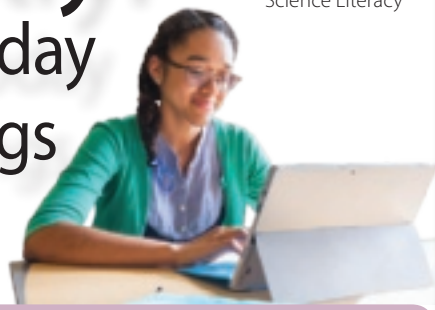
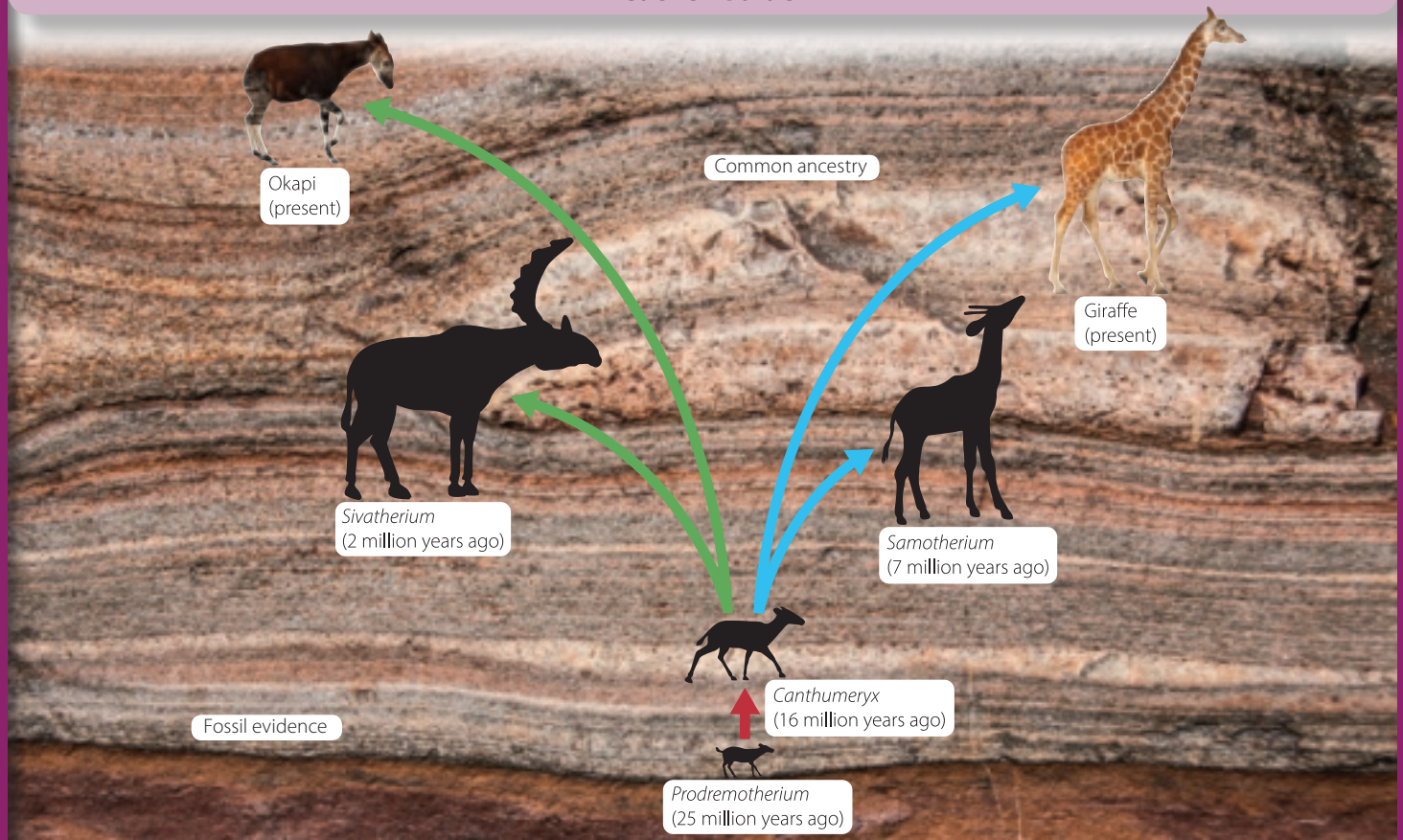
Natural Selection and Common Ancestry:

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

Science Literacy



Teacher Guide



GRADE 8 Core Knowledge Science®

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This unit is a modified version of a unit that has earned the NGSS Design Badge. The sole instructional modification is the addition of Core Knowledge Science Literacy content. The modification has not been reviewed.

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BEFORE YOU BEGIN

Before introducing the unit, please become fully acquainted with the program instructional model and classroom routines by reading the online resource **Teacher Handbook: Overview of the Core Knowledge Middle School Science Program**.

Online Resources 	Use this link to download the **CKSci Online Resources Guide** for this unit, which includes specific links to: • the unit's comprehensive materials list • a full unit pacing snapshot • lesson guidance slides • all other recommended resources. **www.coreknowledge.org/cksci-online-resources**
Student Work Pages 	All student handouts and exercise pages are included in the consumable Student Work Pages book so that there is no need to print copies of these resources.
Student Books 	All student handouts and exercise pages are included in the consumable Student Work Pages book so that there is no need to print copies of these resources. Students also will use the Student Procedure Guide and the Science Literacy Student Reader throughout the unit.

UNIT OVERVIEW

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

In this unit, students investigate the connections between ancient and modern organisms. In the four lesson sets, students develop a model for natural selection and use it to account for patterns between the body structures and behaviors of ancient organism fossils and similar organisms living today.

The unit begins with students hearing about the surprising fossil of an ancient penguin (nicknamed "Pedro") in a podcast from the researchers who found and identified the fossil. Students also read a photo journal from their research. Students question how penguins living today could be connected to this fossil of a much larger penguin from long ago and record their noticings and wonderings. Students then explore the different species of penguins alive today through a series of videos and data cards. Students develop initial explanations for how today's penguins could be connected to Pedro or other penguins from long ago. Their models need to explain (a) where did all the ancient penguins go, and (b) where did all the different species of modern penguins come from? They expand the range of phenomena by considering other types of organisms that lived long ago and look different from similar types of organisms alive today. Students then develop a Driving Question Board (DQB) to guide future investigations.

In the first lesson set (Lessons 1-6), students investigate the connections between organisms living today and those that lived long ago. Students explore heritable traits in modern penguins (Lesson 2) and examine similar data for ancient penguins (Lesson 3). Students then revise their initial models of how modern penguins could be connected to ancient penguins to account for the time-related and trait-related patterns they have uncovered (Lesson 4). In Lesson 5, students analyze data from ancient and modern species of horses, whales, and horseshoe crabs to see whether these organisms have similar patterns. In Lesson 6, students put together what they have figured out to explain the patterns they uncovered in how organisms change. Their Penguin Timeline model includes the ideas that (a) traits in some modern populations have changed over millions of years from the ancient organisms they are descended from and (b) these changes may be related to changes in the environment from long ago to the present.

In the second lesson set (Lessons 7-11), students work on explaining these patterns to develop and use a model of adaptation by natural selection. In Lesson 7, students begin to investigate five cases in which a trait changed in a population over a few generations. In Lesson 8, they identify common mechanisms that underlie the causes for each of the changes in the populations and develop a model for natural selection that explains all five cases. In Lessons 9 and 10, students use computer simulations to test this model in different environmental conditions and over different lengths of time. An assessment in Lesson 11 then requires students to use their natural

selection model to explain how some of the trait differences in a population of lizards could be the result of natural selection.

In the third and fourth lesson sets (Lessons 12-13 and 14-15 respectively), students extend their model of the cause of trait changes in populations over time to include the mechanisms of mutation and sexual reproduction they developed earlier. In Lesson 13, they use their natural selection model to explain how some body structure variations in different species of modern penguins could result from natural selection and how these penguins could descend from a common ancient ancestor penguin population. In Lesson 14, students analyze embryological data from different stages of development for different species to add to their argument about how different types of living things (species) may be connected. Finally, in Lesson 15, students take stock of all the questions they answered in this unit, and consider questions they look forward to figuring out in high school.

Through these investigations, students will do the following:

- Analyze and interpret data to reveal patterns of connection among modern organisms and between modern and fossil organisms based on anatomical similarities and differences.
- Analyze and interpret data regarding the changes that have occurred in different types of organisms and in the environment throughout the history of life on Earth.
- Ask questions about the mechanisms that cause changes in the heritable traits in a population of organisms over time.
- Obtain, evaluate, and communicate information about structures and how their functions support survival and successful reproduction in new environments.
- Develop and use a model of cause-and-effect mechanisms (natural selection) that lead to the predominance of certain trait variations in a population and to the suppression or elimination of others.
- Use arguments based on empirical evidence and scientific reasoning to support an explanation for how characteristic behaviors and specialized structures affect the probability of successful reproduction of different species of penguins in different environments.
- Construct an explanation for lines of evolutionary descent using evidence for what traits remain relatively stable and which are changing and explain how natural selection could cause these changes.
- Argue using data from the physical structures apparent in different types of animals (species) at different stages of embryological development that emphasize new ideas about how different types of living things (species) may be connected.

Building Toward NGSS Performance Expectations

MS-LS1-4: Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.

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

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

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

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

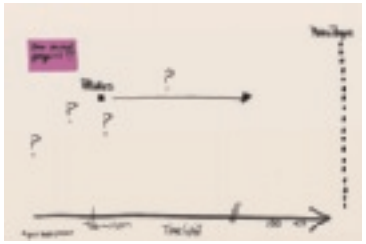
MS-LS4-6: Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.

UNIT STORYLINE

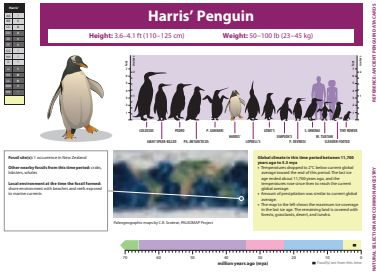
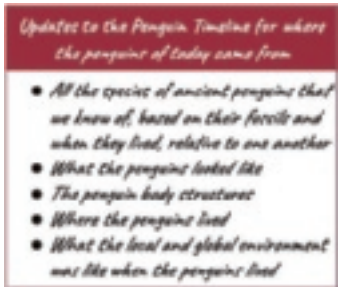
How students will engage with each of the phenomena

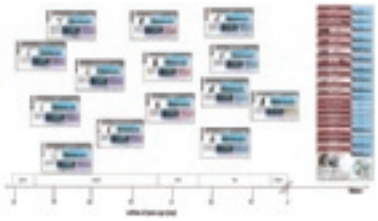
HANDS-ON/ LAB ACTIVITIES	VIDEOS OR IMAGES	DATA SETS	READINGS	COMPUTER INTERACTIVES

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

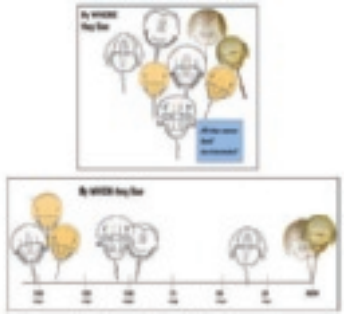
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 **4 days** **How could penguins and other things living today be connected to the things that lived long ago?** Anchoring Phenomenon	 *A giant penguin, named Pedro, that lived 36 million years ago has important anatomical similarities to and differences from penguins that are alive today.*	We record what we notice and wonder about a fossil of a giant penguin from long ago and we analyze data about penguins living today. We develop initial explanations of how these penguins could be connected. We brainstorm possible mechanisms to help explain two things: (1) Where did all the ancient penguins go? (2) Where did all the different species of modern penguins come from? We develop a DQB to guide future investigations. We figure out: • There are 18 different species of penguins alive today. All have similar body structures as well as some noticeable differences. • Scientists found a giant penguin fossil (nicknamed "Pedro") that lived 36 million years ago in Peru. It is bigger and it had a much longer beak than any penguins alive today. • We have different ideas about where today's penguins and other organisms come from: maybe none, some, or all of today's penguins (and other organisms) are descendants of Pedro (or other organisms from long ago).	

⇩ **Navigation to Next Lesson:** Since we had some disagreement about what happened to ancient penguins and where all the different species of modern penguins came from as well as many questions about how they might be connected, we want to see more data on all known penguins (modern and ancient ones).

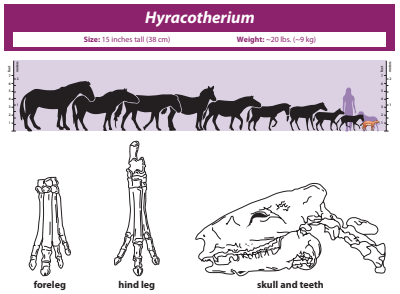
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 2 **2 days** **How similar or different are different species of penguins?** Investigation	 *Heritable physical structure and behavior variations have been measured for different modern penguins, and some of these have been measured for Pedro.*	We analyze a data set of heritable external structures and behavior in modern penguins to look for patterns and infer connections among them and Pedro. We develop questions on how other heritable internal structures would compare for these penguins and for other ancient penguin fossils. We figure out: • Penguins have heritable external structures like beak color, feather shape, and eye ring patterns. • Penguins have heritable behaviors such where they lay their eggs. • Penguins have heritable internal structures like bones. There is some variation in these across different species of penguins. • Some species of penguins share many more structures and behaviors in common with other species of penguins than others.	
⇩ **Navigation to Next Lesson:** After analyzing data for body structures in modern penguins and Pedro, we wonder how these structures compare in ancient penguins—we want to look at more fossils.			
LESSON 3 **2 days** **How do the body structures of other ancient penguins compare to modern penguins?** Investigation	 *Body structure data from fossils for different penguin species found at different sites provide information on how old the fossils are and the environment the ancient penguins lived in.*	We analyze data tables of bone structures for ancient penguin fossils and modern penguins and develop a timeline-based representation of the patterns in the data. We analyze images, maps, and descriptions of where these fossils formed. We figure out: • None of the ancient penguins have all the same body structures in common with any modern penguins. • Ancient penguin fossils tend to have more body structures in common with each other the closer they are in time. Modern penguins have more in common with less-ancient penguin fossils than with more-ancient ones. • Ancient penguins lived in some of the places modern ones do. Other organisms that lived in these areas have changed over time.	
⇩ **Navigation to Next Lesson:** There is a lot that we uncovered about modern and ancient penguins that wasn't in our initial Penguin Timeline. We want to revise that to make a model in our next lesson so we have a common public record of what we agree on to refer to going forward.			

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 4 **2 days** **Why are there similarities and differences in the body structures of modern and ancient penguins?** Putting Pieces Together, Problematizing	 *When multiple fossils of the same species are found, they have the same variations. We also put pieces together from all phenomena we explored in Lessons 1 through 3.*	We revise our initial explanation to account for the patterns in data from previous lessons, including several candidate ideas for what might be causing these patterns. We revisit our Driving Question Board and our list of related phenomena and decide to investigate connections among other ancient and modern organisms. We figure out: • Some species (one or multiple) of ancient penguins must have produced 18 lines of descendants that are alive today. We might be missing fossils of penguins that are more similar to the ones of today. • We suspect that different species of penguins live(d) in different places–they have different body structure variations that could help them survive better in certain environments. • We establish that a sample of one penguin fossil can generally represent the entire population at that time, but there is variation among individuals within populations. Since there are not very many penguin fossils available, we want to look at other organisms.	

⇩ **Navigation to Next Lesson:** We need some more fossil data from our related phenomena to see if there are similar patterns in other ancient and modern organisms and to help us figure out what we are missing because we do not have all the data from penguins that we need.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 5 **2 days** **How might other living things be connected to ancient organisms?** Investigation	 *Body structure variation data have been collected from modern whales, horses, and horseshoe crabs, as well as from ancient fossils of these organisms. The specific locations where these fossils were found also provide information on how old they are and what their local and global environments were like at that time the fossils formed.*	We investigate organisms other than penguins to see if patterns of connections between ancient and modern organisms also occur in other types of organisms. We sort data cards for ancient and modern horseshoe crabs, horses, and whales to see what patterns of similarities and differences exist in their body structures. We discuss how patterns we notice in their body structures might be connected to when or where they live(d). We figure out: • The structures of some other living things today look similar to but not exactly like the most similar-looking fossils we can find. • Sometimes, but not always, there are noticeable differences in specific body structures (limbs, skulls, teeth, shells) and/or changes in overall size of the organism. • The further back in the fossil record we go, the more pronounced the structural differences are. • Sometimes, but not always, body structures of organisms seem to match the environment in which they live(d).	

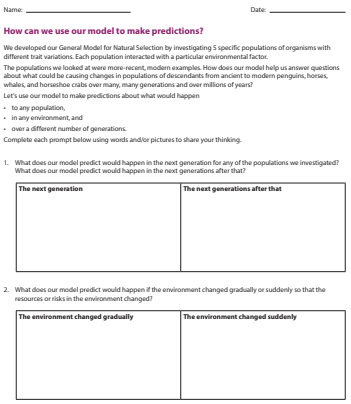
⇩ **Navigation to Next Lesson:** We saw some patterns across all the different types of organisms we analyzed. We think we are ready to revise our original explanations around the questions, Where did all the ancient penguins go? and Where did all the different species of modern penguins come from?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 6 **2 days** **How could organisms living today be connected to organisms that lived long ago?** Putting Pieces Together, Problematizing	 *No new phenomena are introduced in this lesson. We put the pieces together for all phenomena we previously explored in Lessons 1 through 5.*	We argue for whether the fossil data we've been investigating represents what is found in only one individual or represents what is typical of any individual in their population. We construct revised explanations for how modern organisms are connected to ancient organisms. We figure out: • There are clear patterns of differences in the body structures of some organisms over really long periods of time and across different environments. • There must have been some population(s) of ancient organisms that had offspring that were lines of descendants that led to modern organisms. • The body structure variations are somehow changing in a line of descendants from one of the ancient populations to one of the modern ones.	

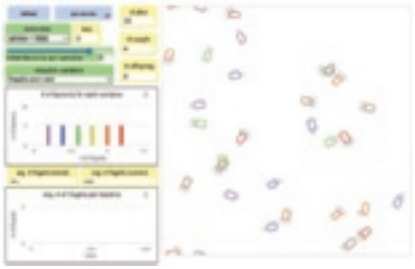
⇩ **Navigation to Next Lesson:** Since something was changing in these populations over time and we can't go back in time to observe it as it was happening to figure out how the change occurred, we need some cases with firsthand observations of a population-level trait change happening over a shorter time (a few generations).

LESSON 7 **3 days** **How do traits found in a population change over a shorter amount of time?** Investigation	 *In five different populations (cliff swallows, peppered moths, finches, sticklebacks, and mustard plants) scientists measured a rapid shift in the distribution of a trait variation in a population over multiple generations.*	We explore five cases where trait distributions in the population changed over a few generations. We use a jigsaw strategy to analyze data from different studies on our group's assigned case. We develop a model to explain what was causing the shift in trait distribution over time for our individual cases. We figure out: • Scientists collected a lot of different kinds of data to try to figure out what caused the shift in trait distribution over time. • Thinking about the relationship among structure and function, change and stability over time, and the causes and effects on both individuals and the population can provide useful lenses for developing a model to explain a complex biological system. • We have ideas from specific cases that changes in the distribution of traits in a population is related to successful survival (and reproduction) in certain environments.	

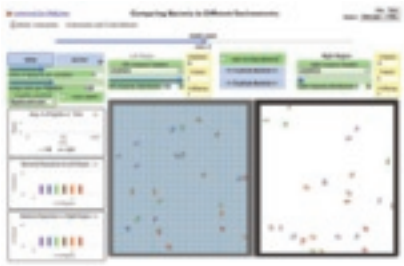
⇩ **Navigation to Next Lesson:** Though we have a case-specific set of causes and effects that explain the trait changes in a population in our system, we want to see whether there are any similar mechanisms that help explain the trait changes in the other populations across the rest of the case studies.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 8 **2 days** **How can we model what is causing the changes in the populations happening across all our case studies?** Putting Pieces Together	 Name: _____ Date: _____ **How can we use our model to make predictions?** We developed our General Model for Natural Selection by investigating 5 specific populations of organisms with different trait variations. Each population interacted with a particular environmental factor. The populations we looked at were more-recent, modern examples. How does our model help us answer questions about what could be causing changes in populations of descendants from ancient to modern penguins, horses, whales, and horseshoe crabs over many, many generations and over millions of years? Let's use our model to make predictions about what would happen • to any population, • in any environment, and • over a different number of generations. Complete each prompt below using words and/or pictures to share your thinking. 1. What does our model predict would happen in the next generation for any of the populations we investigated? What does our model predict would happen in the next generations after that? **The next generation** / **The next generations after that** 2. What does our model predict would happen if the environment changed gradually or suddenly so that the resources or risks in the environment changed? **The environment changed gradually** / **The environment changed suddenly** *No new phenomena are introduced in this lesson. We put the pieces together for all phenomena we explored in Lesson 7.*	We compare case-specific system models (for finches, moths, swallows, sticklebacks, and plants) and argue for which parts and interactions these cases have in common. We develop a general model to explain what causes changes in the population and use it to make predictions about what would happen in any population, in any environment, and over a different number of generations. We figure out: • There was variation in specific traits between individuals in a population in the past. • Individuals with certain trait variations are sometimes able to more easily access available resources needed for survival, causing them to survive better and reproduce more than other individuals. • The traits that grant an advantage for surviving or reproducing can be passed on to their offspring. • Distribution shows more individuals with the trait variation that allows them to survive or reproduce better.	

