707). Elsevier, Inc. <https://doi.org/10.1016/B978-0-12-384719-5.00089-7>
- McHorse, B. K., Biewener, A. A., & Pierce, S. E. (2019). The evolution of a single toe in horses: Causes, consequences, and the way forward. *Integrative and Comparative Biology*, 59(3), 638–655. <https://doi.org/10.1093/icb/icz050>
- *On your toes: AMNH*. American Museum of Natural History. (2021). Retrieved from <https://www.amnh.org/exhibitions/horse/the-evolution-of-horses/on-your-toes>
- Williams, P. (2016). *The remarkable comeback of Przewalski's Horse*. Retrieved from <https://www.smithsonianmag.com/science-nature/remarkable-comeback-przewalski-horse-180961142/>

Reading: Version 1: Horseshoe Crabs—Ancient and Modern



Horseshoe crabs have survived all five major extinction events. The oldest (nearly complete) fossils of horseshoe crabs were found in 445-million-year-old rocks in Manitoba, Canada. They look similar to the creatures we find living on beaches today. Younger, 148-million-year-old fossils from a Polish quarry also have shapes and sizes virtually identical to today's horseshoe crabs. When these fossil animals lived alongside the dinosaurs, their ancestors had already lived on Earth for about 300 million years. In their 480-million-year history, the fossil record shows horseshoe crabs to be virtually unchanged.

Ancient horseshoe crabs lived in brackish (somewhat salty) pools near shorelines and in the shallow areas at the edges of oceans. Those ancient environments were rich in resources such as algae, worms, and other invertebrates for horseshoe crabs to eat. They ate harder-shelled organisms by crushing them between their legs first, then passing the food to their mouths and gizzards for further grinding. The global climate and environments changed over time, with varying temperatures, levels of carbon dioxide in the atmosphere, ocean salinity, and sources of prey. However, the local environments that horseshoe crabs continued to inhabit were relatively stable, and horseshoe crabs remained successful.

Modern horseshoe crabs also live along shallow beaches that are rich in food resources such as algae, clams, crustaceans, and worms. Modern horseshoe crabs' predators include alligators, sea turtles, and

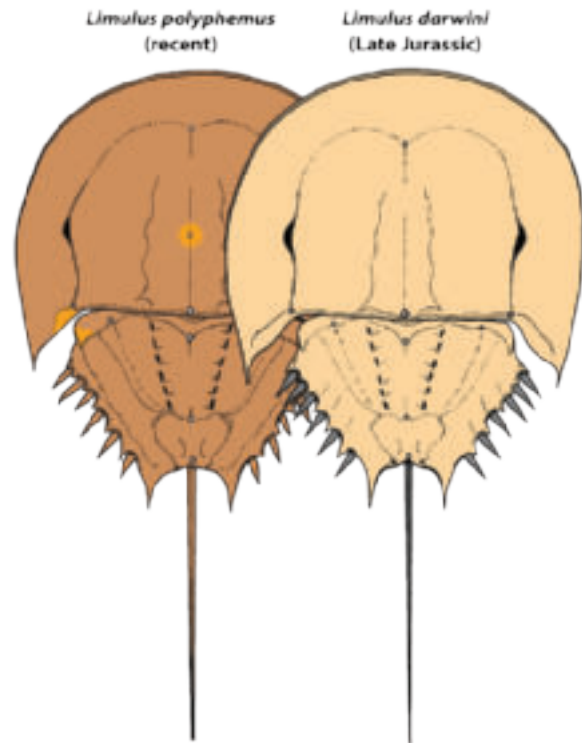


sharks. The shallow marine environments horseshoe crabs inhabit protect them from some of these predators.

Modern horseshoe crabs gather in large nesting groups on beaches when temperatures are warm, laying the most eggs during the spring and fall. Horseshoe crab larvae emerge from their nests several weeks after the eggs are laid. Juvenile horseshoe crabs look like adults except that they are smaller with relatively shorter tails. The young spend most of their time on the sandy bottoms of intertidal flats (zones above the low-tide mark) and feed on various invertebrates. The reproduction habits of ancient horseshoe crabs are not known. However, many smaller fossils have been found, indicating that ancient young horseshoe crabs had similar habits to modern young.

Horseshoe crabs have a hard, tank-like shell that is difficult to break or crack open. Their long, straight tail is called a telson. The telson serves as a rudder during swimming and also as a lever to help right the animal if it flips upside-down on land. The telson is not used to sting or penetrate. Horseshoe crabs get oxygen through book gills located behind their legs, and they can survive out of the water for up to four days as long as their gills stay wet. They can tolerate very low levels of oxygen and high levels of salinity long enough to move to an area with more desirable conditions.

Modern adults of the North American species can weigh about 10 lb (4.5 kg), with bodies that are 1 ft (30 cm) in diameter and with a foot-long telson. Modern horseshoe crabs' mouths are surrounded by their twelve legs. The smallest pair of legs is dedicated to sweeping food into the mouth. The five larger pairs of legs are used for walking and swimming. Horseshoe crabs swim upside down (feet up) with their armored body headed forward to plow through the water. They angle their body at about 30 degrees and can swim up to 0.3 miles (0.5 kilometers) per hour.



Modern horseshoe crab *Limulus polyphemus* (left) and the oldest known horseshoe crab



References

- Romeo, J. (2020, November 16). The horseshoe crab: Same as it ever was? *JSTOR DAILY*. Retrieved from <https://daily.jstor.org/the-horseshoe-crab-same-as-it-ever-was/>
- Florida Fish and Wildlife Conservation Commission. (n.d.). *Facts about Horseshoe Crabs and FAQ*. Retrieved from <https://myfwc.com/research/saltwater/crustaceans/horseshoe-crabs/facts/>
- Hennings, J., & Lynch, H. (2021). *Horseshoe Crabs: Living Fossils*. EarthDate. Retrieved from <https://www.earthdate.org/horseshoe-crabs-living-fossils>
- American Oceans. (n.d.). *Horseshoe Crab*. Retrieved from <https://www.american oceans.org/species/horseshoe-crab/>

Reading: Version 2: Horseshoe Crabs—Ancient and Modern



Horseshoe crabs have survived all five major extinction events. The oldest (nearly complete) fossils of horseshoe crabs were found in 445-million-year-old rocks in Canada. They look similar to the creatures we find living on beaches today. Younger, 148-million-year-old fossils of horseshoe crabs were found in Poland. They also have shapes and sizes almost identical to today's horseshoe crabs. These ancient animals lived alongside the dinosaurs, and their ancestors had already lived on Earth for about 300 million years. The fossil record shows that horseshoe crabs have not changed much in their 480-million-year history.

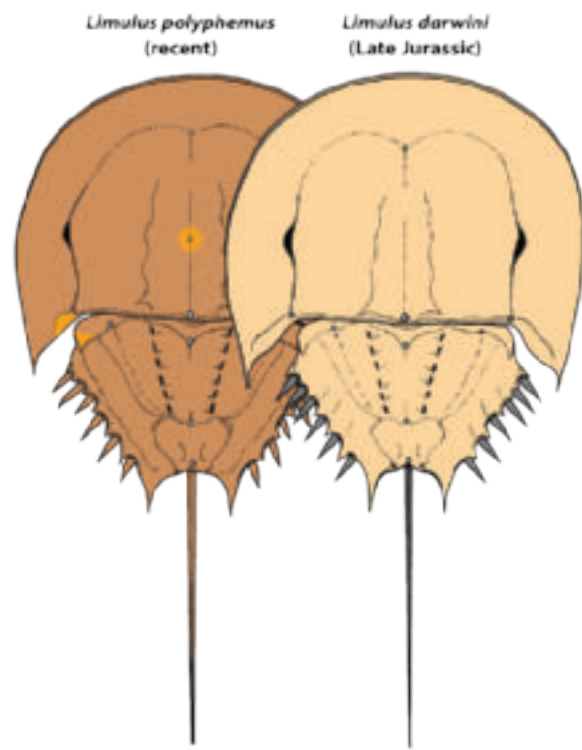
Ancient horseshoe crabs lived in ocean tide pools and shallow shorelines. Those ancient environments had many food sources for the horseshoe crabs. They ate algae, worms, and other invertebrates. If an animal had a hard shell, the horseshoe crab would crush it between its legs. Then it would move the food into its mouth and chew it more. The climate and environment across the globe changed over time. Temperatures, the amount of carbon dioxide in the atmosphere, and the amount of salt in the oceans all varied. However, the local environments that horseshoe crabs continued to inhabit were relatively stable. So, horseshoe crabs remained successful.

Modern horseshoe crabs also live along shallow beaches. These environments also have many food resources such as algae, clams, crustaceans, and worms. Modern horseshoe crabs' predators include alligators, sea turtles, and sharks. Living in these shallow marine environments protects horseshoe crabs from some of these predators.