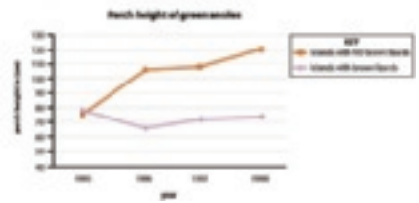
⇩ **Navigation to Next Lesson:** Though we think our model is general enough that it should apply to any population (e.g., penguins), we want to test it on a new context or case to see how good it is at predicting and explaining what should or would happen to other populations, in different environments, or over different lengths of time.

LESSON 9 **2 days** **How well does our General Model predict and explain the changes happening over time in a different population?** Investigation	 *A simulation that includes trait variation in a salmonella bacteria population and two types of white blood cells produces shifts in the distribution of the bacteria trait variations.*	We carry out two investigations using a computer simulation. We argue for why we get different outcomes when we simulate different types of white blood cells in the environment with the same starting population of bacteria. We figure out: • Changes in the environment can lead to different changes in the trait variations of the population. • Trait variations that provide an individual a competitive advantage in one environment may give it a disadvantage in another environment. • Competitive advantage affects the chances (or probability) of certain individual outcomes. • The longer this process (natural selection) continues (over more generations), the more variations tend to be removed from the descendant population.	

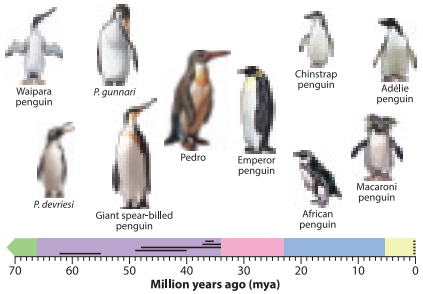
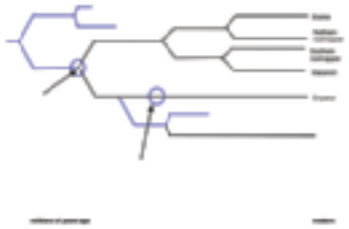
⇩ **Navigation to Next Lesson:** Though we figured out that our model could explain the changes in the trait variation distribution in a population of simulated bacteria due to one type of changing environment (predators), we wondered if it would predict and explain outcomes from other changes to the environment.

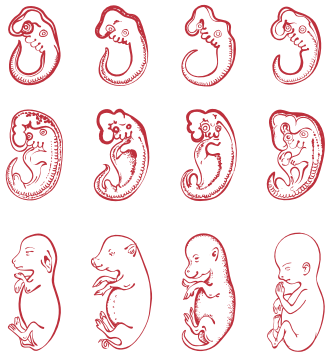
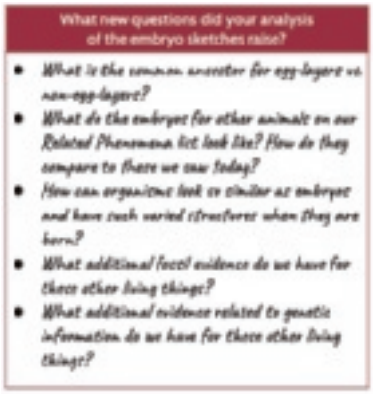
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 10 **2 days** **Why does our General Model tend to produce different outcomes in different environmental conditions?** Investigation, Putting Pieces Together	 *A simulation of two different bacteria populations produces different shifts in the distribution of trait variations in the populations over time depending on the type of distribution of food in the environment.*	We plan and carry out an investigation using a new bacteria simulation to test what will happen when we change the environment by a different factor other than predation. We run our investigation, collect data, and use our General Model for Natural Selection to explain our results. We figure out: • Our model (General Model for Natural Selection) tends to produce different outcomes in different environmental conditions. • Any change in the environment that affects the resources needed for survival and reproduction can lead to shifts in the distribution of trait variations in a population. • Natural selection tends to remove certain variations from a population over time; this outcome becomes more pronounced as time goes on.	

⇩ **Navigation to Next Lesson:** Our General Model for Natural Selection seems able to predict and explain changes in a population over several generations. We want to try our model on a new phenomenon.

LESSON 11 **1 day** **Can we use our General Model for Natural Selection to explain changes over time in green anole lizards?** Putting Pieces Together	 *On islands with green and brown anole lizards, the green lizards now live higher (than in the past) in the trees than on islands without brown anole lizards.*	We demonstrate what we have learned on an assessment. We give and receive peer feedback on our explanations. We revise our explanation based on peer feedback. We figure out: • Green lizards live higher in the trees after the brown lizards are introduced to their habitat because of trait variation in the initial population of green lizards those with larger toe pads and more sticky scales have a competitive advantage that allows them to survive long enough to reproduce and pass down those trait variations to their offspring. • This results in a shift in trait variation distribution in the population after the change (the introduction of brown lizards), with an increase in toe pad size and amount of sticky scales.	

⇩ **Navigation to Next Lesson:** We tested our General Model for Natural Selection on a new phenomenon. Next, we want to see if we can use our model to explain the types of changes we think are happening over millions of generations.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 12 **2 days** **Can our model explain changes over really long periods of time?** Putting Pieces Together, Problematizing	 *Ancient and modern horses and horseshoe crabs have body structures that help(ed) them survive in their specific environments.*	We update our General Model for Natural Selection to include mutation and use it to explain differences in body structures in horses and horseshoe crabs over very long periods of time. We figure out: • Mutation is the source of new variation and can explain body structures in modern organisms that are not seen in ancient organisms. • Natural selection could be the mechanism that is causing the greater changes we see over longer periods of time. • Mutations and natural selection could link modern organisms with their ancestors far back in time. • We have questions about how our model might explain how there are so many species of penguins (and other organisms) with such different body structures.	
⇩ **Navigation to Next Lesson:** We wonder if the General Model for Natural Selection can explain cases where there are several different modern species with many different body structures.			
LESSON 13 **2 days** **Can we apply the General Model for Natural Selection over millions of years to explain how all the ancient and modern penguins are connected?** Putting Pieces Together	 *No new phenomena are introduced in this lesson. We put the pieces together for penguin phenomena we explored throughout the unit.*	We use what we know about natural selection and mutation to develop a model to show how modern penguins could be connected to one another and to ancient penguins. We construct a hypothetical explanation for how the penguins are connected and compare our explanations with others. We figure out: • When populations are in different environments for longer amounts of time, the accumulation of random mutations combined with natural selection leads to differences in body structures in each population. • Penguins that have fewer differences in body structures shared the same environment (and a common ancestor) more recently than penguins that have more differences in body structures. • The relationship between the amount of time populations have been separated and the number of differences in body structures can be used to propose which organisms shared the most recent ancestors and how modern and ancient penguins are connected.	
⇩ **Navigation to Next Lesson:** What other kinds of evidence would you want to help you figure out how all species trace back to their ancestors?			

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 14 **2 days** **What do the patterns in embryo development tell us about how things living today could be connected to the things that lived long ago?** Investigation	 *Similarities exist between the physical structures of embryos for different animal species that are not evident in the fully formed anatomy.*	We analyze sketches of embryos at different points in development for a variety of living things, such as a chicken, a turtle, a rabbit, and a human. We construct an argument and raise questions about how and why different organisms share so many physical structures in common in their embryological development. We share these arguments and questions as a class. We figure out: • Early in development, there are similarities in the structures that make up different organisms, including both egg-layers and mammals. • These similarities in structures are not always evident later in development. Similar structures early in development point to similar processes responsible for growth and development for different organisms.	
⇩ **Navigation to Next Lesson:** We considered another line of evidence to explain how organisms today are connected to organisms of long ago. We want to revisit our DQB to see what questions we can answer.			
LESSON 15 **1 day** **What can we explain now, and what questions do we still have?** Putting Pieces Together	 *Asking questions about phenomena gives us a mission for our science learning.*	We identify the questions from our DQB that we can now answer. We celebrate all that we have learned in this unit and across the school year. We spend time identifying the questions that we did not answer and build a new DQB of these questions. We create a plan to answer some of them on our own and in school next year and beyond. We figure out: • Science learning is about asking questions and gathering evidence to answer those questions. • As some questions get answered, new questions come up.	
⇩ **Navigation to Next Lesson:** This is the last lesson in the unit.			
LESSONS 1-15 **31 days total**			

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices within the context of hands-on investigations and demonstrations, whether student scientists are working in a classroom, in a traditional laboratory setting, or in the field. In this way, teachers need to be aware of any school or district safety policies, legal safety standards, and better professional practices that are applicable to hands-on science activities being undertaken.

Science safety practices in laboratories or classrooms require engineering controls and personal protective equipment (e.g., safety goggles, nonlatex aprons and gloves, eyewash and shower station, fume hood, fire extinguishers). Science investigations should always be directly supervised by qualified adults, and safety procedures should be reviewed annually prior to initiating any hands-on activities or demonstrations. Prior to each investigation, students should also be reminded of the safety procedures that need to be specifically followed. Each of the lessons within the units includes teacher guidelines for applicable safety procedures for setting up and running an investigation as well as taking down, disposing of, and storing materials.

Prior to the first science investigation of the year, a safety acknowledgement form for students and parents or guardians should be provided and signed. You can access a model safety acknowledgement form for middle school activities at the following location: http://static.nsta.org/pdfs/SafetyAcknowledgmentForm-MiddleSchool.pdf

Disclaimer: The safety precautions of each activity are based in part on use of the specifically recommended materials and instructions, legal safety standards, and better professional safety practices. Be aware that the selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

Please follow these lab safety recommendations for any lesson with an investigation:

1. Wear safety goggles (specifically, indirectly vented chemical splash goggles), a nonlatex apron, and nonlatex gloves during the setup, hands-on investigation, and take-down segments of the activity.
2. Immediately wipe up any spilled water and/or granules on the floor, as this is a slip-and-fall hazard.
3. Follow your *Teacher Guide* for instructions on disposing of waste materials and/or storage of materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.

Specific safety precautions are called out within the lesson using this icon and a callout box.



TEACHER BACKGROUND KNOWLEDGE

What is the anchoring phenomenon and why was it chosen?

The unit begins with students hearing about the surprising fossil of an ancient penguin (nicknamed "Pedro") in a podcast with the researchers who found and identified the fossil. Students also read a photo journal from their research. Students question how penguins living today could be connected to this fossil of a much larger penguin from long ago and record their noticings and wonderings. Students then explore the different types of penguins alive today through a series of videos and data cards. Students develop initial explanations for how today's penguins could be connected to Pedro or other penguins from long ago. Their models explain their ideas about these questions: (a) Where did all the ancient penguins go? and (b) Where did all the different species of modern penguins come from? They expand the range of phenomena to investigate by considering other types of organisms that lived long ago and look different from similar types of organisms alive today. Students then develop a Driving Question Board (DQB) to guide future investigations.

Each unit's anchoring phenomenon is chosen from a group of possible phenomena after analyzing student interest survey results and consulting with external advisory panels. In addition to this process, we chose Pedro and the ancient penguins' connection to modern penguins as the anchoring phenomenon for this unit for these reasons:

- In the student survey results, investigating fossil-related phenomena ranked higher than questions about different organisms found in different environments today. Among the latter type of phenomena, a question about why different flightless birds are found in some parts of the world and not others ranked higher than one on colorful frogs and one on sticky-footed lizards. In an attempt to blend the need for investigating some line of fossil data related to an organism alive today, we selected penguins as a type of flightless birds that are also charismatic animals that have distinct physical structures and behaviors compared to other birds.
- Due to the accessibility of zoos, aquariums, and pop culture, penguins are relevant to most students as a model organism.
- Penguins have a variety of similar body structures that can show easily recognizable variation between species.
- The penguin fossil record is relatively intact and spans many years.
- Recent discoveries regarding evidence for different types of giant penguin fossils provide a novel line of new data from the field to explore.
- The paleontologists (Dr. Julia Clarke and Sr. Ali Altamirano) who made some of the discoveries concerning Pedro were interested in working with us to reframe their data and research in a way that students could figure out key ideas related to the target PEs for this unit.
- Dr. Julia Clarke and Sr. Ali Altamirano come from backgrounds that are often less represented in science curriculum in the United States.
- A pre-field-release pilot of this anchor produced Driving Question Boards that had over 85% of the students' questions on them and ideas for the types of investigations and sources of data needed to answer those questions, as anticipated by the unit development team, and were specifically targeted in the field-test version of the storyline.

What are the NGSS dimensions developed in this context?

This unit spans four lesson sets. In the first lesson set (Lessons 1-6), students investigate the connections between organisms living today and those that lived long ago. Students explore heritable trait variations in modern penguins as well as in ancient penguins and then analyze data from ancient and modern species of horses, whales, and horseshoe crabs to see whether these organisms have similar patterns. By the end of this lesson set, the classroom consensus model will include the ideas that (a) traits in some modern populations have changed over millions of years from the ancient organisms they are descended from and (b) these changes may be related to changes in the environment from long ago to the present.

In the second lesson set (Lessons 7-11), students develop and use a model of adaptation by natural selection to explain patterns they see. Students begin by investigating five cases in which a trait changed in a population over a few generations and then identify common mechanisms that underlie the causes for the changes in each case and develop a model for natural selection that explains all five cases. Students then use computer simulations to test this model in different environmental conditions and over different lengths of time.

The third lesson set includes Lessons 12 and 13, in which students identify a gap in their current model: it lacks a mechanism for how new heritable trait variations could appear in the descendent population that were not present in previous generations. Students make connections back to ideas they developed in the *Muscles Unit* to identify mechanisms that can produce new heritable

trait variations in offspring: mutation and sexual reproduction. They revise their model to include these ideas, use it to explain patterns of change in other organisms over millions of years, and then extend it to explain how populations of descendents that look very different from each other can emerge from a common ancestor due to gradual, accumulated changes over time (adaptation). They then use this model to explain where all the different species of modern penguins came from and where all the ancient penguins went.

The fourth and final lesson set consists of Lessons 14 and 15, which expand the scope of students' questions to lines of descent for organisms other than those they've explored in the unit already. Those questions are motivated in part by the exploration of patterns in additional evidence—the structures of the embryos of different types of organisms. That work references other lines of evidence they use to try to figure out the ancestors and lines of descent for the most ancient penguins and other organisms from their related phenomena.

Since this is the final unit in the 8th grade sequence in the program, students have already been developing each element of the SEPs and CCCs for middle school. For this reason, students engage with many elements of multiple SEPs and CCCs across the lesson-level performance expectations in the unit. However, there are three focal SEPs and four focal CCCs that are more fully developed or used in more sophisticated ways than in previous units.

This unit builds toward these performance expectations:

MS-LS1-4.* Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors ~~and specialized plant structures~~ affect the probability of successful reproduction of animals ~~and plants, respectively~~.

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

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

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

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

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

*PEs marked with an asterisk are partially developed in this unit and shared with other units, as explained in the DCI column of the table in the "What additional ideas will my students have or know from earlier grades or units?" section that follows.

Focal Disciplinary Core Ideas**	Focal Science and Engineering Practices	Focal Crosscutting Concepts
LS1.B. Growth and Development of Organisms: Animals engage in characteristic behaviors that increase the odds of reproduction. Students will develop and use these ideas in Lessons 2, 7, and 11 when they investigate, compare, and contrast the behaviors of various animals. Note that the PE related to this DCI element is shared with *Unit 8.5: Why are living things different from one another? (Muscles Unit)*. **LS4.A. Evidence of Common Ancestry and Diversity** • The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth. • Anatomical similarities and differences between various organisms living today, and between them and organisms in the fossil record, enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. • Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully formed anatomy. Students will draw on the above ideas in several lessons. Students analyze and interpret data from the fossil record specifically in Lessons 3, 5, 6, 12, and 13, in which they investigate penguins, horseshoe crabs, horses, and whales. Students use evidence from those investigations to develop their model for how ancient organisms are connected to modern ones over millions of years. In Lesson 14, students investigate how the structures of embryos of different organisms reveal similarities not evident in their fully formed anatomy and use that information as one of the lines of evidence to try to figure out the ancestors and lines of descent for the most ancient penguins and other organisms from their related phenomena.	**Analyzing and Interpreting Data:** This unit **intentionally develops** this practice as students investigate large data sets for variations in animals' body structures and changes over time. Although students have had prior experience with this practice, the data sets they use in this unit are the largest and most complex that they have worked with in. Throughout the unit, students analyze and interpret data from photos, sketches, modern and ancient world maps, organism size comparison charts, timelines, tables displaying multiple categories of body structures, environmental and behavioral information, linear models, histograms, and box-and-whisker plots. Students consider the role of randomness in the simulations they use to describe the shifts in distribution and central tendency of trait variations in populations. The work of this unit requires students to synthesize these data sets in more-complex ways than they did in past units. Students combine evidence from their analyses and interpretation of data about multiple organisms to support the models they develop throughout the unit. The unit provides several different opportunities to assess students' work in this practice. **Constructing Explanations and Designing Solutions:** This practice is **intentionally developed** in this unit. Students construct explanations throughout the unit as they gather evidence for the mechanism in their General Model for Natural Selection in efforts to explain "Where did all the ancient penguins go?" and "Where did all the different species of modern penguins come from?"	**Patterns:** The crosscutting concept of "patterns" is **key to the sensemaking** students do around the connections between modern and ancient organisms in this unit, and this crosscutting concept is also frequently assessed. Students use patterns in data to identify cause and effect relationships between the body structures of ancient and modern penguins, then use the patterns they've identified to determine that some of the traits in a population of descendents must have been changing over millions of years. Students identify patterns related to the environment, heritability, and survival and reproduction in graphs of case study data and in the data produced by simulations. Students infer relative time spent in different environments based on patterns in the numbers of similar or different body structures between modern and ancient penguin species, and they use sketches of embryos to identify particular similarities (patterns) between the physical structures of different species that are not evident in the fully formed anatomy. **Cause and Effect:** The crosscutting concept of "cause and effect" is **key to the sensemaking** students do in this unit. Students use the CCC of "cause and effect" across the second lesson set as they develop their General Model for Natural Selection, which then allows them to explain in Lesson Set 3 how ancient and modern penguins are connected through changes over time.

Focal Disciplinary Core Ideas**	Focal Science and Engineering Practices	Focal Crosscutting Concepts
LS4.B. Natural selection leads to the predominance of certain traits in a population and the suppression of others. Students will develop and use these ideas in Lessons 7-13 when they investigate five different cases, in which for each a trait changed in a population over a few generations, and from there build their General Model for Natural Selection. **LS4.C. Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common and those that do not become less common. Thus, the distribution of traits in a population changes.** Students will develop and use these ideas in Lessons 7-13. From the five cases mentioned above, on which they build their General Model for Natural Selection, students determine how changes in a population are related to different environmental conditions. Students test their model using a computer simulation to see how the distribution of trait variations in a population changes because trait variations that support successful survival and reproduction in the new environment become more common and those that do not become less common. Students use their model to explain how populations of descendents that look very different from each other can emerge from a common ancestor due to gradual accumulated changes over time (adaptation).	Students have experience with this SEP from prior units, including with long time scales and small changes accumulating over time, but now they are building that kind of explanation in living systems. There are multiple opportunities to assess students' independent use of this practice throughout the unit, including a peer feedback activity in Lesson 11 during which students respectfully provide critiques about each other's explanations and respond by adding more elaboration and detail. **Engaging in Argument from Evidence:** This practice is **key to the sensemaking** students do in this unit. Arguing from evidence they have collected from multiple investigations is deeply embedded into students' work supporting their scientific explanations for how populations of organisms can change over time and how they are connected to those long ago. A key goal of the unit is for students to be able to say not only what they think happened in these cases of natural selection but also how the evidence supports that explanation. Students specifically engage in this practice in Lessons 5, 6, 8, and 14, at which points they can also be assessed. The following practices are also **key to the sensemaking** in the unit: • Asking questions and defining problems • Developing and using models • Planning and carrying out investigations • Obtaining, evaluating, and communicating information	Students only just began their work with cause and effect relationships that are probabilistic in the prior *Muscles Unit*. Students extend that thinking in this unit when developing and using the ideas that competitive (dis) advantage for particular trait variations are probabilistic in nature and that there is variability in the outcomes of natural selection (e.g., how quickly particular trait variations disappear from a population). **Stability and Change:** The crosscutting concept of "stability and change of systems" is **key to the sensemaking** students do in this unit as students are continually evaluating trait variations in populations before and after an environmental change. In Lesson Set 1, students develop an explanation for "Why are there similarities and differences in the body structures of modern and ancient penguins?" which highlights what has remained stable and what has changed in the different species' body structures. In Lesson Set 2, students develop the ideas that the trait variations found in a population may shift relatively rapidly due to sudden environment changes and that trait variations found in a large population may remain relatively stable when the environment doesn't change. Students figure out that seemingly small changes in organisms can accumulate over generations and add up to relatively large amounts of change over long periods of time.

Focal Disciplinary Core Ideas**	Focal Science and Engineering Practices	Focal Crosscutting Concepts
		Structure and Function: The crosscutting concept of "structure and function" is **key to the sensemaking** students do in this unit. Students bring a vast amount of experience with structure and function thinking into this unit from prior work which they now use to support their investigations and make sense of data in almost every lesson. As they consider how organisms could be connected over time, students analyze the body structures of those organisms and consider how they function in similar or different ways and in similar or different environments. The models they develop for natural selection and common ancestry are informed by structure and function thinking.

**"Disciplinary Core Ideas" are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. DOI: https://doi.org/10.17226/13165. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

Connections to the Nature of Science

Which elements of NOS are developed in the unit?	How are they developed?
• Scientific explanations are subject to revision and improvement in light of new evidence. (NOS-SEP) • Science findings are frequently revised and/or reinterpreted based on new evidence. (NOS-SEP) • Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. (NOS-CCC) • Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. (NOS-CCC)	• Students revise and improve their explanations about how penguins and other ancient and modern organisms are connected across time based on new evidence they discover throughout the unit. • This unit introduces students to the following scientists from various backgrounds: Ali Altamirano, a researcher in Perú; Julia Clarke, a professor of paleontology at the University of Texas at Austin; Sara Bertelli, a researcher from Argentina. Students use the information these people and their colleagues have collected to build their science knowledge and figure out where ancient penguins and other organisms went and how they're connected to current species today.

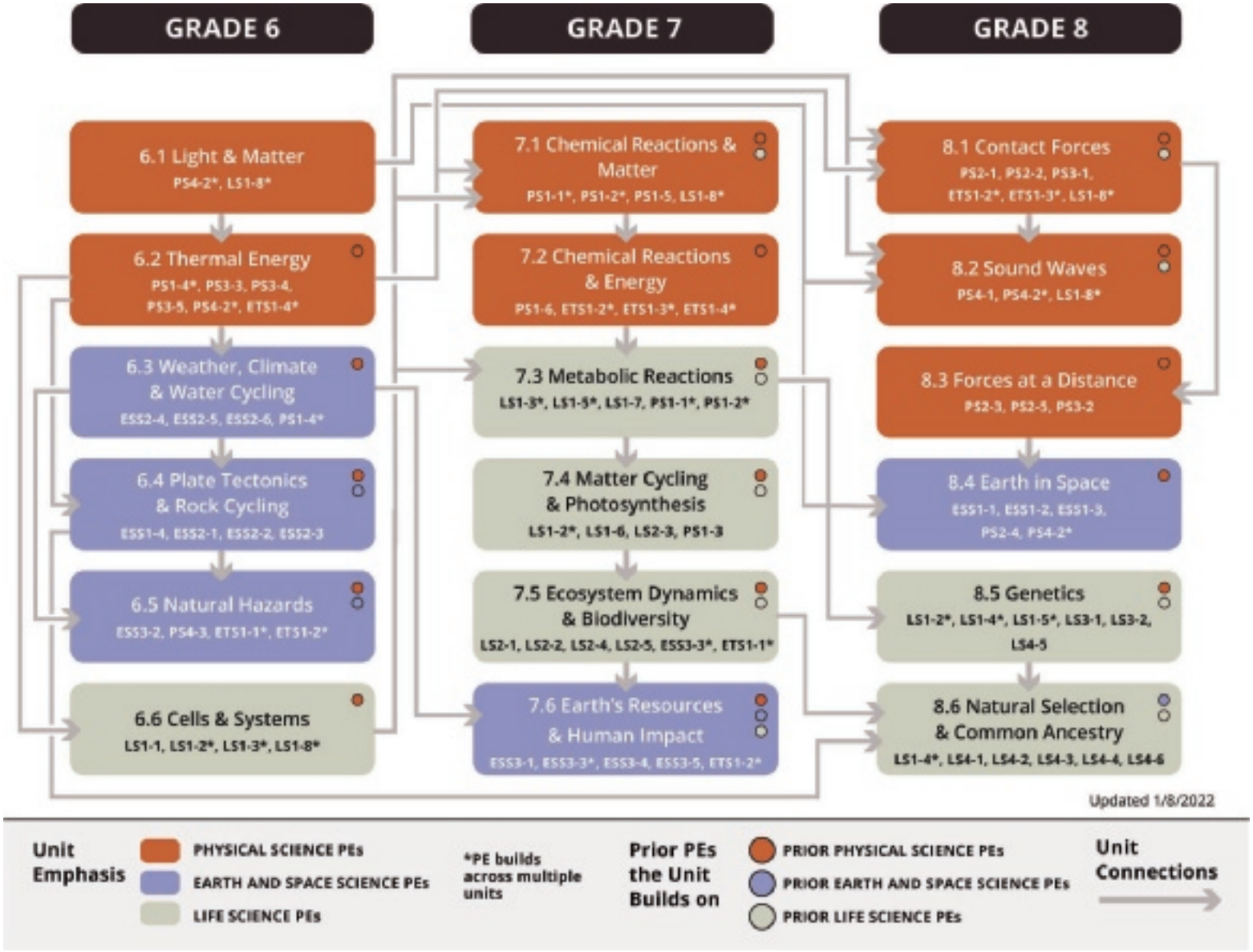
How is the unit structured?

The unit is organized into four lesson sets, each of which help make progress on a subquestion related to the driving questions for the entire unit. Lessons 1-6 focus on developing science ideas behind common ancestry. Lessons 7-11 focus on gathering evidence to build a general model for natural selection. Lessons 12-13 incorporate the ideas of mutation and sexual reproduction into their General Model for Natural Selection. Lesson 14 transitions to thinking about the anatomical similarities across species during embryologic development. Lesson 15 is a reflection on the progress made on the Driving Question Board and in students' experience with the middle school program.



Where does this unit fall within the Scope and Sequence?

This is the last unit in the program. This unit is designed to be taught just after the *Muscles Unit* in the Scope and Sequence. Students investigate structures that modern animals do or do not have in common with ancient animals and how certain traits in a population increase some individuals' probability of surviving and reproducing. As such, it leverages ideas developed in the *Muscles Unit* about mutations, sexual reproduction, and inheritance. See the table in the next section for additional examples of how this unit develops or extends students' understanding of other science ideas.



What additional ideas will my students have or know from earlier grades or units?

In this unit, students build upon ideas from earlier grades and units, as listed in the table below. This unit also prepares students for building on this work in high school. The DCI progression in the table indicates how this unit reinforces and builds from the following grades 3-5 DCIs and DCIs from units earlier in the Scope and Sequence.

DCI	Prior grades (K-5)	Middle school
Focal Disciplinary Core Ideas		
LS1.B. Growth and Development of Organisms	**By grade 2:** Adult plants and animals can have young. In many kinds of animals, parents and the offspring themselves engage in behaviors that help the offspring to survive. **By grade 5:** Reproduction is essential to the continued existence of every kind of organism. Plants and animals have unique and diverse life cycles.	**In this unit, students draw on the DCI elements they developed in the *Muscles Unit*: Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. Plants reproduce in a variety of ways, sometimes depending on ~~animal behavior and~~ specialized features (such as ~~attractively colored~~ flowers) for reproduction.** Students use these ideas to help them continually revise their model for how modern organisms are connected to organisms from long ago and then develop their General Model for Natural Selection. Also, the idea of passing genetic information (that results in heritable trait variations) to offspring is a required element students use to build the General Model for Natural Selection. Students will draw on these ideas in Lessons 2, 4, and 6-12.
LS4.A. Evidence of Common Ancestry and Diversity	**By grade 5:** Some living organisms resemble organisms that once lived on Earth. Fossils provide evidence about the types of organisms and environments that existed long ago.	**In this unit, students will draw on these DCI elements they developed in *Everest Unit*: The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found ~~or through radioactive dating~~) is known as the fossil record. It documents the existence~~, diversity, extinction, and change of many life~~ forms throughout the history of life on Earth.** Students use these ideas to help them sort the penguins and other organisms based on the data on their cards and strips and to infer how they might be connected to organisms from long ago. Students will draw on these ideas in Lessons 1 and 3-6.
LS4.B. Natural Selection	**By grade 5:** Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing.	**In this unit, students will draw on these DCI elements they developed in *Muscles Unit*: In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring.** Students will use these ideas beginning in Lesson 8 when they develop their General Model for Natural Selection after investigating five specific populations of organisms with different trait variations. Each population interacted with a particular environmental factor. They use these ideas to help make predictions about any population, in any environment, and over a different number of generations and then continue to revise their General Model for Natural Selection in Lessons 9, 10, and again in 12 (when they add mutations as a factor).

DCI	Prior grades (K-5)	Middle school
LS4.C: Adaptation	**By grade 5:** For any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive at all.	**In this unit, students will draw on these DCI elements they developed in grade 5.** Students will begin to use these ideas in Lesson 8 as they make predictions about the question: How does our model help us answer questions about what could be causing changes in populations of descendants from ancient to modern penguins, horses, whales, and horseshoe crabs over many, many generations and over millions of years? Students will add to these ideas in Lessons 9-13 as they revise their General Model for Natural Selection to explain changes we see over millions of years, in any population, in any environment, and over a different number of generations.
Supporting Disciplinary Core Ideas		
ESS2.B. Plate Tectonics and Large-Scale System Interactions	**By grade 5:** Earth's physical features occur in patterns, as do earthquakes and volcanoes. Maps can be used to locate features and determine patterns in those events.	**In this unit, students will draw on these DCI elements they developed in *Everest Unit*: Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart.** Students should be familiar with the idea of land masses changing position on Earth due to plate movement over time so they can infer connections between modern and ancient organisms and the environments, time periods, and locations where they lived. Students use these ideas about the global maps on the organism data cards that show shifts in the continents and mountain ranges on the map. Students will use these ideas in Lessons 1, 3, and 5.
LS3.A. Inheritance of Traits LS3.B: Variation of Traits	**By grade 2:** Individuals of the same kind of plant or animal are recognizable as similar but can also vary in many ways. **By grade 5:** Different organisms vary in how they look and function because they have different inherited information; the environment also affects the traits that an organism develops.	**In this unit, students will draw on these DCI elements they developed in *Muscles Unit*:** Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Variations of inherited traits between parent and offspring arise from genetic differences that result from the sub-set of chromosomes (and therefore genes) inherited. In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others are harmful, and some are neutral to the organism. Students will use the ideas above in Lessons 7, 8, 12, 13, and 14 as they develop a General Model for Natural Selection using

DCI	Prior grades (K-5)	Middle school
		the categories of *population before the change*, *environment*, *environmental interactions*, *survival and reproduction*, *offspring and inheritance*, and *population after the change*. Eventually, they will also add the role of random mutations to their General Model to explain the questions: Where did all the ancient penguins go? Where did all the different species of modern penguins come from? How could things living today be connected to the things that lived long ago?
LS2.A: Interdependent Relationships in Ecosystems	**By grade 5:** Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Organisms can survive only in environments in which their particular needs are met.	**In this unit, students will draw on these DCI elements they developed in *Palm Oil Unit*: Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. In any ecosystem, organisms and populations with similar requirements for food, water~~, oxygen,~~ or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. Growth of organisms and population increases are limited by access to resources. Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms.** Students will use these ideas in Lessons 7-11 and 13 as they develop and apply their General Model for Natural Selection to explain how modern and ancient organisms are connected through time.

What are some common ideas that students might have?

- Students may hold Lamarckian views (acquired traits can be inherited, evolutionary change occurs because of need, evolutionary change occurs because of use or disuse of traits).
- Students may think that adaptation through natural selection involves a purposeful striving toward higher forms.
- Students may think that the environment itself (not natural selection, genetic mutation or sexual recombination) causes traits to change over multiple generations.
- Students may view the individual, rather than the population, as adapting and fail to see the importance of genetic variation.
- Students may think time is more important than the number of generations for the amount of adaptation that accumulates in a population.
- Students may think that changes in a population occur through a gradual change in all members of a population rather than from the survival of a few individuals that preferentially reproduce.
- Students may think that only a few of the many species of organisms that lived in the past are now extinct or that most of the species of organisms that lived in the past are still alive today.
- Students may think all species began at the same time and still exist today.
- Students may think members of different species could not share a common ancestor.

How will I need to modify the unit if taught out of sequence?

This is the final unit in 8th grade in the Scope and Sequence. OpenSciEd placed this unit in 8th grade given the science and mathematical ideas and practices that the models in this unit need to build on. Therefore, several

important modifications would need to be made if teaching this unit earlier in the middle school curriculum. These include the following:

- If taught before *Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)* or at the start of the school year, be sure to include these supports: supplemental teaching of classroom norms, setting up the Driving Question Board, and asking open-ended and testable questions. These supports are built into the *Collisions Unit* and could be adapted accordingly for this unit if needed.
- Given the nature of the target DCIs, this unit relies a great deal on students building on prior understanding of the ideas outlined in the "What are the NGSS dimensions developed in this context?" and "What additional ideas will my students have or know from earlier grades or units?" sections.
    - If this unit is taught before *Unit 8.5: Why are living things different from one another? (Muscles Unit),* make sure to provide students with instructional experiences that help them develop the set of related ideas outlined above for LS3.A: Inheritance of Traits, LS3.B: Variation of Traits, and LS1.B Growth and Development of Organisms.
    - If this unit is taught before *Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit),* make sure to provide students with instructional experiences that help them develop the set of related ideas outlined above for LS2.A: Interdependent Relationships in Ecosystems.
    - If this unit is taught before *Unit 6.4: What causes Earth's surface to change? (Everest Unit),* make sure to provide students with instructional experiences that help them develop the set of related ideas outlined above for ESS1.C: The History of Planet Earth and ESS2.B: Plate Tectonics and Large-Scale System Interactions.
    - If any supplemental instruction is necessary to orient students to the ideas from the three units listed above, it will influence students' future experiences in those units. Parts of those units will help students figure out the related pieces of the DCI in this unit and, if taught out of order, those concepts will be redundant for students.
- This unit highly relies on 7th-8th grade math (that is often taught later in 7th grade or in 8th grade).
    - If this unit is taught in grade 7, teachers will need to modify the scatterplots and lines of best fit to a more grade-appropriate representation. In addition, teachers will need to work closely with a 7th grade math teacher to understand when students will learn about sampling, certainty, and probability, as well as assessing the amount of visual overlap between the distribution of the data from two different data sets. This unit can reinforce those concepts in a real-world problem context, but they should not come before students have developed these ideas in their math classes (or working in conjunction with math and science simultaneously).
- This unit engages students in complex data analysis tasks that include a spatial and temporal component, along with other dimensions in the data.
    - If this unit is taught in grade 7, teachers may want to earmark an additional day for exploring connections in initial data cards in the anchor and include an additional day or half day in both Lessons 2 and 3 for analyzing the data strips and data cards.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

This is a substantial unit requiring 6-7 weeks of instructional time with 45-minute class periods. The length of the unit can be modified in the following ways. To shorten or condense parts of the unit without eliminating important sensemaking for students, consider the following:

- Lesson 1: If students are familiar with penguins, consider skipping the live penguin cameras. They will gather more information about penguins from the *Data Cards for Modern Penguins and Pedro*.
- Lesson 7: If your high school uses the Galápagos finch case as an anchoring phenomenon, consider using just the fish, moths, mustard plants, and swallows cases in this unit.
- Lesson 14: This lesson explicitly addresses MS-LS4-3. If you skip this lesson, you will only build towards the other five unit performance expectations.

To extend or enhance the unit, consider the following:

- Lesson 2: If students are curious about what the Latin names are for some of those structures, that further detail is provided in the teacher reference *Extended Key for Penguin Structures and Behaviors.*
- Lesson 3: All students will experience sorting cards and data for ancient and modern penguins. However, there are also data strips for more-incomplete ancient penguin fossils for interested students or, if time allows, your whole class. Additionally, students may complete *Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?* in class as opposed to home learning.

- Lesson 4: Highly interested students may challenge using the word "all" when referring to all adult king penguins being taller than all adult Galápagos penguins, even after examining the distribution of variation in each population. If so, you might take a moment to discuss how scientists come up with the ranges of size that are listed (even though the statistics involved are beyond what we need to know for this lesson).
- Lesson 13: If you have students who are curious about the environmental factors that influenced changes in the ancient penguins millions of years ago, the *Penguin Environments - Ancient and Modern* reading is provided.
- Lesson 14: There are two versions of the non-egg-laying embryo handout. Consider using the one with humans to give students additional data and encourage students to think about connections between all living multicellular organisms.
- Lesson 15: If time allows, consider making this a two-day lesson and giving students more time to reflect in their Progress Tracker.

What math concepts are required to fully access the unit's learning experiences?

Throughout the unit, students will engage in mathematical thinking. They will use ideas from 6th grade CCSS related to measures of central tendency and variation to compare the distribution of trait variations in a population over time in Lessons 6 through 9. They will use ideas from 7th grade CCSS related to drawing inferences from sampling a population in Lessons 4 and 6. They will analyze and interpret scatterplots, lines of best fit, histograms, and box-and-whisker plots in Lessons 7, 9, and 10. Prerequisite math concepts that will be helpful include the following:

- CCSS.MATH.CONTENT.6.SP.A.3 Recognize that a measure of center for a numerical data set summarizes all of its values with a single number, while a measure of variation describes how its values vary with a single number.
- CCSS.MATH.CONTENT.6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots.
- CCSS.MATH.CONTENT.7.SP.B.3 Informally assess the degree of visual overlap of two numerical data distributions with similar variabilities, measuring the difference between the centers by expressing it as a multiple of a measure of variability.
- CCSS.MATH.CONTENT.8.SP.A.1 Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.
- CCSS.MATH.CONTENT.8.SP.A.2 Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.

What additional strategies are available to support equitable science learning in this unit?

Units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies that are integrated throughout the routines and are intended to increase relevance and provide access to science learning for all students. Units support these equity goals through several specific strategies such as these: (1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and provide more-accessible ways in which students can engage in learning experiences, (2) developing and supporting classroom norms that provide a safe learning culture, (3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas, and (4) supporting emerging multilingual students in science classrooms.

Many of these strategies are discussed in the *Teacher Guides* in sidebar callout boxes titled "Attending to Equity" and subheadings such as "Supporting Emerging Multilingual Learners" or "Supporting Universal Design for Learning." Other callout boxes with strategies are found as "Additional Guidance," "Alternate Activity," and "Key Ideas" and various discussion callouts. Finally, each unit includes the development of a Word Wall as part of students' routines to "earning" or "encountering" scientific language.

For more information about each of these different strategies with example artifacts, please see the *Teacher Handbook*.

What are recommended adult-level learning resources for the science concepts in this unit?

The instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the disciplinary core

ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the "Where we are going" and "Where we are not going" sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (LS4.A, LS4.B, LS4.C, and parts of LS1.B), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and the performance expectations bundle for this unit:

- To learn more about ancient penguins and the fossil record of penguins:
  - https://www.youtube.com/watch?v=J0ji2sYD3hg&t=1540s
  - https://fossilpenguins.wordpress.com/
- To learn more about horseshoe crabs' seemingly unchanged structures: https://daily.jstor.org/the-horseshoe-crab-same-as-it-ever-was/
- To learn more about phylogeny and modeling evolutionary relationships:
  - https://www.nature.com/scitable/topicpage/reading-a-phylogenetic-tree-the-meaning-of-41956/
  - https://www.nature.com/scitable/topicpage/trait-evolution-on-a-phylogenetic-tree-relatedness-41936/
- To learn more about the role of mutation:
  - https://www.nature.com/scitable/topicpage/genetic-mutation-1127/
- For a general overview of natural selection: https://www.youtube.com/watch?v=0SCjhI86grU

GUIDANCE FOR DEVELOPING YOUR WORD WALL

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have "earned" that word and can add the specific term to the class Word Wall. These "words we earn" should be recorded on the Word Wall using the students' own definition whenever possible. On the other hand, "words we encounter" are "given" to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, words we encounter are helpful just in that lesson and need not be recorded on the Word Wall. However, if a word we encounter will be frequently referred to throughout the unit, it should be added to the Word Wall. As such, the Word Wall becomes an ongoing collection of words we will continue to use, including all the words we earn in the unit and possibly a few key words we encounter.

It is best for students if you create cards for the Word Wall in the moment, using definitions and pictorial representations that the class develops

together as they discuss their experiences in the lesson. When they co-create the posted meaning of the word, students "own" the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emerging multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support whenever possible.

Sometimes creating Word Wall cards in the moment is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate. If you keep one Word Wall in your classroom for several sections of students, you might choose to record each class's definition separately and then propose an "official" definition to post the next day that captures the collected meaning.

The words we earn and words we encounter in this unit are listed in the following table and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they're trying to figure out.

Lesson	Words we earn	Words we encounter	Words we reinforce or apply from previous units
L1		humerus, femur	species, fossil
L2	heritable	characteristic, ancient ancestors, immediate ancestors, generation(s)	offspring, variation, genes, alleles, genetic information
L3	extinction		
L4	fossil record, population (species), sample, distribution, mean,		typical, trait
L5			
L6	line of descendants		
L7			
L8	environmental interactions, competitive advantage, selection, natural selection		offspring, abiotic, biotic
L9		salmonella, flagella	asexual reproduction
L10			
L11			
L12	adaptation by natural selection		mutation
L13	common ancestor, species (revised)		
L14		embryo	
L15			

HOME COMMUNICATION

Dear Guardian,

Your child's 8th grade science class is starting a unit called *How could things living today be connected to the things that lived long ago?* as part of the middle school science curriculum. This is a life science unit that builds science ideas about evidence for common ancestry, natural selection, and the **production of variation within population(s) of animals**. Within this unit, students meet Pedro, an ancient penguin fossil.