Modern horseshoe crabs gather in large nesting groups on beaches when temperatures are warm. They lay most of their eggs during the spring and fall. Horseshoe crab larvae hatch several weeks after the eggs are laid. Young horseshoe crabs look like adults except that they



are smaller with shorter tails. The young spend most of their time in shallow water zones above the low-tide mark and eat various invertebrates. The reproduction habits of ancient horseshoe crabs are not known. However, many smaller fossils have been found that indicate young ancient horseshoe crabs had similar habits to modern young.



Modern horseshoe crab *Limulus polyphemus* (left) and the oldest known horseshoe crab

Horseshoe crabs have a hard, tank-like shell. This shell is difficult to break or crack open. Their long, straight tail is called a telson. They use the telson to steer their bodies while they swim. Also, it can be used to flip them upright if they turn upside-down on land.. The telson is not used to sting or penetrate. Horseshoe crabs get oxygen through book gills located behind their legs. They can survive out of the water for up to 4 days if their gills stay wet. They can survive very low levels of oxygen and high levels of salt in the water long enough to move to an area with better conditions.

Modern adults of the North American species can weigh about 10 lb (4.5 kg). Their bodies are 1 ft (30 cm) in diameter, and their telson is 1 foot long. Modern horseshoe crabs' mouths are in the middle of their twelve legs. The smallest pair of legs is used to sweep food into the mouth. The five larger pairs of legs are used for walking and swimming. Horseshoe crabs swim upside down with their feet facing up. They point their armored body headed forward to plow through the water. They angle their body at about 30 degrees and can swim up to 0.3 miles (0.5 kilometers) per hour.

References

- Romeo, J. (2020, November 16). The horseshoe crab: Same as it ever was? *JSTOR DAILY*. Retrieved from <https://daily.jstor.org/the-horseshoe-crab-same-as-it-ever-was/>
- Florida Fish and Wildlife Conservation Commission. (n.d.). *Facts about Horseshoe Crabs and FAQ*. Retrieved from <https://myfwc.com/research/saltwater/crustaceans/horseshoe-crabs/facts/>
- Hennings, J., & Lynch, H. (2021). *Horseshoe Crabs: Living Fossils*. EarthDate. Retrieved from <https://www.earthdate.org/horseshoe-crabs-living-fossils>
- American Oceans. (n.d.). *Horseshoe Crab*. Retrieved from <https://www.american oceans.org/species/horseshoe-crab/>

Reading: Penguin Environments - Ancient and Modern

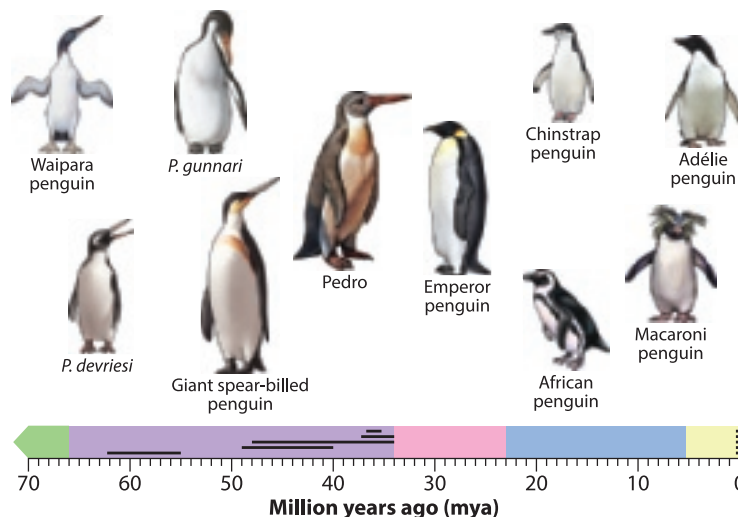
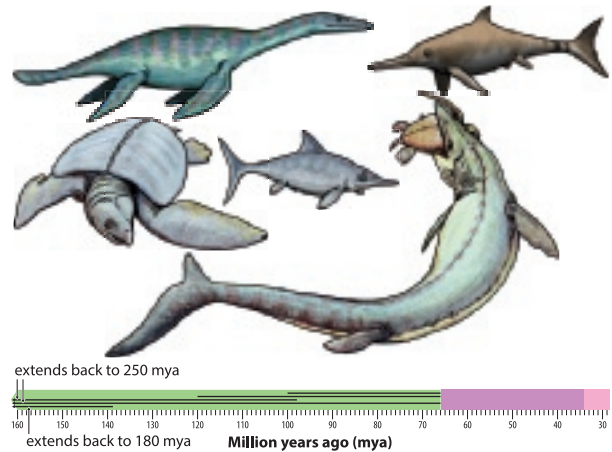
Just like environments on land have changed over millions of years, so too have Earth's oceans. Scientists learn about how the ocean environment has changed over time by studying the fossil record.