Imagine a modern penguin, black and white and possibly marching across a frozen landscape. But what if there was a penguin found in Peru and human-sized! Meet Pedro (also known as *Inkayacu* or water king), the fossil remains of an ancient penguin dating back 36 million years ago. In the beginning of this unit students listen to a podcast and read a photo journal about the discovery and history of Pedro. Students then examine 18 different species of modern penguins and wonder how all 18 penguins and Pedro are connected.

In the Penguins Unit, students examine patterns within large data sets showing the different body structure variations across modern penguin species and several ancient penguins in addition to Pedro. These patterns build the basis for students to explain how these different penguins are connected and how these similarities and differences exist.

Helping your child make sense of their learning

- Encourage your child to expand and clarify their own thinking by asking to give examples or to say more.
- Ask your child what data they examined so far and to describe what relationships, patterns, or evidence they noticed about the different kinds of penguins or animals.
- Ask your child to share their model(s) so far and to describe how different components interact with one another.
- Rephrase or paraphrase what your child says as a way to clarify their ideas. Hearing their idea from someone else is a powerful reflective tool for a child.

Having conversations about science

- Encourage your child's curiosity through talking about their own noticings and wonderings when running errands or on a walk.
- Provide your child space and time to think aloud with a drawing, objects, or their voice about different (maybe conflicting) ideas for processing. Sometimes processing ideas won't lead to a clear "answer" or solution yet.
- Ask your child to reflect on prior units to see connections about different science ideas and what's around them.



TEACHING SCIENCE LITERACY

How does the Core Knowledge Science Literacy routine integrate with the unit investigations?

The Core Knowledge Science Literacy Student Reader and the weekly Science Literacy routine layer varied reading opportunities into the science unit. In their lives after graduating from high school, most students will not become scientists. They will no longer routinely participate in guided investigations to figure out how phenomena work. They will, however, read text about science and scientific claims, day in and day out. The ability to learn and think about science through reading is a skill unto itself and is important in tandem with investigative learning. It is natural to primarily associate emerging literacy with reading and writing instruction at the elementary level, but middle school is an important time to hone literacy skills—specifically in science in the era of politicization of science topics, polarization among adults, and proliferation of misinformation on social media. Detection and construction of well-reasoned explanations are important not just in science, but throughout everyday life. Using claims and evidence in reasoning is the way that thoughtful people think about things, and writing is thinking in print. Students become voters as they emerge from high school, so it is important that they acquire skills for detection of faulty information and practice legitimate communication about scientific issues in the years leading up to that civic benchmark.

Throughout the course of the unit's investigative lessons, students write in their science notebooks in some fashion almost daily, and significant emphasis is placed on the speaking and listening communication threads of the CCSS. The instructional design of the investigations is deliberately light on having students access disciplinary core content through text. NGSS emphasis is on students investigating phenomena along the storyline, so students' interaction with text within lessons is minimal and in service to the unit's storyline. The Science Literacy routine is integrated to exercise students' ability to interact with text about science topics. The routine presents students with short reading selections in a variety of styles, all related to the unit in which students are engaged. Each reading selection is accompanied by a brief but thoughtful writing exercise.

The subject matter of the reading selections ties back to the unit, but the timing for the assigned readings is such that students do not read about specific facets of the subject before they have completed the lessons to investigate that content. In other words, the reading enhances and reinforces the knowledge that students have built in previous lessons; the reading does not reveal beforehand the key takeaways that students are intended to learn through lesson interactions.

When is it done within a unit?

The Core Knowledge Science Literacy Student Reader includes one reading collection per week for every week of the unit. A week's reading collection relates to the lessons completed in the previous week. The reading is assigned at the beginning of the week with the accompanying writing exercise due at the end of the week.

The reading and writing exercises are designed to be completed by students independently, with brief, supporting, teacher-facilitated discussions at the beginning, midpoint, and end of the week.

How do students typically represent their thinking as part of the routine?

Students generate a written product associated with each reading selection. The products are varied in form, and include graphic organizers, concept maps, cartoons, memes, infographics, storyboards, outlines, and paragraphs. The complexity of the products increases from week to week, with the final product for the unit being a single, thoughtfully reasoned, and well-constructed paragraph.

Put Yourself in This Scene

Literacy Objectives

✓ Initiate thinking about the need to evaluate information in text and images.

Literacy Exercises

- Read a brief scenario to pique interest, launch discussion, and begin to frame expectations.

Instructional Resource



Science Literacy Student Reader, Preface
"Put Yourself in This Scene"

No Prerequisite Investigations

The reading of the Preface is appropriate during the first week of unit instruction. The reading does not preemptively tell students facts about the topic that they are intended to learn throughout the course of their investigations.

Standards and Dimensions

NGSS

Disciplinary Core Idea LS4.B: In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring.

Science and Engineering Practice: Asking Questions and Defining Problems

Crosscutting Concept: Cause and Effect

CCSS

English Language Arts

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

RST.6-8.8: Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. No Core Vocabulary terms are highlighted in the Preface.

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

gene **gene therapy** **scientific literacy**
skepticism **technology**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the Science Literacy Student Reader.
- Friday: Set aside time at the end of the week to facilitate a brief discussion about the reading.

You'll proceed with the in-class lesson investigations during this week.

2. Preview the assignment and set expectations. (Monday)

- Let students know that for the Science Literacy routine, they will read independently and then complete short writing assignments. The reading selections relate to topics they will be exploring in their Natural Selection and Common Ancestry unit science investigations.
- The reading and writing will typically be completed outside of class (unless you have available class time to allocate).
- The first week's reading is a short introductory segment in the book, and there is no accompanying writing exercise as the unit is getting started.
- The class will discuss the reading together at the end of the week.

SUPPORT—The Preface about the gene therapy scenario is written at approximately Lexile 1000. You may wish to introduce a word identification and comprehension convention into your routine to support struggling readers. Hang an envelope near the door with the label, "When we talk about the next reading selection, I could use a little more help understanding the word(s). . . " Encourage students, as they are reading, to jot words, phrases, or sentences that they are unclear about onto small scraps of paper and tuck them into the envelope at any time preceding the discussion of the reading. Whenever you facilitate class discussion about a reading selection, check the envelope first, and layer in added examples and repeat definitions to help students build comprehension and fluency for terms or complex sentences about which they have revealed they are uncertain.

3. Facilitate discussion.

(FRIDAY)

Facilitate a brief class discussion about the Science Literacy Student Reader Preface, entitled "Put Yourself in This Scene."

Pages 2–3 Suggested prompts	Sample student responses
How would you summarize the "scene" referred to in the title?	*It is a conversation between two friends, arguing about whether gene therapy can make you taller and more successful.*
Why was Luka skeptical about the claims Bo made about getting taller?	*maybe because Bo did not give any source information, other than to say they "I read on the internet"*
What questions should Luka ask Bo about what Bo read about tall people on the internet?	*On what website(s) did you read that?* *What expertise does the author have?* *How many people were studied?* *How did they define "successful"?*
From reading the Preface, how would you define "gene therapy"?	*It's a way of editing, or changing, genes that control traits you want to change.*
How is Bo defining a "successful" person?	*someone who makes a lot of money*
Gene therapy technologies have been focused on curing inherited diseases. Each process has to be approved by the U.S. Food and Drug Administration. What do you predict is the future of gene therapies to make people taller?	*Since being short is not a disease that affects your overall health, developing a gene therapy for height is probably not going to be addressed for a long time, if ever.*
In Unit 5 Collection 1, you saw a graph showing height data for adult men and women. What did that graph show about the variation in the trait of human height?	*that the range of heights for women and men is pretty broad* *that most people's heights are in the middle of the range* *that men, as a group, are taller than women but that some women are taller than some men*
What questions could you ask Bo about a desire to be taller?	*Exactly how tall do you want to be?* *Would you want to be one of the very few people who are extremely tall?* *If you could get gene therapy to make you taller, wouldn't many other people do the same? Would that result in many people being tall?*

Student Reader



Preface

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Pages 2–3 Suggested prompts	Sample student responses
What reliable sources could Bo use to learn more about gene therapies and if the traits they introduce can be inherited?	• *a reference librarian* • *websites from government health agencies* • *research hospital websites* • *university websites* • *books and articles written by genetic scientists or science writers*
What does it mean to be scientifically literate when looking at online content?	*choosing content produced or edited by science experts* *knowing how to look up terms you don't understand* *using the science you have learned to interpret what you see or read* *being skeptical about claims that seem unusual or are not supported with evidence*

KEY IDEA—Some of the information Bo found online is accurate, and some is not. And either way, Bo draws conclusions that do not follow from the information. Point out that, without further research into which genes affect height, how traits are inherited, and gene therapy technologies, there isn't really a way to predict if and when it will be possible for people to get gene therapy to change their height. And the assumption that such a change would be passed on is an unsupported conclusion. Both the investigations and the reading selections in the unit ahead will help students advance to a place where they have more knowledge to apply to the scenario, and they will circle back to the topic of gene therapy at the end of the unit.

LESSON 1

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

Previous Lesson

There is no previous lesson.

This Lesson

Anchoring Phenomenon

4 DAYS



We record what we notice and wonder about the fossil of a giant penguin from long ago found in present-day Peru. We analyze data cards about penguins living today. We develop initial explanations of how these penguins could be connected. We brainstorm possible mechanisms to help explain two things: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from? We brainstorm other related phenomena of organisms alive today that also might be connected to organisms that lived long ago. We develop a Driving Question Board to guide future investigations.

Next Lesson

We will analyze data on a set of heritable body structures and behaviors in modern penguins to look for patterns and infer connections among them (and Pedro). We will develop questions of how heritable bone structures would compare between these penguins and ancient penguin fossils other than Pedro.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

1.A Analyze and interpret data using data cards containing photos, maps, charts, measurements, and descriptive text to find patterns in penguins that are alive today.

1.B Develop an initial explanation and identify evidence needed to determine what caused the observed changes in the existence, diversity, and disappearance of different kinds of penguins throughout history.

1.C Ask questions that arise from initial observations of patterns in the images depicting anatomical similarities and differences of penguins that are alive today and of a fossil of a penguin from long ago.

What Students Will Figure Out

- There are 18 different species of penguins alive today. All have similar body structures and behaviors as well as some noticeable differences.

- Scientists found a giant penguin fossil (nicknamed "Pedro") that lived 36 million years ago in Peru. It is bigger and it had a much longer beak than any penguins alive today.
- We have different ideas about where the penguins (and other organisms) of today come from: maybe none, some, or all of the penguins (and other organisms) of today are descendants of Pedro (or other organisms from long ago).

Lesson 1 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	17 min	**MEET PEDRO, A HUMAN-SIZED PENGUIN** Listen to a story and examine a photo journal about a joint team of researchers who recently found a fossil of a human-sized penguin in the deserts of Peru.	A-B	*Reference: Podcast Transcript and Photo Journal*, transparent tape, 8.6 Lesson 1 Pedro's Discovery (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), 1 meterstick, computer and speakers, 5–6-inch piece of masking tape or a sticky note
2	8 min	**BRAINSTORM TYPES OF EVIDENCE NEEDED** Brainstorm how things alive today could be connected to one another and the kinds of evidence needed to determine whether Pedro is connected to the penguins alive on Earth today.	C	Types of Connections poster, Evidence We Need poster, markers
3	15 min	**MEET THREE SPECIES OF PENGUINS ALIVE TODAY** Observe and compare the physical traits and behaviors of three species of penguins living today.	D-J	*Penguin Comparison*, transparent tape, only the emperor and Adélie and southern rockhopper cards from *Data Cards for Modern Penguins and Pedro*, 1 Earth squish ball with countries labeled, 1 Earth squish ball with no labels, 2 paper hot-cup sleeves, emperor penguin video, rockhopper penguin video, Adélie penguin video (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**), 1 classroom globe (optional)
4	5 min	**CONSIDER CONNECTIONS AMONG PENGUINS** Discuss in small groups how the three species of penguins we observed compare to one another and to Pedro.	K	*Penguin Comparison*, only the emperor and Adélie and southern rockhopper cards from *Data Cards for Modern Penguins and Pedro*, 1 Earth squish ball with countries labeled, 1 Earth squish ball with no labels, 2 paper hot-cup sleeves, Types of Connections poster

End of day 1

Part	Duration	Summary	Slide	Materials
5	5 min	**PREDICT PATTERNS IN PENGUINS** Review the need for evidence to support or refute claims. Make predictions about the kinds of patterns we might see comparing similarities and differences among penguins.	L	3″ x 3″ sticky notes (optional)
6	20 min	**LOOK FOR PATTERNS AMONG PENGUINS** Look for patterns in the data by grouping penguin information cards in various ways. Share and discuss observations and new questions that surface.	M-N	*Data Cards for Modern Penguins and Pedro*, 1 Earth squish ball with countries labeled, 1 Earth squish ball with no labels, 2 paper hot-cup sleeves
7	3 min	**PREDICT WHERE OTHER PENGUIN FOSSILS COULD BE FOUND** Make suggestions for places to look for additional penguin fossils and brainstorm what these additional fossils might look like.	O	
8	7 min	**PREDICT PENGUINS FROM LONG AGO** Make predictions about the characteristics other penguins living long ago would have had when they were alive.	P	*Predictions on Other Penguins That Lived Long Ago*, transparent tape, colored pencils, 1 or more cards from *Data Cards for Modern Penguins and Pedro* (optional), chart paper, markers, Pedro's card from *Data Cards for Modern Penguins and Pedro* (optional)
9	9 min	**COMPARE PENGUINS AND DEVELOP A TIMELINE MODEL TO REPRESENT OUR THINKING** Compare penguin characteristics that are similar and different in individual representations. Develop a timeline model of what we have figured out.	Q-R	*Predictions on Other Penguins That Lived Long Ago*, chart paper, markers, transparent tape
				End of day 2
10	5 min	**NAVIGATION** Brainstorm additional questions about what happened to ancient penguins and where modern penguins came from.	S	Penguin Timeline model
11	16 min	**WRITE AND COMPARE INITIAL EXPLANATIONS** Develop an initial explanation framed around two subquestions: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from?	T-U	*Initial Explanations*, transparent tape

Part	Duration	Summary	Slide	Materials
12	13 min	**HOLD AN INITIAL CLASS CONSENSUS DISCUSSION** Develop a whole-group record of where we agree and where we have competing ideas around the questions, (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from?	V	*Initial Explanations*, chart paper, markers
13	7 min	**BRAINSTORM AND SHARE RELATED PHENOMENA** Brainstorm and share ideas of other examples of species of organisms that lived in the past that have similar type(s) of modern organism(s).	W	Penguin Timeline model, Related Phenomena poster, 5–6-inch piece of masking tape, markers, 3" x 3" sticky notes
14	4 min	**NAVIGATION** Take stock of where we are in our thinking and consider whether the reasons for the differences in past and present organisms are the same as for differences in past and present penguins.	X	
				End of day 3
15	8 min	**DEVELOP INITIAL QUESTIONS** Look back at earlier resources from this lesson to list questions related to what has been observed so far.	Y	*Predictions on Other Penguins That Lived Long Ago*, *Initial Explanations*, *Reference: Podcast Transcript and Photo Journal*, *Data Cards for Modern Penguins and Pedro*, Related Phenomena poster, Penguin Timeline model, T-charts from day 3
16	4 min	**REVISE QUESTIONS** Refine questions in preparation for constructing the Driving Question Board.	Z	2 3" x 3" sticky notes or index cards, 1 marker, chart paper, markers
17	20 min	**BUILD THE DRIVING QUESTION BOARD** Develop a Driving Question Board to create a shared space for student questions.	AA	questions on sticky notes, 3" x 3" sticky notes or index cards, markers
18	10 min	**BRAINSTORM IDEAS FOR INVESTIGATIONS** Identify the data and information needed that would help answer each category of questions.	BB	Driving Question Board, Ideas for Future Investigations and Data We Need poster, markers

Part	Duration	Summary	Slide	Materials
19	3 min	**NAVIGATION** Conclude the lesson by summarizing the progress made and a plan for next steps.	CC	

End of day 4

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Reference: Podcast Transcript and Photo Journal* • transparent tape • *Penguin Comparison* • *Predictions on Other Penguins That Lived Long Ago* • colored pencils • 1 or more cards from *Data Cards for Modern Penguins and Pedro* (optional) • *Initial Explanations* • 2 3″ x 3″ sticky notes or index cards • 1 marker • questions on sticky notes	• only the emperor and Adélie and southern rockhopper cards from *Data Cards for Modern Penguins and Pedro* • 1 Earth squish ball with countries labeled • 1 Earth squish ball with no labels • 2 paper hot-cup sleeves • *Data Cards for Modern Penguins and Pedro*	• 8.6 Lesson 1 Pedro's Discovery video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources** • 1 meterstick • computer and speakers • 5–6-inch piece of masking tape or a sticky note • Types of Connections poster • Evidence We Need poster • markers • emperor penguin video • rockhopper penguin video • Adélie penguin video (See the **Online Resources Guide** for links to the videos. **www.coreknowledge.org/cksci-online-resources** • 1 Earth squish ball with countries labeled • 1 Earth squish ball with no labels • 2 paper hot-cup sleeves • 1 classroom globe (optional) • 3″ x 3″ sticky notes (optional) • chart paper

	per student	per group	per class
			• Pedro's card from *Data Cards for Modern Penguins and Pedro* (optional) • transparent tape • Penguin Timeline model • Related Phenomena poster • 5–6-inch piece of masking tape • 3" x 3" sticky notes • T-charts from day 3 • 3" x 3" sticky notes or index cards • Driving Question Board • Ideas for Future Investigations and Data We Need poster

Materials preparation (30 minutes)

Online Resources



Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Prepare the handouts for this lesson:

- Make one copy each of *Penguin Comparison* and *Predictions on Other Penguins That Lived Long Ago* per student and trim to fit notebooks.
- Make one copy of *Initial Explanations* per student.
- Each student should receive the handout of *Reference: Podcast Transcript and Photo Journal* (printed in grayscale or color and trimmed to fit notebooks), or they can access the color version in the student edition.

Gather color copies of *Data Cards for Modern Penguins and Pedro* to have enough for each group of 3 students in your largest class (class set). If you do not have the materials kit, print a class set in color on cardstock and cut each penguin card separately. Consider laminating the cards for future use. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally. Use a binder clip to keep each set of these together. These are nonconsumables that you collect and reuse in all classes.

Prepare these posters ahead of time: Types of Connections, Evidence We Need, Related Phenomena (in horizontal orientation), Ideas for Future Investigations and Data We Need.

If you have not already done so, download and print the *Communicating in Scientific Ways* file from the website or this unit's materials folder. This one-page document can be blown up and printed as a class poster, printed on 8.5" × 11" paper and posted near students' desks, and/or printed scaled down and taped into students' science notebooks.

Determine where to set up the Driving Question Board and posters so that students can gather around them.

Make and post a Discussion Norms poster near your DQB space if you haven't already. See the *Teacher Handbook* for more information about developing norms to support productive discussions.

Test the audio recording to make sure it plays 8.6 Lesson 1 Pedro's Discovery (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Test the videos to make sure they play:

- emperor penguins
- rockhopper penguins
- Adélie penguins (See the **Online Resources Guide** for links to the videos. **www.coreknowledge.org/cksci-online-resources**)

Depending on your students' prior knowledge of penguins, you may want to take a few minutes on day 1 to show a live feed of a penguin encampment from a zoo or aquarium. If there is a zoo or aquarium close to you that has penguins, check whether they have a live camera feed of them. Other options include the following:

- Detroit Zoo
- Georgia Aquarium
- Monterey Bay Aquarium
- Tennessee Aquarium
- Aquarium of the Pacific
- New England Aquarium
- San Diego Zoo

(See the **Online Resources Guide** for links to these resources. **www.coreknowledge.org/cksci-online-resources**)

As a reminder about supporting students with visual disabilities: This unit in general and this lesson specifically use images as data. So, you will need to make accommodations so that students with visual disabilities can access these data. Depending on your students' needs, suggested modifications include enlarging and/or brightening the provided digital versions of these photos or using alternate text descriptions. Your students' IEP or 504 case leaders should also be able to provide you with specific resources and possible modifications to use.

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

This lesson elicits students' initial ideas about how living things of today could be connected to living things of the past. The word choice of *connected* is intentional, providing the broadest possible description to encourage students to propose and look for many possible patterns.

On days 1 and 2 of this unit, students use data cards to compare penguins of today to one another and to a fossil of a penguin from long ago. There is a lot of information on these cards, and therefore they are a relatively complex data set to work with. This will be a challenging data analysis task for students as they will be looking for patterns in the complex data set.

However, students will be working with *Data Cards for Modern Penguins and Pedro* again in Lesson 2 and a more complex version of the cards in Lesson 3. So it's OK if students feel a bit overwhelmed with trying to look at all the cards at once during their first exposure to them in this lesson. There is guidance in the lesson for helping students work with a smaller number of cards at first, before looking for patterns across the entire set of data.

One pattern that will be particularly challenging for students to look for in this lesson will be the geographic distribution of different species of penguins. This is because the orientation of the maps used on the *Data Cards for Modern Penguins and Pedro* have a Southern Hemisphere view of the globe. This view will likely be unfamiliar to students. Using the physical squishy globes to help orient students to this view of Earth will be helpful. Students will have some prior experience in the *Storms Unit*, the *Everest Unit*, the *Tsunami Unit*, and the *Palm Oil Unit* working with maps, and specifically ones that reference locations in the Southern Hemisphere where Lima, Peru, is located (a city relatively close to the fossil dig site of Pedro). The data card for Pedro includes a global map that shows the shifted location of the continents, mountain ranges, and sea levels for Earth at that time. In a previous unit, *Unit 6.4: What causes Earth's surface to change? (Everest Unit)*, students built the idea that the continents were in different positions millions of years ago.

Where We Are NOT Going

By the end of the unit, students will be able to explain the relationships between organisms from long ago and organisms alive today in terms of how closely related they are via natural selection. This lesson, however, avoids introducing the words *related* or *descended* as possible connections between Pedro and modern penguins, although some students may introduce these words themselves. Here is the reasoning behind this choice. The word *related* has multiple meanings, including being related on a family tree such as the pedigrees students used in *Unit 8.5: Why are living things different from one another? (Muscles Unit)*. This meaning assumes an idea we want students to derive in the unit and converge on toward the end of the unit (but not now in Lesson 1)—that different species of organisms descend from a common ancestor at some point in the past.

When the word *descended* is used to describe connections between things living today and things living long ago, it is assuming an idea we want students to derive in the unit—that a species alive today could have descended from a different species in the past. It precludes an idea that students may hold—that the organisms alive today are not different from their ancient ancestors. It will be productive for some students to wrestle on their own with competing ideas around this. In Lesson 6, they will converge on the idea that, for many organisms, the body structures found in a population of descendants appear to be changing over millions of generations.

This lesson refers to different species of penguins. The use of the word *species* in this context is referring to a more general definition. We acknowledge that the word *species* is used beginning in elementary (3rd grade): LS4.B: Natural Selection—*Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing.* We start deepening our understanding of *species* in Lesson 4, and it continues throughout the unit. This unit, however, does not develop the ideas behind *speciation*, which is an area of inquiry that is more productive to save for high school when it will be better aligned to the disciplinary core ideas in that grade band.

The unit does not name the mechanisms of natural selection until Lesson 9, which is after students derive them from case studies themselves first. Students may come into this unit with many partial understandings about natural selection. If such ideas come up during the unit, don't be afraid to put them up on the initial model and explanation as ideas to consider with question marks. But don't elevate any of these ideas yet. Remind students that we need to be able to defend our ideas with evidence, so the class can collect data and decide which ideas are best supported by evidence. Having norms in class around a growth mindset will help students know that it's OK and very productive to change our mind about our ideas. That's how we grow and learn.

LEARNING PLAN FOR LESSON 1

1. Meet Pedro, a human-sized penguin. 17 MIN

Materials: science notebook, *Reference: Podcast Transcript and Photo Journal*, transparent tape, 8.6 Lesson 1 Pedro's Discovery (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), 1 meterstick, computer and speakers, 5–6-inch piece of masking tape or a sticky note

Introduce the phenomenon. Show **slide A**. Tell students that you recently heard about a really amazing discovery made in Peru of a 36-million-year-old giant penguin fossil. Ask students, *What experiences have you had with penguins? What do you know about penguins?* Give students a few minutes to share and listen for them to tell where they have seen penguins, where they think penguins live today, how penguins move, and what they eat.

***Attending to Equity**
Universal Design for Learning: Reading the transcript of the podcast as they are listening to it provides students multiple *representations* (audio, photos, and text) of the information, which could be harder to interpret from audio alone.

Alternate Activity

If students' comments during this sharing time indicate to you that they may not be familiar with what penguins of today look like or how they behave, you may want to take a few minutes here to show a live feed of a penguin encampment from a zoo or aquarium. If there is a zoo or aquarium close to you that has penguins, check whether they have a live camera feed of them. Some other options include the following:

- Detroit Zoo
- Georgia Aquarium
- Monterey Bay Aquarium
- Tennessee Aquarium
- Aquarium of the Pacific
- New England Aquarium
- San Diego Zoo

(See the **Online Resources Guide** for links to these resources. **www.coreknowledge.org/cksci-online-resources**)

Spend no more than 5 minutes on the penguin cam or recording. Once students have watched the penguins for 2-3 minutes, have them turn and talk with a partner to share their noticings and wonderings while they continue to watch for the remainder of the time.

Once they have had an opportunity to watch the penguins, return to the discussion about what we notice about penguins of today.

Share and note the height of the fossil penguin. Continue to share about the penguin fossil that was found by telling students that it was the size of a human!

Using a meterstick against a wall, measure approximately 5 feet (about 1.5 meters) up from the ground. Indicate this height on the wall using something like a 5–6-inch piece of painter's tape, a sticky note, or masking tape at the 5-foot

mark to show students how tall the penguin was. Ask, *How does this compare with what you know about penguins living today?* Students should suggest that this is much taller than penguins of today.

Foreground the purpose of examining an audio recording and photo journal. Project **slide B** and say, *What is really cool is that we were able to get in touch with two members of the research team that found this penguin fossil to learn more about their discovery. And what is also really great is that they shared with us some of the photos they took of their work.*

Distribute *Reference: Podcast Transcript and Photo Journal* to students. Explain that while they listen to the recording students can follow along using the transcript and photos. Before playing the recording, tell students to annotate the transcript as they listen with any ideas that stand out to them as particularly interesting and any questions that they have. When they are finished, they can tape this document into their notebook.

Science Notebook



This is the first use of the science notebook for this unit, so you may need to take time to organize a new section in the notebook. It is recommended to have students do the following:

- Reserve a blank page at the start of the section for this unit, to be titled on day 3 of this lesson when students are given the unit question.
- After the title page, reserve 4 pages (2 pages front and back) for the table of contents (unless all tables of contents are at the front of the notebook).
- Reserve 20 pages (10 pages front and back) for the Progress Tracker section.
- Number the pages so that everyone begins the first investigation of the unit on the same page number.

Remind students that the notebook is their tool for recording their observations, evidence, and ideas to share with the classroom community. They should see it as a space to brainstorm and record their thinking as well as a place to show how their thinking changes as they learn more.

Listen to the recording of the story about Pedro's discovery. Play 8.6 Lesson 1 Pedro's Discovery while students jot down notes on their copy of the transcript. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

After listening to the recording, have a few students share some of the ideas that they found particularly interesting or exciting. Briefly recall what we know about fossils from the *Everest Unit* unit. Ask, *What do you know from the Everest Unit unit about how a fossil would become exposed so a scientist like Señor Altamirano could find it?*

Sample student responses

- When plates move and collide, land can get pushed up and expose fossils that were buried.
- When plates move apart, fossils that were buried could be exposed.
- Erosion from wind and rain can wear away the land and expose fossils.
- Sometimes both plates moving and erosion is what leads to fossils being exposed like the fossil at the top of Everest.

Home Learning Opportunity



Consider posting the podcast and transcript files on your classroom website or similar space for students who are interested in listening to it again outside of class and encourage them to share both the transcript and podcast with others in their family. Some students may find a variety of ways it is *relevant* to themselves and to others in their community, beyond the discovery of Pedro. Examples include the stories of what drew these people into their careers, international connections, a diverse group of scientists, and/or thinking about what the environment and things that lived in it were like in one's own local area many millions of years ago.

Additional Guidance

Another name for Pedro is *Inkayacu*, or water king. This word is derived from *Inka* and *yacu*. Both of these words are part of the indigenous language family spoken by the Quechua peoples, living primarily in the Peruvian Andes, which are where the fossil was found. *Inka* means emperor or king, and *yacu* means water.

Some students may wonder why the scientists nicknamed the fossil "Pedro". The backstory on this from Señor Altamirano is that after he and Dr. Rodolfo Salas discovered the scales on this giant, fossilized penguin foot sticking out of the ground, they tried to picture what the penguin would have been like walking around. They both immediately thought of a character from a popular telenovela series at the time who was often referred to as "Scaly Pedro". The character was portrayed as well meaning but was also quite large and clumsy, which led to much physical comedy. If you watch penguins move on land for a bit, that physical awkwardness in some of their movements often stands out.

2. Brainstorm types of evidence needed.

8 MIN

Materials: Types of Connections poster, Evidence We Need poster, markers

Lead an Initial Ideas Discussion about potential connections between Pedro and penguins alive on Earth today. Project **slide C** and say, *The podcast raised the question of how penguins alive today might be connected to the penguins that lived long ago, like Pedro. Let's consider this question as a class.*

Hang the Types of Connections poster. As students share their ideas, list them on the poster.

Key Ideas

Purpose of this discussion: The purpose of this discussion is to get students' initial ideas and experiences on the table about possible connections living things have with one another. The goal is to provide a supportive opportunity for students to make sense of what may not be fully formed ideas and to promote their curiosity.

Listen for these ideas:

- Living things can be connected in many different ways, such as they may live in the same place, live in the same time period, share similar genetic information, or be related like a sibling, parent, grandparent, and so forth.
- There are gaps in our understanding that we want to know more about.

Suggested prompt	Sample student responses
What are different ways that living things could be connected to one another?	*They might live in the same place.* *They might live during the same time period.* *They could be siblings or cousins or parents.* *They could share similar traits or variations.* *They share similar behaviors.* *They eat the same things.* *They could share similar genetic information.* *They could live in the same environment or climate even if they don't live in the same place.* *They could have some kind of living thing that mutually interacts with them in a common way (e.g., a tick could bite a deer or a human).* *One could be an ancestor to another.*

Make note of the most likely connections listed on the poster. Say, *It sounds like living things can be connected in a lot of different ways. Let's think about the most likely ways that Pedro might be connected to the penguins alive on Earth today.*

As students share their ideas, place an asterisk next to any of the connections that the class identifies as a "likely" type of connection between Pedro and penguins alive today. At this point, accept all student ideas.

Suggested prompt	Sample student responses
Which of these types of connections do you think Pedro might have with penguins alive today?	*They might live in the same place.* *One could be an ancestor to another.* *They could share similar traits.* *They could share similar genetic information.* *They could live in the same environment or climate.* *They share similar behaviors.* *They eat similar things.*

Lead a class discussion about the evidence needed to determine a connection. Say, *It sounds like there might be some kind of connection between Pedro and the different kinds of penguins alive today, but we aren't really sure how they might be connected, or even if they are connected!*

Put up the Evidence We Need poster and keep a running list of evidence we need. As students share their ideas, pay particularly close attention to any ideas related to learning more about modern penguins.

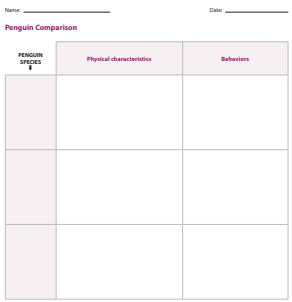
Suggested prompt	Sample student responses
What kinds of data would you need to determine whether penguins alive today are connected to Pedro?	*We would need to know where the modern penguins live.* *We would need to know more about where Pedro and other kinds of penguins like Pedro used to live.* *We would need to know more about the traits of the modern penguins and of Pedro.* *We would need to know more about the genetic information or genes of modern penguins and of Pedro.* *We would need to know what other kinds of critters Pedro and the modern penguins interact with, such as predators, prey, and symbiotic relationships.*

Say, *It sounds like we need to find out a bit more about modern penguins. Señor Altamirano and Dr. Clarke referenced the idea that Pedro is similar in some important ways to all the different species of penguins today. Maybe we can start by looking at a few of these penguins.*

3. Meet three species of penguins alive today.

15 MIN

Materials: science notebook, *Penguin Comparison*, transparent tape, only the emperor and Adélie and southern rockhopper cards from *Data Cards for Modern Penguins and Pedro*, 1 Earth squish ball with countries labeled, 1 Earth squish ball with no labels, 2 paper hot-cup sleeves, emperor penguin video, rockhopper penguin video, Adélie penguin video (See the **Online Resources Guide** for links to the videos. **www.coreknowledge.org/cksci-online-resources**), 1 classroom globe (optional)


Name: _____ Date: _____

Penguin Comparison

PENGUIN SPECIES	Physical characteristics	Behaviors

Prepare to meet three species of penguins alive today. Project **slide D** and say, *Let's get ready to document some of what we observe about the kinds of penguins alive today.* Share that you have some videos and information cards about three different species of penguins alive today.

Distribute a copy of *Penguin Comparison* to each student and have them tape it into their notebook. Tell students that the data table will help to organize our thinking about the three kinds of penguins we're going to look at first. Orient students to the features of the table, pointing out the first column for listing the penguin species and the remaining columns of the table for adding details about specific physical traits and behaviors noticed for each penguin species.

Introduce the emperor penguin. Share that the first species of penguin we are going to observe is an emperor penguin. This is the first of three videos students will watch to make observations about the penguins. Show 8.6

***Attending to Equity**

Universal Design for Learning: To support students in map reading during this activity section, hold up a larger globe, if you have one, to orient students to the corresponding locations on their own globes. You may want to also point out where the North and South Poles are on the globe. Providing physical objects and spatial models to convey perspective can help support *representation*, according to the UDL framework.

Lesson 1 Emperor Penguin in the Wild (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**, also linked on **slide E**.

Then project **slide F**, which shows the emperor penguin card. Arrange students into groups of three and provide each group with a copy of the emperor penguin card from *Data Cards for Modern Penguins and Pedro*.

Orient to locations on the globe.* Say, *This penguin card and other penguin cards you will use include a map of where that species of penguin lives. This map is not a typical view of Earth you often see, as it is only showing the Southern Hemisphere. Let's orient to that view a bit using some globes, which you can keep at your desk as you work with your group to help visualize where these locations are on Earth.*



Distribute both types of squish ball globes and 2 hot-cup sleeves to each trio. Hold up a squish ball globe (or larger globe) and instruct students to demonstrate the following with their own squish ball globes:

- Using the hot-cup sleeve as a base to keep the squish ball from rolling around, place each Earth squish ball on its own sleeve so that the northern pole is pointed to the ceiling.
- Ask students to each point to where we live on both globes.
- Find Peru.
- Locate South America, the southern tip of Africa, Australia, New Zealand, and Antarctica.
- Flip each Earth squish ball on the stand so that Antarctica is pointed toward the ceiling.



Say, *Looking downward on your globe from above gives you a view of the Southern Hemisphere. That is the view shown on the map on the data card, and this is the kind of map orientation you will see on other penguin data cards.*

Record ideas from the emperor penguin data card. Students may wish to share their ideas with their group prior to adding to their data table. Give students a few minutes to examine the card information for the emperor penguin and add to their data table.

***Attending to Equity**
If time permits, consider asking students to share with their group their responses to the following questions: "Which of the penguins that we just observed was your favorite? Why?" This gives students more time to process the information they just heard and read about the three different species of penguins. It also gives students a safe space to begin going public with their ideas in this unit.

Additional Guidance

As students look at the penguins cards, they may notice that skuas or giant petrels are listed as predators. Tell students that skuas and giant petrels are carnivorous birds—birds that tend to eat the eggs or young of other birds. You may wish to pull up photographs of these carnivorous birds to show them.

Introduce the southern rockhopper penguin, followed by the Adélie penguin. Use the same process as for the emperor penguin. First, show 8.6 Lesson 1 Rockhopper Penguin in the Wild (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) on **slide G**. Then project the penguin card on **slide H** and distribute a southern rockhopper penguin card to each group. Next, show 8.6 Lesson 1 Adélie Penguin in

the Wild (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) on **slide I**, then project the penguin card on **slide J** and distribute an Adélie penguin card to each group. Give students time after each penguin introduction to add to the data table information from the videos and *Data Cards for Modern Penguins and Pedro*. Spend about 4 minutes with each species of penguin.*

4. Consider connections among penguins.

5 MIN

Materials: science notebook, *Penguin Comparison*, only the emperor and Adélie and southern rockhopper cards from *Data Cards for Modern Penguins and Pedro*, 1 Earth squish ball with countries labeled, 1 Earth squish ball with no labels, 2 paper hot-cup sleeves, Types of Connections poster

Discuss how the three species of penguins we observed compare to one another and to Pedro. Project **slide K** and say, *Remember the question that we started considering at first was how Pedro and other penguins that lived long ago might somehow be connected to the penguins alive today. Let's revisit that question now.*

Instruct students to look back at the list on the Types of Connections poster for how living things could be connected to one another *and* the comparisons that they made among the penguins on *Penguin Comparison*. Give students time in their groups to discuss the questions on the slide. Then bring the class together for a whole-class discussion.

Suggested prompt	Sample student responses
What claims can you now make about how the emperor, southern rockhopper, and Adélie penguins are connected to one another?	*The penguins have similar features and eat similar food.* *All three penguins live in the Southern Hemisphere.* *All three penguins appear to be black and white.* *All three penguins lay eggs.* *The rockhopper and Adélie eggs are incubated by both parents, while the emperor egg is only incubated by the father.* *All the penguins swim, but the emperor dives the deepest.* *The Adélie and emperor penguins live in and around Antarctica.* *All three penguins eat fish, krill, crustaceans, and squid.* *All three penguins have similar predators—carnivorous birds, leopard seals, killer whales.*

Suggested prompt	Sample student responses
What ideas do you have about how these three species of penguins might be connected to Pedro? What additional evidence would you need to support or refute that claim?	*The three penguins or maybe just one or two of the species of penguins could be distant relatives of Pedro—like a great, great, great, great grandchild. We would probably need to compare their traits to support or refute this claim.* *The three penguins or maybe just one or two of the species of penguins could be connected to Pedro because they live or lived in similar environments. We would need to know more about the environment that Pedro lived in to support or refute this claim.* *The three penguins or maybe just one or two of the species of penguins could be connected to Pedro by interacting with the same kinds of other living things, like predators and prey. We would need to know if similar kinds of predators and prey were alive when Pedro was living.*

Emphasize that it sounds like we are going to want to look at more data in order to figure what additional connections might exist between penguins of today and Pedro.

Additional Guidance

Students will likely bring up the idea that the penguins could be connected through "lines of descent." Embrace this as an idea that we can pursue. It is important, though, to neither confirm nor deny this idea at this point in the process so that students are motivated to further investigate their ideas about lines of descent.

Additional Guidance

Students enter this unit with many different ideas about how living things from the past could be connected to living things today. These connections, the associated evidence, and the underlying science ideas are complex. In order to help students develop strong, evidence-based explanations that incorporate key science ideas, it is important to work with developing student ideas and root the development or change of ideas over time in evidence. We have provided extensive guidance in the "Teacher Background Knowledge" section of the *Teacher Edition* (or see the "Unit Overview Materials" file in Google Drive) to help you navigate these complexities at critical moments throughout the unit. Within lessons, we call out these critical moments and reference that Teacher Background Knowledge section.

Before leaving class, have students turn in their cards from *Data Cards for Modern Penguins and Pedro*, their 2 squish globes, and the 2 paper hot-cup sleeves for use in the next class and the following day of this lesson.

Before the next day of this lesson, add the emperor, rockhopper, and Adélie penguin cards back in to *Data Cards for Modern Penguins and Pedro* so that each set includes all 18 penguins alive today (with the red-background header boxes on them) and a Pedro card (with a gray-background header box on it).

End of day 1

5. Predict patterns in penguins.

5 MIN

Materials: 3″ x 3″ sticky notes (optional)

Review the need for evidence. Remind students that they have already made some claims about the ways that the three species of penguins living today we looked at are connected to one another and how they might be connected to Pedro. Tell students that in addition to the three species of penguins they already explored, there are 15 other species of penguins for a total of 18 different species of penguins living today. Show **slide L** to prompt a Turn and Talk around these questions:

- What patterns in 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?

Additional Guidance

Students might be surprised to hear that there are 18 different species of penguins living today. If it comes up, capture students' thoughts as questions on sticky notes. For now, post these questions in a common space in the classroom. Later, you can add them to the Driving Question Board. Possible student questions might include the following:

- Where did all the ancient penguins go?
- Where did all the different species of modern penguins come from?
- Are the penguins alive today really *that much* different from one another that we can call them different species?

Additional Guidance

We acknowledge there is not a consensus among experts as to whether there are 17 or 18 different species of penguins alive today. Some experts do not recognize the southern rockhopper and northern rockhopper penguins as two different species. In this unit we have chosen to recognize these as two different species of penguins since there are differences between the two species of birds.

Predict patterns in penguins. Invite students to share their thinking with the class about the questions on **slide L**.

Suggested prompt	Sample student responses
What patterns in connections do you expect to find among the penguins alive today?	*The penguins alive today are all likely good swimmers.* *The penguins alive today probably all eat the same kinds of food and are eaten by the same kinds of predators.* *There might be some species of penguins that are bigger than others and some species of penguins that are smaller than others.* *There might be some species of penguins that dive deeper than others and some species of penguins that dive shallower than others.* *Most penguins alive today probably live in the Southern Hemisphere.* *Some penguins alive today might live in Antarctica, while others might live further north.*

Suggested prompt	Sample student response
How might those patterns help us consider other possible connections between the penguins of today and Pedro?	*(Accept all responses.)*

Motivate finding out more about the penguins alive today. Say, *We don't have time to watch videos for all the other fifteen different species of penguins alive today, but we can take a look at the penguin cards for the other penguins. Let's see what we notice.*

6. Look for patterns among penguins.

20 MIN

Materials: *Data Cards for Modern Penguins and Pedro*, 1 Earth squish ball with countries labeled, 1 Earth squish ball with no labels, 2 paper hot-cup sleeves

Set up the globes again. Put students into groups of three and redistribute to each group one each of the two types of Earth squish balls and two paper hot-cup sleeves. Remind students to place the globes on the sleeves so that Antarctica is facing upward on each.