By looking into the catalog of fossils that have been found, we see the variety of species of organisms change and diversify over time. As we see evidence for more species, we also see that they increase in size. By around 150 million years ago, there is evidence for all main groups of animals that are still found in nature today (fish, amphibians, reptiles, birds, and mammals).

There was a mass extinction event 66 million years ago that resulted in the disappearance of dinosaurs and many other terrestrial reptiles from the fossil record. Large marine reptiles suffered a similar fate at this time. Larger fish that were once prey to these large reptiles became abundant in certain parts of these environments where there were now fewer predators.

Shortly after this time giant penguins with long, spear-like beaks appear in the fossil record. Scientists are very interested in learning about how the ancient penguins used these beaks (which are very different from any of the beaks of modern penguins). However, there are no ancient penguins alive to study.

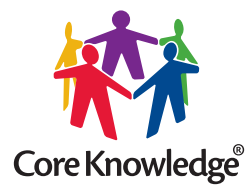
Instead, scientists observe modern birds that live in or near water and inherit long beaks, such as the aninga and the heron. Studying how these birds use their beaks along with details like muscle-attachment sites of the giant penguin skulls causes scientists to hypothesize that the structure of these beaks would function to catch and eat large fish by spearing them. Birds with longer beaks can successfully catch larger fish this way.



Larger marine animals can dive deeper and for longer amounts of time in pursuit of large fish. This body size to diving time relationship can also be seen in modern penguins. The penguins that inherit smaller bodies tend to feed at the surface of the water and can come up for air more often. Upwelling brings cold, nutrient-rich waters to the surface where phytoplankton (at the base of the food chain) bloom and feed the fish, krill, and squid that penguins eat. Larger penguins like the king penguin frequently dive to 300 feet (91 m), and emperor penguins can reach depths around 1,700 feet (518 m) as they hunt for lanternfish and Antarctic silverfish which live at these depths. Emperor penguins dive deeper than killer whales and other sea birds that also eat this food source.

Data adapted from these sources:

- National Park Service. (2015). *Anhinga*. Retrieved from <https://www.nps.gov/bicy/learn/nature/anhinga.htm>
- Dunham, W. (2016). *Mysterious extinction of prehistoric marine reptiles explained*. Retrieved from <https://www.reuters.com/article/us-science-reptiles/mysterious-extinction-of-prehistoric-marinereptiles-explained-idUSKCN0WA2K2>
- Hall, D. (Reviewed by B. Fraser). (2018). *Penguins*. Smithsonian Ocean. Retrieved from <https://ocean.si.edu/ocean-life/seabirds/penguins>
- BBC. (2019, August 14). *Human-sized penguins lived in New Zealand*. Retrieved from <https://www.bbc.com/news/world-asia-49340715>
- King, M. (2018, December 22). *Fish Beware! – Penguins Adapt Effective Means of Capturing Prey* [blog]. Retrieved from <https://www.penguinsinternational.org/tag/how-do-penguins-catch-fish/>
- Marine life. (2021, January 02). Retrieved from https://en.wikipedia.org/wiki/Marine_life
- Marshall, M. (2009, July 14). *Timeline: The evolution of life*. Retrieved from <https://www.newscientist.com/article/dn17453-timeline-the-evolution-of-life/>
- McCauley, D., Pinsky, M., Palumbi, S., Estes, J., Joyce, F., & Warner, R. (2015, January 16). *Marine defaunation: Animal loss in the global ocean*. Retrieved January 06, 2021, from <https://science.sciencemag.org/content/347/6219/1255641>
- Olson, S. L. (1985). *The fossil record of birds*. *Avian Biology*, 79-238. doi:10.1016/b978-0-12-249408-6.50011-x
- Watson, T. (2017, March 29). *How giant marine reptiles terrorized the ancient seas*. Retrieved January 06, 2021, from <https://www.nature.com/news/how-giant-marine-reptiles-terrorized-the-ancientseas-1.21722>
- Zimmer, C. (2017, December 12). *Ancient penguins were giant waddling predators*. Retrieved January 06, 2021, from <https://www.nytimes.com/2017/12/12/science/ancient-penguins-kumimanu.html>



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