Examine penguins alive today and Pedro. Project **slide M** and say, *Let's take a closer look at the different species of penguins alive today and at Pedro to identify patterns in the data.* Hand out one set of 19 *Data Cards for Modern Penguins and Pedro* to each group of students. Be sure you have added the emperor, rockhopper, and Adélie penguin cards back in so that each set includes all 18 penguins alive today (with the red-background header boxes on them) and a Pedro card (with a gray-background header box on it).

Say, *First, let's explore what's on these cards a little more before we try to sort them.* Instruct students to examine the cards, paying close attention to potential categories for groupings. Have students share several of their ideas for categories. List these ideas on the board. Groupings may include the following:

- height
- weight
- number of eggs
- distribution on map
- diving depth



Instruct students to work in their group and come up with several different ways to sort the cards. Suggest to students that each group member should take a turn deciding how to sort the *Data Cards for Modern Penguins and Pedro*. Also recommend that they set aside Pedro's card at first, and begin working with only the 18 cards for penguins alive today. You may choose to have the groups each work together to sort all their cards in three different ways. Or, if the number of cards is overwhelming to students, instruct groups to divide the cards equally among group members and agree on one way to sort the cards (one category of grouping). Then have each group member sort their subset of cards according to that category. The group can then combine their sorted cards to look at all 18 penguins. As a group, they can then divide the cards again and use a different way to sort the penguins.

Additional Guidance

Though the card deck includes Pedro, the task at hand is to figure out more about the penguins alive today. Then, after they have analyzed the 18 cards of the penguins alive today and sorted them in different ways, they can compare what they found as patterns to Pedro's card. In this way students can look for connections between modern penguins and Pedro.

Assessment Opportunity

Building towards: 1.A Analyze and interpret data using data cards containing photos, maps, charts, measurements, and descriptive text to find patterns in penguins that are alive today.

What to look and listen for: Each student should take the lead for at least one of the three ways their small group sorts the cards and co-facilitate the discussion about the patterns they notice as they do this. Students will get to work with these data sets and others multiple times over the course of the early lessons in the unit, so look for growth in fluency with this sort of data analysis in this lesson and as the unit progresses.

What to do: Though students will have had prior experience with this element, this data set is larger and more complex. If some students find it overwhelming to look at all the cards at once, suggest that the group divide their set among them, as described above. You might also suggest a category students could begin sorting with, and then help them find other possible categories to use after that.

Share groupings, observations, and new questions that surfaced. After students have had sufficient time to sort the cards, have several groups share what they noticed, how they sorted the cards, and any new questions that came up. As students share their ideas, take note of the groupings; consider writing the groupings on the board.

Suggested prompts	Sample student responses
How did you sort your cards? What connections did you discover?	*We sorted based on distribution—where they usually live. We noticed that most penguins are in Antarctica, but some are in slightly warmer climates. We also noticed that all penguins live in the Southern Hemisphere.* *We sorted based on penguin height. We noticed that there are clearly some very large penguins and some small penguins, but most penguins seem to be medium sized.* *We sorted based on how deep the penguins can dive. We noticed that the bigger penguins can dive deeper.*
What new questions came up?	*(Accept all responses.)*

Emphasize that we have already made some big progress in finding connections among these penguins just by looking for patterns in the different categories of data.

Examine the pattern of distribution more closely using a map. Refer to any suggestion that came up regarding patterns related to geography and say, *Patterns in geographic location can be tricky to visualize without a map. Let's discuss that one further by referencing the map of the Southern Hemisphere that's on our data cards and then let's discuss again some of the patterns you noticed.*

Project the map on **slide N** and ask students about the patterns in distribution. At this point, accept all student ideas.

Suggested prompts	Sample student responses
What patterns did you notice in the geographic location of different species of penguins?	*All penguins live in the Southern Hemisphere.* *All penguins live on or near a coast.* *Some penguins lived closer to the center of the map—the South Pole—than others.* *The largest penguins lived closer to the South Pole.* *There was an overlap in the areas where some of the penguins lived.* *Pedro was in the same place as some of the penguins of today.*
What questions do you have now?	*Why do the bigger penguins live further south?* *Why don't any penguins live in the Northern Hemisphere?* *Are there other "Pedros" out there?* *Are there fossils of other kinds of penguins?* *Where would other penguin fossils be found?* *Are there fossils of other kinds of animals that lived at the time of Pedro that were the predators or prey of penguins?*

Summarize by saying, *Just from considering geographic connections we came up with new questions. And many came from thinking about where Pedro's fossil was found. So far, we have only looked at Pedro's fossil, but we heard ideas and questions related to where else penguin fossils might be found. Let's dig into that line of thinking a bit more.*

7. Predict where other penguin fossils could be found.

3 MIN

Materials: None

Brainstorm where other fossils would be found. Project **slide O** and ask, *Where on Earth do you think we'd be likely to find more penguin fossils?*

Suggested prompt	Sample student responses
Where do you think we should dig to find more penguin fossils?	*Probably on coastlines or slightly in from the coast, like where Pedro was found.* *Maybe on different continents slightly in from the coastline, like New Zealand or Australia.* *All living penguins seem to be in the Southern Hemisphere, so we should probably dig there.* *A lot of penguins seem to be in Antarctica, so let's dig there, though it might be hard because of all the ice.* *Penguins spend a lot of time in the water, so I would want to dig under the ocean, but that would be really hard.* *Pedro was found in a desert inland in Peru. Maybe we should dig there or in other similar deserts.*

Start considering what kinds of fossils we might find. Next, ask students what they think we would find if we dig in the places they mentioned. As a class, consider a few of the possible locations of penguin fossils to think about how the penguin fossils might have looked compared to the penguins living today. Say, *If we dug here* (point to one of the locations on the slide map suggested by students) *and found a penguin fossil, what would that species of penguin have looked like when it was living? And what if we dug in another spot* (point to another one of the locations) *and found a penguin fossil, what would that penguin have looked like when it was living? Let's take a moment to put our predictions on paper.*

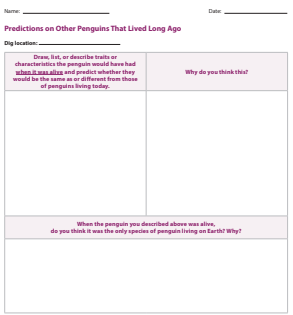
8. Predict penguins from long ago.

7 MIN

Materials: science notebook, *Predictions on Other Penguins That Lived Long Ago*, transparent tape, colored pencils, 1 or more cards from *Data Cards for Modern Penguins and Pedro* (optional), chart paper, markers, Pedro's card from *Data Cards for Modern Penguins and Pedro* (optional)

Draw or describe a penguin from long ago. Project **slide P** and distribute *Predictions on Other Penguins That Lived Long Ago*. Say, *Let's think a little more specifically about any one of the dig sites that we identified earlier. Let's be really specific about what we think we would find if we dug in one of these locations.*

Instruct students to individually pick one of the dig site locations that they can recall from their previous discussion or a new dig site location that they might be interested in exploring and describe that location on *Predictions on Other Penguins That Lived Long Ago*. Ask students to imagine that they found a penguin fossil at that location and then imagine the traits or characteristics that penguin would have had *when it was alive* and to predict whether those characteristics would be the same as or different from those of penguins living today.


Name: _____ Date: _____

Predictions on Other Penguins That Lived Long Ago

Dig location: _____

Draw, list, or describe traits or characteristics the penguin would have had when it was alive and predict whether they would be the same as or different from those of penguins living today.	Why do you think this?

When the penguin you described above was alive, do you think it was the only species of penguin living on Earth? Why?

***Attending to Equity**

Universal Design for Learning: Allow students to use multiple ways of expression in describing ancient penguins. If students prefer, they can use words instead of drawings to describe what they think their penguin looked like.

Additional Guidance

At this point, we are using the words *characteristic* or *trait* since students are drawing or describing a single penguin (of a single species, so it makes sense to talk about traits), but then also making initial comparisons to multiple species alive today (hence the broader characteristics). When they get to Lessons 2 and 3, students will be making careful comparisons across species, and then we will use the terms *body structure* and *behavior*. We will continue to use the term *characteristic* occasionally, as well. It is not important to make distinctions about these terms with students. See the "Where We Are Going and Not Going" section of the *Lesson 2 Teacher Guide* for more information.

Encourage students to put any of the data cards of the penguins they have analyzed so far in front of them as a reference if they wish. Emphasize that after a couple of minutes they should move on to the other boxes on the handout to explain their reasons for their predictions and to answer the remaining handout questions, all of which are listed below.**

- Draw, list, or describe traits or characteristics the penguin would have had when it was alive and predict whether they would be the same as or different from those of penguins living today. Why do you think this?
- When the penguin you described above was alive, do you think it was the only species of penguin living on Earth? Why?

***Supporting Students in Engaging in Argument from Evidence**
It is important that students focus on the justification for the decisions they made in their penguin drawing, list, or description of traits. This focuses students on explaining why there are commonalities and differences in the characteristics of living things rather than simply itemizing features.

Additional Guidance

If students want to draw a picture but don't understand how they could draw a picture of something that no one has ever seen, it might help to refer to the image of the artist's rendering of Pedro on his data card. Explain that Dr. Clarke and her team didn't know exactly what Pedro looked like, but they had some evidence that they could share with an artist. The artist then took that evidence (bone width, bone length, beak shape) into consideration when they first developed an outline of the penguin to show the relative sizes of these structures.

9. Compare penguins and develop a timeline model to represent our thinking.

9 MIN

Materials: science notebook, *Predictions on Other Penguins That Lived Long Ago*, chart paper, markers, transparent tape

Look for similarities and differences in characteristics. Show **slide Q**. Give students two minutes to talk with a partner about the ways their long-ago penguins might have been similar to or different from penguins living today.

Develop an initial consensus model. Show **slide R**. Ask students to share some of the possible differences they identified in the characteristics of penguins from long ago compared to today's penguins. Then follow up with discussing whether they think there were other species of penguins in the past.

Suggested prompt	Sample student responses
Let's talk about some of the ways that you predicted penguins from long ago might have looked different from penguins of today. What were some of those differences you identified in the predictions you and your partner made?	*They might all have been bigger than the emperor penguin.* *Maybe some were even smaller.* *Maybe they all had pointier beaks and bigger feet.* *They all would have looked like Pedro.* *They might be colored differently.*

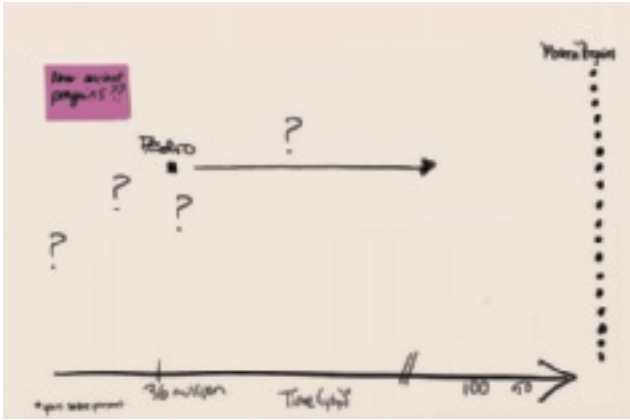
***Attending to Equity**
Supporting Emergent Multilingual Students: "Modern penguins" and "ancient penguins" are terms we will use going forward to keep the distinction between penguins that are alive now versus those that are found in the fossil record and were alive millions years ago. The Spanish word for *modern* is "moderna/o", and the Spanish word for *ancient*

Suggested prompt	Sample student responses
Do you think there would have been other species of penguins living on Earth at the same time as when your species of long-ago penguin was living? Why?	*Some might have looked a little bit like Pedro and a little bit like the ones of today.* *They might have been deep divers, but some today are not.* *No, they all would have been like Pedro.* *No, there were fewer species of penguins in the past than now.* *Yes, there must have been all the species of penguins alive today in the past too.* *Yes, there were many different kinds of dinosaurs, so there were probably different kinds of penguins.* *There are different species living now, so doesn't that mean there would have to have been different species living at some point in the past too?*

is "antiguo/a". Additionally, the Spanish word for penguin is "pingüino". Using cognates is a helpful strategy to support emerging multilingual students.

Motivate capturing these competing ideas. Say, *OK, we have some ideas about how penguins that lived long ago might have been similar to and different from the penguins of today. We also have differences in the claims we are making about whether there was more than one species of penguin at a certain point in the past. So, let's take some time to represent our current thinking about the one or more different species of penguins living at different points in time.*

Create a penguin timeline on chart paper. Refer to **slide R.** Position a blank piece of chart paper horizontally and title it "Penguin Timeline." Draw and label a horizontal arrow as "time (years before present)" with a long gap in time between the "recent past" and the "past from very long ago". Add labels for "50" and "100" years ago to the "recent past" section of the line. Say, *This axis will represent the years before present. So 50 and 100 years ago are the more-recent past. This break in the line represents a jump back to millions of years ago. I will label a point on the far left side of the arrow as "36 million years ago", which is when Pedro lived.*



Additional Guidance

The choice to mark 50 and 100 years as our "recent past" is connected to how long people have been observing and recording trait measurements of penguins. In some cases, for some species of penguins, that record goes back more than 50 years, while in other cases it does not.

Ask students how many species of penguins are living today. They will say, "eighteen". Say that you are going to represent each of these species with a dot, all stacked above the line on the far right side of the timeline, to emphasize that they are living today.

Add a dot labeled "Pedro" at 36 million years ago and an arrow with a question mark over it pointing forward in time. Suggest that this line shows that we don't know how long ago the *Inkayacu*, which is Pedro's species of penguin, lived on Earth, but we do know that at some point in the past they no longer were living on Earth because they aren't alive today. Tell students that we will refer to this image as our initial consensus model of the Penguin Timeline.

Introduce a way to distinguish modern and ancient penguins. Say, *We are talking about these penguins from long ago and penguins from today. When we are considering penguins from millions of years ago, let's refer to any of those penguins as "ancient penguins". When we are referring to penguins of today, let's call those "modern penguins".*

Add labels to the Penguin Timeline model. Add a label of "ancient penguins" over the section of the timeline on the left. Add a label over the 18 dots that says "modern penguins".*

Revist the area(s) of uncertainty around other species of ancient penguins. Say, *So what did we think about penguins alive millions of years ago? Do we know if there are any other species of penguins that lived when Pedro lived?* Students will say, "No". Suggest that we add a lot of question marks around Pedro's dot to represent this.

Say, *So let's think about this. Pedro was an ancient penguin. But what happened to the Pedro species of penguin? Where did they go? And if there were other species of ancient penguins besides Pedro, then where did they go? And let's also consider the reverse. Today there are 18 different species of modern penguins. Where did these modern penguins come from?*

Give students a minute to think on their own about these questions and then say, *Let's pick up there next time and try to figure out how we can fill in some of this area where there is a big gap in our model and where we have all these question marks.*

Have students tape their *Predictions on Other Penguins That Lived Long Ago* into their notebook. If time permits, you may also wish to have students add the Penguin Timeline model to their notebook.

End of day 2

10. Navigation

5 MIN

Materials: Penguin Timeline model

Turn and talk to share initial ideas about where ancient penguins went and where the modern penguins came from. Point to the question marks around Pedro's dot on the Penguin Timeline model that represent questions we had about how long Pedro's species of penguin lived and if there were other species of penguins living before, at the same time as, and after he did.

Project **slide S** and point out these main ideas that have been raised so far:

- 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.

Emphasize that at the end of the last class we had two questions that came up about the gap we have in our model as we started considering connections over time:

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

Give students several moments to turn and talk with a partner about these questions. At this point, students should just be sharing their initial ideas. Bring the class back together and select a few students to share their ideas. Accept all student ideas.

Say, *It sounds like these two questions—Where did all the ancient penguins go? and Where did all the modern penguins come from?—are helping us consider other ways that Pedro could be connected to the penguins alive today.*

11. Write and compare initial explanations.

16 MIN

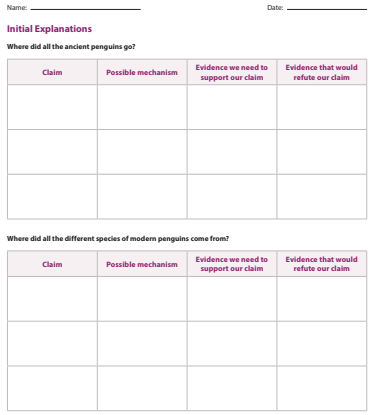
Materials: science notebook, *Initial Explanations*, transparent tape

Write an initial explanation. Project **slide T** and distribute *Initial Explanations* to each student and have them tape it into their science notebook (so they can refer to it in future lessons as well as this one). Say, *Let's take some time to gather our initial ideas about the questions we just discussed.*



Instruct students to use the handout to develop an initial explanation in response to each of these questions: Where did all the ancient penguins go? Where did all the different species of modern penguins come from?

Point out that there are rows on the handout to list multiple claims. Say, *We might wonder if there are several different things going on here. Make more than one claim to answer each question, and for each claim, identify a possible mechanism and the evidence that would be needed to either support or refute that claim.*



Name: _____ Date: _____

Initial Explanations

Where did all the ancient penguins go?

Claim	Possible mechanism	Evidence we need to support our claim	Evidence that would refute our claim

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

Claim	Possible mechanism	Evidence we need to support our claim	Evidence that would refute our claim

5

Assessment Opportunity

Building towards: 1.B Develop an initial explanation and identify evidence needed to determine what caused the observed changes in the existence, diversity, and disappearance of different kinds of penguins throughout history.

While we are at the end of 8th grade and you can expect students to have practiced constructing explanations in prior units, this is a pre-assessment opportunity to establish a baseline understanding of students' use of this practice, and they will have several other opportunities throughout the unit to show growth in this practice and around these ideas as they investigate evidence and develop key ideas.

What to look and listen for: (1) Students make more than one claim about what happened to the penguins from long ago and about where the modern penguins came from, (2) students support their claim by providing a possible mechanism, (3) students articulate evidence needed to either support or refute their claim.

What to do: If students are struggling you can allow them to work with a partner and/or use the following prompts to push them in their thinking:

- What evidence would you need to support your claim?
- What evidence would you need to refute the claim?
- How might that piece of evidence support (or refute) your claim?
- Why would that evidence convince you? What other kinds of evidence might you need?

Additional Guidance

If students struggle with the word *mechanism*, restate the idea of a mechanism as identifying the "working parts" or steps that could make something happen.

Compare initial explanations. As students finish their initial explanations, project **slide U** and arrange students in small groups. Have students share their initial explanations in their small group, listening for similarities and differences among their explanations. Have each team member keep track of the similarities and differences among their explanations in their science notebook.

12. Hold an Initial Class Consensus Discussion. 13 MIN

Materials: science notebook, *Initial Explanations*, chart paper, markers

Build an initial class consensus explanation.* Project **slide V** and gather students in a Scientists Circle with their science notebooks and *Initial Explanations*. The task will be to build an initial class consensus explanation through discussion of the two subquestions: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from?

During the discussion, capture students' claims and possible mechanisms on chart papers titled with each subquestion for future reference. Consider making a T-chart under each question with "claims" on the left side and "mechanisms" on the right. Note areas of disagreement or uncertainty (or places we agree on but need to support with evidence) with question marks. You will record evidence that could support or refute these claims on day 4.*

***Attending to Equity**
Supporting Emerging Multilingual Students:
Remember to use the words that students use whenever possible. Allow and encourage students to speak using both content-specific and everyday words and phrases when expressing their ideas. This helps students fully express themselves, allowing others to question, evaluate, and build off their ideas. Switching back and forth between different registers is especially important for emerging multilingual students because it helps them draw on their full range of meaning-making resources.

Key Ideas

Purpose of this discussion: Develop an initial class consensus explanation to capture the ideas we agree and disagree on regarding what happened to penguins of the past and the possible connections between penguins of long ago and penguins alive today. Help students realize that, while we have common agreement with some ideas, we still have many questions.

Listen for these ideas:

1. Where did all the ancient penguins go?

<u>Areas of agreement</u>

- Some species (like Pedro) that were alive in the past aren't alive today.
- Everything dies.

<u>Possible areas of disagreement or uncertainty</u>

- how many species were alive at any one time
- how similar or different these species were
- whether the penguins alive long ago were *exactly* like the penguins alive today

- whether some penguin descendants changed over many generations vs. there were just a lot of kinds of penguins long ago, and only some kinds had descendants that have survived into the modern day
- whether some penguins from long ago became modern penguins

2. Where did all the different species of modern penguins come from?

Areas of agreement

- They came from other living things (they had parents and grandparents who looked like them).
- There must be a line of ancestors they came from that stretches back millions of years.

Possible areas of disagreement or uncertainty

- whether modern penguins are a "new" kind of penguin or just a very different-looking penguin from those of long ago
- how modern penguins look so different from ancient penguins
- why (and how) there are so many different species of modern penguins

Scientists Circle

You will form a Scientists Circle in many lessons in this unit. If this is your first time forming one, you will need longer than 10 minutes to coordinate it. If your class is familiar with the Scientists Circle, the movement in and out of the circle can happen fairly quickly. Setting up the norms and logistics for forming, equitably participating in, and breaking down that space is important to do if this is your first time forming such a space. Having students sit in a circle so that they can see and face one another can help build a sense of shared mission and a community of learners working together. Returning to this Scientists Circle throughout the course of the unit to take stock of what the class has figured out and where students need to go next will be an important tool in helping the class take on greater agency in steering the direction of their learning. This circle will also help build a sense of pride in their work. You may want to inform students that professional scientists also collaborate with one another to brainstorm, discuss, and review their work.



13. Brainstorm and share related phenomena.

7 MIN

Materials: science notebook, Penguin Timeline model, Related Phenomena poster, 5–6-inch piece of masking tape, markers, 3" x 3" sticky notes

Consider related phenomena.* Project **slide W** and say, *So far, we have been talking about penguins from long ago and penguins alive today, but we know penguins aren't the only creatures that were found both long ago and today.* Ask, *What other organisms do you know of that lived in the past? What is a similar type(s) of organism(s) alive today? Make a table in your science notebook like the one on the slide. Take a couple of minutes to brainstorm with a partner and record your ideas in your science notebook. Be ready to share.*

You may want to discuss an example together before having students brainstorm additional examples. The most common example of a group of organisms that students will say lived long ago will be dinosaurs. Once they raise just one example of a modern organism connection, pause and cue students to continue brainstorming additional examples with a partner.

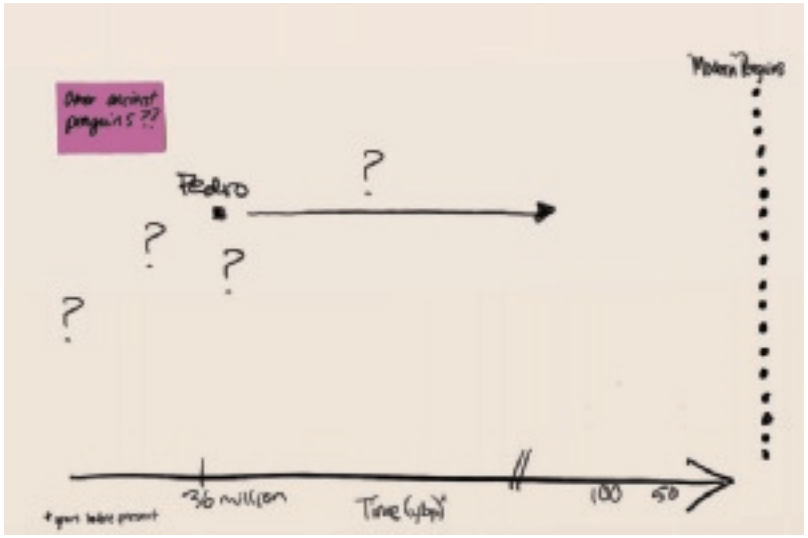
***Attending to Equity**
Generating related phenomena is a key element of the anchoring phenomenon routine. Tapping into prior knowledge and experiences broadens students' thinking related to this phenomenon and helps to make the unit phenomenon become more personally meaningful to each student. It is OK at this point if

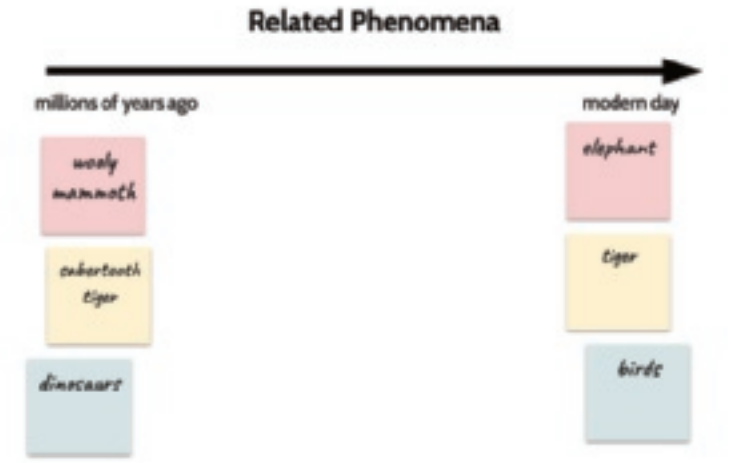
After discussing in pairs, students share their ideas with the class. Bring the class back together for a whole-group discussion of the ideas students produced. Accept all student responses. Try to draw out a wide variety of related phenomena, which will likely include organisms from across many different time periods and scales (single lifetime to millions of years), which is OK.

students share related phenomena that are not all that related.

Position the Related Phenomena poster horizontally underneath the Penguin Timeline model. Below the title draw a horizontal arrow pointing right and write "millions of years ago" at the left side of the arrow and "modern day" at the right side. Have students write the names of the ancient organisms and modern-day organisms on sticky notes and place them along the timeline when they think they lived. An example is shown on the next page.

Prompt students to keep a record of the related phenomena in their science notebook as it will be a helpful reference later in the lesson and the unit.





14. Navigation

4 MIN

Materials: None

Discuss new questions. Project **slide X** and prompt students to consider possible reasons for these differences between the ancient and modern types of organisms they brainstormed and shared with the class. After students discuss in pairs, have a few share their ideas and highlight new questions raised.

Summarize by saying, *There are many different organisms that seem like they might be connected—just like Pedro and modern penguins. Maybe investigating Pedro and modern penguins can help us figure out how living things today could be connected to things that lived long ago.*

End of day 3

15. Develop initial questions.

8 MIN

Materials: science notebook, *Predictions on Other Penguins That Lived Long Ago*, *Initial Explanations*, *Reference: Podcast Transcript and Photo Journal*, *Data Cards for Modern Penguins and Pedro*, Related Phenomena poster, Penguin Timeline model, T-charts from day 3

List new questions. Display **slide Y**. Tell students to add a "Questions" section to their science notebook and jot down any questions they have related to what we have observed so far. Instruct students to look back at all their resources from this lesson, including the following items:

- *Reference: Podcast Transcript and Photo Journal*
- *Data Cards for Modern Penguins and Pedro*
- sketch of ancient penguin on *Predictions on Other Penguins That Lived Long Ago*
- *Initial Explanations*
- list of similarities and differences in initial explanations
- list of related phenomena

16. Revise questions.

4 MIN

Materials: science notebook, 2 3" x 3" sticky notes or index cards, 1 marker, chart paper, markers

Prepare to construct the Driving Question Board (DQB).* Reference the questions students jotted down in their notebooks. Say, *We've brainstormed a lot of questions about Pedro, penguins alive today, other penguins from long ago, and other similar phenomena. Let's post our questions to our Driving Question Board and begin thinking about how we're going to investigate to figure out if Pedro could be connected to modern penguins and our two subquestions: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from?*

Develop two questions for the DQB. Project **slide Z** and instruct students to use the question starters on the slide to draft two questions to contribute to the class Driving Question Board. These questions can be ones they already brainstormed, perhaps revised based on the question starters, or they can be new questions. Ask students to write their questions in marker on sticky notes (or index cards), one per note.



***Attending to Equity**

A DQB provides a public representation of the class's joint mission. Students can share their questions and wonderings with one another, and the visual representation offers another modality for students to access science in the classroom. It

They should write their questions so they are big and bold—we want to be able to see the questions. Remind students that it is part of our mission to try to answer these questions.

If the posters from this lesson are not already visible near your DQB space, rehang them there while students are revising their questions. If needed, create a chart paper poster or title a board space for the Driving Question Board.

should be centrally located in the classroom so that it can be referenced and added to throughout the unit.

Assessment Opportunity

Building towards: 1.C Ask questions that arise from initial observations of patterns in the images depicting anatomical similarities and differences of penguins that are alive today and of a fossil of a penguin from long ago.

What to look and listen for

- It is important that *all* questions posed by students be placed on the DQB regardless of whether they are open-ended or close-ended.
- Make note of any close-ended questions and use navigation time throughout the unit to turn close-ended questions into open-ended ones that necessitate a need to examine additional evidence.
- As you move into the discussion of ideas for future investigations and data we need, have students focus on categorizing their questions and then identifying the kinds of data and additional information that would be helpful in answering each category of questions.

What to do: If students are struggling to generate questions connected to their previous observations, direct them to their sketch of a penguin from long ago, related phenomena, and other resources. If students are struggling to seek information that could inform the explanations they developed in *Initial Explanations*, point them to specific points and ask, *What would you need to know more about to figure this out?*

17. Build the Driving Question Board.

20 MIN

Materials: questions on sticky notes, 3" x 3" sticky notes or index cards, markers

Share questions to develop the Driving Question Board. Instruct students to bring their two sticky notes along with their science notebook and meet in a Scientists Circle around the DQB. Share **slide AA** and say, *Now we're ready to post our questions that will help us figure out if Pedro could be connected to modern penguins. We're also working on figuring out our two subquestions: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from?*

Continue, *It is important that we hear everybody's questions, and we might find that we have questions similar to some of our classmates' questions, and when that happens we will group them together. Our DQB will guide our investigations as we attempt to answer the question: How could things living today be connected to the things that lived long ago?*

Instruct students to share their questions, one by one, with the whole group. Explain to students how you will create the DQB:

- The first student reads their question aloud to the class, 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.
- Continue until everyone has at least one question on the DQB.

If the question is a new question and doesn't fit with any questions that are already on the board, students should create a new cluster.

Label or title the clusters of questions. After all students have shared their questions, you will end up with a DQB that has several different clusters of questions. As a class, decide on "umbrella" questions or topics for the clusters of questions. Write these on sticky notes and place them on the DQB near their related cluster.

Here are some examples of the kinds of questions students might come up with:

- What other penguin fossils have been found?
- Where have other penguin fossils been found?
- What were the traits or characteristics of penguins from long ago?
- How closely connected are penguins to other birds living today?
- How did Pedro end up in Peru while all the ones (penguins) now live in colder places?
- Why do most penguins live in Antarctica?
- Will the penguins' food change (in the future)?
- How do organisms change over time?
- What caused the differences in penguins?
- What was the environment like back then?
- How did the location where Pedro was found look in the past?
- Do all these differences help organisms to become better?
- Were there other fossils like Pedro?
- How do scientists or artists determine what an ancient penguin looked like?

Possible clusters might include the following:

- Modern penguins
- Ancient penguins
- Extinction
- Connection between modern and ancient penguins
- How do the changes happen?

Additional Guidance

If there seems to be a cluster of questions about heritable traits, be sure to officially name the cluster on the Driving Question Board. This will be a large focus in Lesson 2. If the cluster doesn't emerge, don't force it. The navigation at the end of this lesson will help us pursue an investigation of heritable traits at the beginning of Lesson 2.



Example Driving Question Board

18. Brainstorm ideas for investigations.

10 MIN

Materials: science notebook, Driving Question Board, Ideas for Future Investigations and Data We Need poster, markers

Brainstorm ideas for data and information we need. Now that the class has created a DQB, tell students that it is time to really dig into the hard work of figuring out what is going on. Stay in the Scientists Circle to brainstorm ideas for data and information we need. Post the Ideas for Future Investigations and Data We Need poster. Present **slide BB** and ask students, *What kinds of information or data do we need to figure out the answers to our questions?*

Prompt students to use the clusters or categories of questions from the DQB to identify types of data and information that would help them answer any of the categories of questions. Students may also wish to look back to their initial explanations at the "Evidence we need to support our claim" and "Evidence that would refute our claim" columns. You can also point back to the T-charts you made on day 3.

Divide the class into as many groups as you have clusters of questions on your DQB, and assign each small group a category of questions. Have students talk with their group mates about their ideas and jot notes in their science notebooks before sharing with the whole group.

Make a class record of future investigations and data we need. Have small groups share their ideas with the whole group. Make sure that all groups get to share at least a few ideas. As students share, create a class record of the ideas on the Ideas for Future Investigations and Data We Need poster. You may also want to prompt students to keep a record of proposed investigations in their science notebook.

Here are some examples of student responses:

- We need to find out what the environment for Pedro was like.
- We want additional information on other modern and/or ancient penguins.
- We want to see a map of the location in the past where Pedro's fossil was found.
- We want to know temperatures in the past of places where penguins live now or may have lived then.
- We want to look into other animals that had similar differences.
- We want to look into their diet (what they were eating) now versus in the past.
- We could look at their poop to see what they ate.
- We want to look at more fossils similar to Pedro.
- We want to look at other animals that lived in the area where Pedro lived.

19. Navigation

3 MIN

Materials: None

Summarize the progress made and a plan for next steps. Conclude the lesson by working with students to decide next steps. Project **slide CC** and say, *We figured out a lot in this lesson! We figured out that penguins living today and penguins that were alive long ago have many important similarities to one another, but also some key differences. We also figured out that we have a lot of questions about how the penguins from long ago could be connected to penguins alive today.*

We could really start investigations anywhere because all our questions are so connected! Let's pick back up next time with what we figured out so far, and we can decide then where to go next.

ADDITIONAL LESSON 1 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-Literacy.RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

On day 1, students gather information from an audio recording and transcript about a giant penguin fossil that was discovered in the desert of Peru and use it to glean important insights about the traits of the penguin fossil that was discovered.

CCSS.ELA-Literacy.SL.8.1.C: Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas.

When the class is building the Driving Question Board, if a student forgets to explain why or how their question is linked to someone else's question, press that student to try to talk through their own thinking. This is a key way to emphasize the importance of listening to and building off of one another's ideas and to help scaffold student thinking.

If students can't figure out which question to connect theirs to, encourage them to ask the class for help. After an idea is shared, ask the original presenter if there is agreement and why, and then post the question.

This lesson's activities rely on students communicating and articulating their thinking. One tool that may support classroom discussion is the *Communicating in Scientific Ways* (CSW) sentence starters. To support discussion, reference the sentence starters on the CSW chart and encourage students to use those sentence starters to help them communicate. The sentence starters can be especially useful for helping students engage in scientific talk, particularly students who may feel reluctant to contribute.

LESSON 2

How similar or different are different species of penguins?

Previous Lesson

We recorded what we noticed and wondered about a fossil of a giant penguin from long ago. We developed initial explanations of how these penguins could be connected to modern penguins. We brainstormed possible mechanisms to help explain two things: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from? We developed a Driving Question Board to guide future investigations.

This Lesson

Investigation

2 DAYS



We analyze data on a set of heritable body structures and behaviors in modern penguins to look for patterns and infer connections among them (and Pedro). We develop questions of how heritable bone structures would compare between these penguins and ancient penguin fossils other than Pedro.

Next Lesson

We will analyze data tables of bone-related structures for ancient penguin fossils and modern penguins, and we will develop a timeline-based representation of the patterns in the data. We will analyze images, maps, and descriptions of the environments of where these fossils formed.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

2.A Analyze and interpret data to find patterns across heritable body structures and behaviors among different species of modern penguins and an ancient penguin.

2.B Ask questions about ancient ancestors of modern penguins based on close analysis of patterns in the body structure and behavior data for modern penguins and Pedro; describe the type of data that would be needed in order to answer some of these questions.

What Students Will Figure Out

- Penguins have heritable external structures like feather color and shape, beak color, and eye ring patterns.
- Penguins have heritable behaviors such as the number of eggs each penguin lays at a time and where they lay their eggs.

- Penguins have heritable internal structures like bones. There is some variation in these across different species of penguins.
- Some species of penguins share many more structures and behaviors in common with other species of penguins than others.

Lesson 2 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	7 min	**NAVIGATION AND BEGIN PROGRESS TRACKER** Introduce the Progress Tracker and determine direction for the class to investigate.	A-B	Driving Question Board, Future Investigations and Data We Need poster, Penguin Timeline model from Lesson 1
2	7 min	**DETERMINE THE TYPE OF DATA NEEDED TO ANSWER QUESTIONS ABOUT CONNECTIONS BETWEEN PENGUINS OVER TIME** Use our Penguin Timeline model to consider immediate ancestors. Identify examples of heritable structures and behaviors and introduce a source of penguin data we can explore.	C-E	Penguin Timeline model from Lesson 1
3	15 min	**EXPLORE A SET OF HERITABLE BODY STRUCTURES AND BEHAVIORS FOR MODERN PENGUINS** Look for patterns of shared body structures and behaviors and organize different species of penguins into groups based on these.	F-J	*Reference: External Structures and Behaviors Key*, 1 strip of penguin stickers, 1 blank sheet of 8.5" x 11" paper, *Data Strips: External Structures in Modern Penguins and Pedro*, *Data Cards for Modern Penguins and Pedro* (optional), 1-2" ball of sticky putty (optional), 1 sheet of chart paper (optional), tape (optional)
4	8 min	**SHARE NOTICINGS OF PENGUIN SIMILARITIES AND DIFFERENCES** Discuss ideas about where the combinations of structures and behaviors shared by the groups came from.	K	paper with annotated grouping of penguins (completed in the last activity)
5	4 min	**ORIENT TO SKELETAL STRUCTURES** Briefly examine several images of bones in order to understand some internal structures that show variation among penguin groups.	L-P	
6	4 min	**RECORD NEW QUESTIONS** Record questions we would like to investigate after learning more about the skeletal structures in penguins and the relationship to structures in our own skeletons.	Q	1 sticky note, *Reference: External Structures and Behaviors Key*, *Data Cards for Modern Penguins and Pedro*, *Data Strips: External Structures in Modern Penguins and Pedro*, 1" ball of sticky putty

End of day 1

Part	Duration	Summary	Slide	Materials
7	5 min	**SHARE NEW QUESTIONS WITH WHOLE CLASS** Share questions that we recorded about internal structures.	R	sticky note with their questions from day 1
8	15 min	**EXPLORE HERITABLE INTERNAL STRUCTURES FOR MODERN PENGUINS AND PEDRO** Work in pairs to sort the penguins based on variations in internal structures.	S-T	1 strip of penguin stickers, *Reference: External Structures and Behaviors Key*, *Reference: Internal Structures Key*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data Cards for Modern Penguins and Pedro* (optional), 1" ball of sticky putty (optional)
9	15 min	**CONDUCT A BUILDING UNDERSTANDINGS DISCUSSION TO SHARE PATTERNS AND MAKE PREDICTIONS** Bring students together in a whole-group discussion to share what patterns they noticed while sorting the penguins.	U	
10	5 min	**MAKE A CLAIM ABOUT PEDRO AND MODERN PENGUINS** Make a claim about whether Pedro is an ancestor to modern penguins and list the evidence students have gathered that support their claim.	V	*New Questions and Ideas for Data We Need*
11	5 min	**NAVIGATION** Record new questions to navigate to the next lesson.	W	*Reference: External Structures and Behaviors Key*, *Reference: Internal Structures Key*, *New Questions and Ideas for Data We Need*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data Cards for Modern Penguins and Pedro*, 1" ball of sticky putty

End of day 2

Lesson 2 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Reference: External Structures and Behaviors Key* • 1 strip of penguin stickers • 1 blank sheet of 8.5″ x 11″ paper • paper with annotated grouping of penguins (completed in the last activity) • 1 sticky note • sticky note with their questions from day 1 • *Reference: Internal Structures Key* • *New Questions and Ideas for Data We Need*	• *Data Strips: External Structures in Modern Penguins and Pedro* • *Data Cards for Modern Penguins and Pedro* (optional) • 1-2″ ball of sticky putty (optional) • 1 sheet of chart paper (optional) • tape (optional) • *Reference: External Structures and Behaviors Key* • *Data Cards for Modern Penguins and Pedro* • 1″ ball of sticky putty • *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* • 1″ ball of sticky putty (optional)	• Driving Question Board • Future Investigations and Data We Need poster • Penguin Timeline model from Lesson 1

Materials preparation (60 minutes)

Online Resources 

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

These are nonconsumables that you will collect and reuse in all your classes:

- Gather the preprinted color copies of *Data Strips: External Structures in Modern Penguins and Pedro* from your kit. There should be one set of 19 data strips and one cover strip clipped together with a binder clip for each pair of students (15 total sets). Or, if you do not have premade data strips from the materials kit, prepare them as follows:
  - Print enough *Data Strips: External Structures in Modern Penguins and Pedro* for half of your largest class.
  - Cut out the strips.
  - Secure each set with a binder clip.
  - Consider laminating the strips since you will reuse them for each class you teach and can keep them year to year.
- Gather the preprinted color copies of *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* from your kit. There should be one set of 19 data strips and one cover strip clipped together with a binder clip for each pair of students (15 total sets). Fold each strip in half so that the external structures and behavior data are on one side of the strip and internal data for the second sorting activity are on the other side

of the strip. Each folded strip can be secured with a paper clip if they are not staying folded. Clip each set back together with a binder clip. Or, if you do not have premade data strips from the materials kit, prepare them as follows:

  - Print enough *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* for half of your largest class.
  - Cut out the strips.
  - Fold each strip in half so that the external structures and behavior data are on one side of the strip and internal data are on the other side of the strip.
  - Secure each set with a binder clip.
  - Consider laminating the strips since you will reuse them for each class you teach and can keep them year to year.
- If your class is using the student editions, students will reference *External Structures and Behaviors Key* and *Internal Structures Key* during this lesson. If you do not have student editions, prepare these keys as follows:
  - Print one of each of the following for every student in your largest class:
    - *Reference: External Structures and Behaviors Key*
    - *Reference: Internal Structures Key*
  - Consider printing these on cardstock and/or laminating them since you will reuse them for each class you teach and can keep them year to year.
- Gather the *Data Cards for Modern Penguins and Pedro* from Lesson 1.

Prepare the penguin stickers as follows:

- Gather the preprinted color copies of the penguin stickers from your kit. Or, if you do not have premade stickers from the materials kit, print in color two sticker strips per student of *Penguin Stickers* onto ¾″ x ¾″ square labels using a zero-inch margin.
- Cut four vertical strips of stickers out of each letter-sized sheet. Each strip will contain 20 total (¾″ x ¾″) stickers: 19 different penguin (modern and Pedro) labels and one blank.
- Each student will use 1 of these strips on day 1 and 1 more of these strips on day 2 when they organize and annotate the patterns they see.

If penguin stickers are not available, there are several other ways students can record their ideas.

- Give each pair of students a piece of chart paper on which to sort the penguin data strips into groups and record their organization by attaching the data strips to the chart paper with tape or sticky putty. Students can annotate directly on the chart paper. If you choose this method, you will need to make extra copies of the data strips so you have enough sets available for each class of students.
- Students may take a photo of the annotated arrangement of their data strips on their desktop or table and share it with their teacher for printing, then they can attach the printout in their science notebook.
- Students can take a photo of their annotated arrangement and transfer the information in the photo to their notebook outside of class time or as part of home learning.

Other consumables

- sticky notes or index cards—1 per student for the exit ticket on day 1
- 8.5" x 11" blank sheet of paper—1 per student
- copies of *New Questions and Ideas for Data We Need*—1 per student

If you have students who are color blind, the comparisons students make in this lesson around different colors of penguin body structures may pose a unique challenge. If you haven't already done so, take some time to talk with your student(s), familiarizing yourself with their way(s) of seeing the world, and ask how you can best support them as they investigate differences among organisms, including but not limited to their color patterns.

Be sure you have materials ready to add the following words to the Word Wall: *heritable*. Do not post this/these word(s) on the wall until after your class has developed a shared understanding of its/their meaning.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

The body structure and behavior variation data used in this lesson were compiled and merged from two resources.

- the supporting online material for *Fossil Evidence for Evolution of the Shape and Color of Penguin Feathers*, published 12 November 2010 in *Science*, DOI: 10.1126/science.1193604
- the appendix published along with Paleogene equatorial penguins challenge the proposed relationship between biogeography, diversity, and Cenozoic climate change. *Proceedings of the National Academy of Sciences*, July 2007, *104*(28): 11545-11550; DOI: 10.1073/pnas.0611099104

Both of these databases were used by Dr. Julia Clarke (one the scientists in the audio recording in Lesson 1) and her collaborators to look for connections between modern penguins and extinct penguin fossils. A subset of this much-larger dataset was selected to use in this lesson to make the data analysis task accessible for students. A supplemental teacher reference that provides the original body structure and behavior IDs in each of these databases is provided in *Extended Key for Penguin Structures and Behaviors*. This document also provides a more detailed description of the body structures and behaviors than what is in the corresponding student keys: *Reference: External Structures and Behaviors Key* and *Reference: Internal Structures Key*.

Students will be working with progressively larger and more complex data sets over this lesson and the next. In this lesson they identify relationships among 19 different penguins using data strips that each list 36 different physical and behavioral characteristics. Large data set analysis work like this is a key element of engaging in analyzing and interpreting data and looking for patterns at the middle school level. This data analysis work will continue in the next lesson when students look for patterns across time and geography for a larger set of ancient penguin fossils. As we add these additional data points, this combined data set will be the largest and most complex one students will have worked with in the middle school program, but since they also have worked with progressively more complex data sets over the scope of the entire program, they should now be well positioned to work with this most complex data set at the end of 8th grade.

This lesson draws on students' knowledge of genes and traits from *Unit 8.5: Why are living things different from one another? (Muscles Unit)* to establish that the structures and behaviors students are comparing in penguins are heritable. The heritable body structures and behaviors that students look at in Lessons 2-5 are introduced with the caveat that they are "largely heritable". Students will know from their work in the *Muscles Unit* that genetically inherited traits can be influenced by environmental factors (e.g., limited amount or type of food or particular nutrients as building blocks available for an individual; so the environment will always have some effect on the amount of variation we see for that trait between two individuals). With that caveat, students will already have familiarity with many of the external structures (such as feather color and shape, beak color, eye ring and eyebrow patterns) being largely heritable as well as some internal body structures, such as bone length.

Where We Are NOT Going

The knowledge of genes and traits that students bring from the *Muscles Unit* will be sufficient to establish that the variations they're seeing in penguins are largely determined by genes. It is possible, however, in making connections to genes and traits that some students may ask for genetic data as well (or they may have suggested that idea at the end of the previous lesson). While genetic data on modern penguins (as well as some ancient ones) are part of the original phylogenetic data sets cited above, students will not be analyzing genetic information nor using such data in subsequent explanations and models. The structure of genetic information and how it can be used to establish lines of descent and common ancestry is related to a set of disciplinary core ideas reserved for high school and is not the focus of this unit.

Students will need to use the idea that the penguin structures studied in the lesson are related to genes, but they may try to extend the idea that they developed in the *Muscles Unit* to conclude that variations between penguin species are caused by having different alleles. This has the potential to be confusing because terms used to describe and compare different individuals of the same species of penguin (e.g., traits, alleles, different versions of specific genes) are not used to describe and compare the differences between species of penguins. When comparing across species, we use the broader terms *body structure* and *behavior*. Occasionally, we also broadly use the term *characteristic*. If students use the term *trait* instead of body structure, behavior, or characteristic, it is not important to redirect them at this point. Note that evolutionary biologists use the term *character* to describe observable features across species, but we chose not to use that word in this unit in order to avoid potential confusion with the many other definitions of *character* that students will already know.

If students are attempting to use alleles to explain differences between species of penguins, agree that there are small differences regarding the genes, and those differences cause the traits of individual penguins to be different, but reinforce the idea that we are comparing different species of penguins not different penguins of the same species.

Also, you may remind students that many of the characteristics we are looking at depend on more than one gene, so it would be too complicated to try to keep track of all the alleles involved.

LEARNING PLAN FOR LESSON 2

1. Navigation and begin Progress Tracker. 7 MIN

Materials: science notebook, Driving Question Board, Future Investigations and Data We Need poster, Penguin Timeline model from Lesson 1

Connect to questions and ideas from the previous class. Have **slide A** displayed as students enter the classroom and ask them to stop by the Driving Question Board, Future Investigations and Data We Need poster, and Penguin Timeline model. Students should look at the groups of questions, ideas for investigation, as well as the ideas we've recorded on the timeline.

As class begins, say, *At the end of our last class we captured a lot of questions about how the penguins from long ago could be connected to penguins alive today. We also started to think about what data we need to see and some ideas for investigations that would help us get that information. As you looked back to the DQB and the Penguin Timeline model when you came in, you may have thought of new or additional ideas for investigations. If that is the case, record those ideas in your notebook now.*

Propose starting a Progress Tracker to keep track of ideas. Say, *As we are looking at this timeline, the questions we had, and the ideas for investigations we thought of so far, it's also clear there are many things that we have already started to figure out, and we didn't yet get a chance to add them to our Progress Tracker. Let's take some time to do that now, and it will also refresh our memories so we can get a productive start on some of these investigation ideas today.*

Science Notebook



If you haven't already, direct students to set aside 20 pages (10 pages front and back) at the end of their notebook to use for the Progress Tracker.

Start the two-column Progress Tracker in students' science notebooks. Ask students to turn to the section in their notebook reserved for their Progress Tracker and create their two-column Progress Tracker as you show **slide B**.

Say, *When we were creating our explanation at the end of the last lesson, we realized we would need to collect a lot more evidence. If we had a place to keep track of all the ideas and patterns that we might eventually use as evidence to support our claim, that would be really helpful. Let's title the second column for that purpose: "What did I see or uncover in the data?"*

Ask students to label the columns as shown on the slide: What do we know about different penguins? What do we know about how they are similar and different?

Have students focus on the Penguin Timeline model to help them recall looking at the penguin data last time and identify ideas and patterns that should go into the Progress Tracker.

Say, *Think about the ideas and patterns we uncovered when looking at the cards for different penguins and creating this timeline. What important ideas or patterns did we see in the data about how the different penguins are similar and different?*

Give students 3-5 minutes to record ideas in their Progress Tracker, while you circulate around the room to see students' thoughts so you'll be able to summarize them when you come back together.

In this example two-column Progress Tracker row, each column has been completed with possible student ideas.

Question	What did I see or uncover in the data?
What do we know about different penguins? What do we know about how they are similar and different?	• There are a lot of different penguins alive today. • There are different ways to group the penguins, such as by location or size. • All the penguins have a lot of characteristics in common even when they aren't the same species of penguin. • We don't know much about Pedro (so we want to investigate more). • Based on what we do know about Pedro, there are some similarities between him and modern penguins.

Additional Guidance

The purpose of this Progress Tracker is to keep track of our ideas, data, and patterns over the course of the storyline that we can later use as evidence to support our claims. In the case of this lesson, another use for the tracker is to recall what happened in the previous lesson and navigate into the current lesson. The tracker also serves as a way to allow students to get comfortable and become confident recording in their own words the ideas they come up with as a class (rather than waiting to copy down the teacher's notes). For this reason Progress Trackers should not be graded and should allow for a way for students to record their ideas. The example provided is just a sample entry of what we predict some students might say based on a class discussion.

Summarize students' ideas to move the class to the next step. Say something like, *We have a lot of ideas about how penguins today are similar and different, and we want more information.*

2. Determine the type of data needed to answer questions about connections between penguins over time. 7 MIN

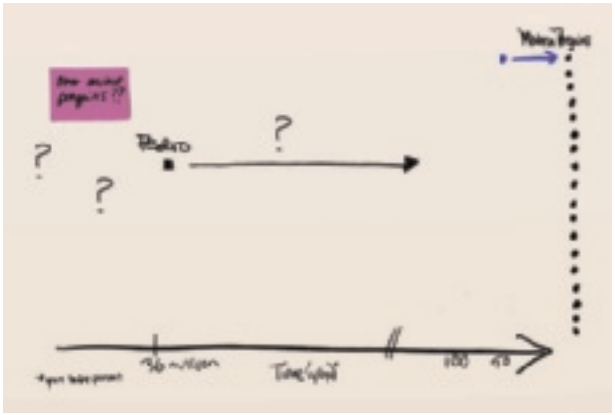
Materials: Penguin Timeline model from Lesson 1

Distinguish between recent and ancient penguins. Refer students to the Penguin Timeline model we created in Lesson 1. Say, *At the end of the last lesson one question we had was, "Where did all the different species of modern penguins come from?" But we also wanted to know where the penguins in the past went and if or how ancient penguins like Pedro are connected to penguins that are alive today.*

Suggested prompts	Sample student responses
Though we aren't sure of how penguins today could be connected to particular penguins in the past, like Pedro from millions of years ago, we do have a pretty good idea about how an individual penguin, let's say, born this year, got here, right? Where did that penguin come from?	*It hatched from an egg.* *It came from its parents.* *When the penguin parents mate, an egg gets fertilized. The female penguin lays a fertilized egg, and that is where the baby came from.*

***Attending to Equity**
Universal Design for Learning: This citation of another scientist's contributions to the data set that students are about to work with can help increase the *relevance* of the work students will be doing. They can (a) see that many scientific efforts require collaboration of multiple scientists or draw on the contributions of many scientists and/or (b) see themselves as having an

On the Penguin Timeline model, add a dot to the left of one of the "modern penguins" dots. Connect these two dots (representing penguins alive today and the parents of those penguins) using an arrow pointing right. Use prompts such as the following to discuss connections between parents and offspring.

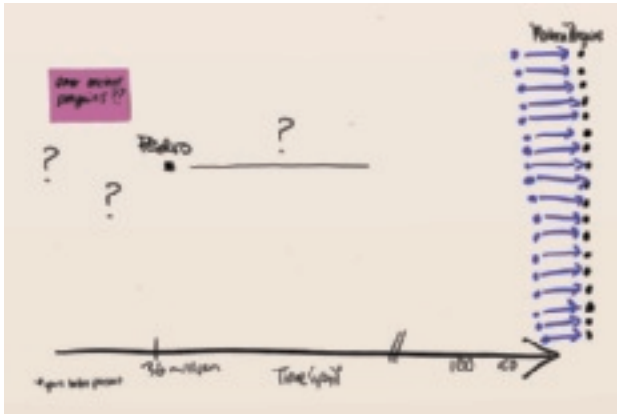


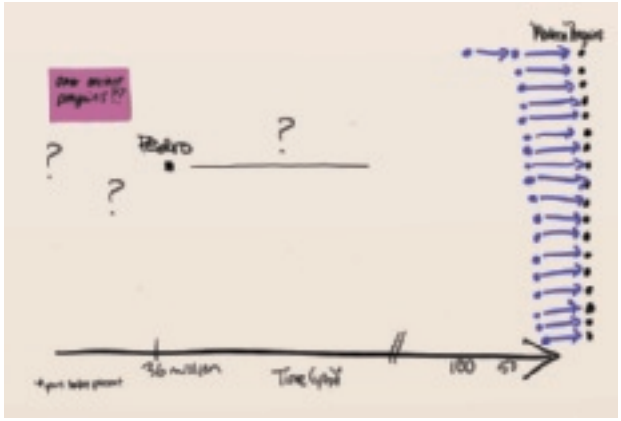
opportunity to contribute to the larger scientific enterprise in the future in a way similar to the work they are doing in class today.

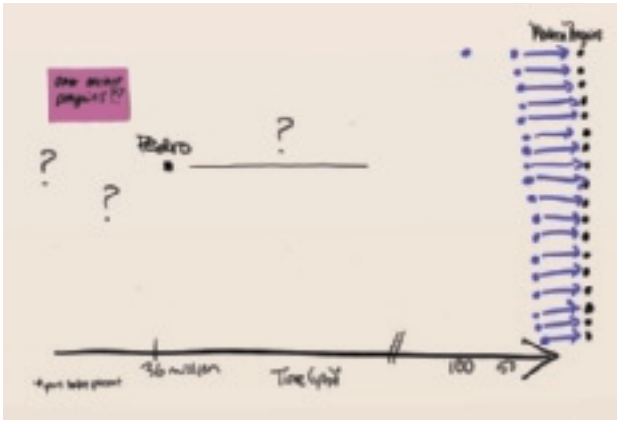
Suggested prompts	Sample student responses
Let's make some claims about the relationship between parents and offspring. Let's say a chick is born and its parents are emperor penguins, then what kind of penguin would the chick be?	*An emperor penguin.*
And what about a different kind of penguin? Let's say a chick is born and it's an Adélie penguin, then what kind of penguins are its parents?	*Adélie penguins.*
The species of penguins we saw on the penguin cards mate with their same species of penguin. So, would we expect two of the same species of penguin parents to randomly give birth to chicks of any of the other seventeen different kinds of penguins?	*No. Parents will have chicks that are the same species of penguin that they are.*

Say, *So we could represent these recent ancestors by adding some dots and arrows like this. A dot represents a generation of that species of penguin, not just a single penguin. And an arrow represents which species of penguins had which offspring.* Return to the Penguin Timeline model and add a dot immediately preceding each dot that represents a group of modern penguins. Add small arrows connecting those dots to the modern penguins.

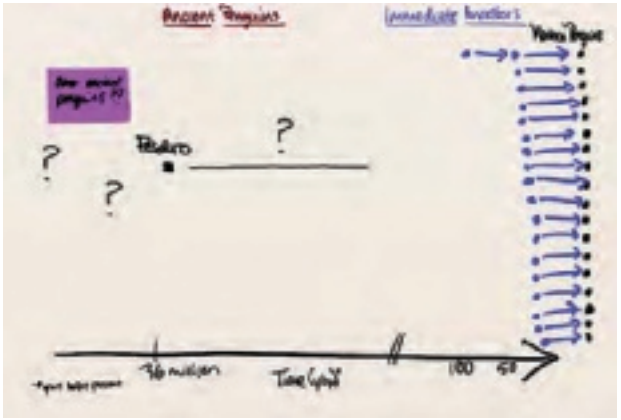
Choose a dot representing one of the parent penguins and add a dot to the left of that one. As students discuss this relationship using the prompts below, also add the arrow.







Suggested prompts	Sample student response
OK, so what about a dot like this? When we connect it with an arrow to the dot to the right, what is that showing?	*It would be the same kind of thing—the dot shows the parents of that group of penguins, or the grandparents of the penguins alive today.*



Say, *OK, so it seems like we can easily explain* ***these*** *ancestors* (refer to the timeline showing the recent ancestors we have just explained). *But we have a lot more questions about the penguins that existed way back here* (refer to the part of the timeline model showing millions of years ago). *Let's add some terminology to help us be able to talk about these different groups more clearly. We'll call the penguins that were living within the last hundred years or so that have a line of descendants alive today—that is, the parents, grandparents, great grandparents, and so on of modern penguins—the "immediate ancestors".* Add "Immediate Ancestors" to the Penguin Timeline model to label the section of the model that goes back a hundred years or so.

Say, *When we are considering a penguin like Pedro from millions of years ago, we'll continue referring to those as "ancient penguins".* Add an "Ancient Penguins" label to the section of the Penguin Timeline model indicating the time these penguins lived is everywhere to the left of the *x*-axis break.

Additional Guidance

Students might wonder why we are going back only about 100 years for the immediate ancestors. You could remind students, as mentioned in Lesson 1 when we set up the Penguin Timeline model, the choice to mark 50 and 100 years as our "recent past" is connected to how long people have been observing and recording measurements of body structures of penguins. For some species of penguins that record goes back more than 50 years, while for other species

it does not. Also, since we aren't sure yet how far back this pattern goes, we will want to gather more evidence before we can follow it farther back.

Consider evidence we would want to collect to support connections between modern penguins and their immediate ancestors. Display **slide C.** Continue to refer to the dots on the Penguin Timeline model and use prompts such as the following—some of which are on the slide—to discuss evidence we would need to make a claim about the connection between modern penguins and their immediate ancestors.

Say, *We're trying to figure out how today's penguins could be connected to penguins from the past.* As you pose the first question, refer to the timeline dots that represent the parents of current penguins and then to the current penguins.

Suggested prompts	Sample student responses
If we did not witness the parent penguins giving birth or caring for any of the current penguins and we wanted to determine which species of penguin the offspring is, what evidence would we want to collect?	*We would see what it looks like and match it to the species of penguin that looks most similar.* *If there were several kinds that looked very similar, we might look at how the parents and offspring act or where they live.*
What if we wanted to see how modern penguins are related to moredistant ancestors that still fall within the "Immediate Ancestor" time frame, like say, great-great-great-grandparents, what evidence would we want to collect?	*We would look for the same kinds of things—we look at the records of the characteristics of the possible great-great-great grandparent penguins and try to find the penguins that looked most like the modern one we're wondering about.*
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?	*We would need to look at characteristics that are mostly inherited because that's what we know can be passed down from generation to generation.*

Say, *Yes, to see how penguins might be connected to their ancestors, we would need to compare characteristics that are mostly inherited genetically, or heritable. We have already compared some characteristics of penguins alive today, but we have not specifically looked at ones that we know are heritable.*

Continue, *Let's remind ourselves what it means for a characteristic to be heritable. We learned in the Muscles Unit that trait variations are always impacted by* ***both*** *genes and the environment, but those factors don't always have equal impact. Sometimes genes have a greater impact on trait variations and sometimes the environment has a greater impact.*

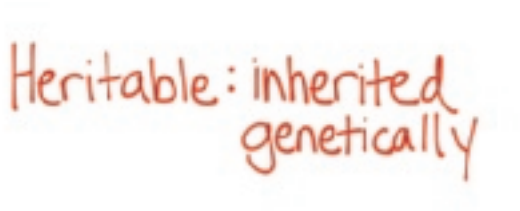
Additional Guidance

We are looking into heritable body structure and behavior variations in Lessons 2-5 with the caveat included that they are "largely heritable". We know that even these characteristics can be influenced by environmental factors (e.g., limited amount or type of food or particular nutrients as building blocks available for an individual; so the environment will always have some effect on the amount of variation in a trait we see between two individuals).

Revisit the examples of heritable traits we've studied before. Go to **slide D.** Say, *These are some of the organisms we looked at in the Muscles Unit.*

Suggested prompt	Sample student responses
What were some trait variations in these organisms that we argued were mostly heritable, meaning that the environment played a relatively minor role in the variation we saw in the trait between individuals?	*Extra-big muscles in cattle.* *Coloring in some cases (e.g., petals, scales, seeds) but not others (e.g., flamingos' pinkness).* *Length of our arm spans.*

Take a moment to co-construct a definition of *heritable* and add it to the class Word Wall. An example definition is "inherited genetically."



Connect these ideas to penguins.* Show **slide E** and say, *Scientists like Dr. Sara Bertelli have collected data on body structures and behaviors of penguins. Some of those characteristics, like feather color, are similar to the external structures you mentioned from other organisms. The body structures and behaviors these scientists collected data about are also largely heritable ones. That is, these are body structures and behaviors for which the environment plays only a minor role in the variation we see. Like being heavily muscled in cattle or having a certain scale color in goldfish, the physical characteristics these scientists looked at are based mostly on the genetic information the organism received from its parents. Dr. Bertelli and her team collected data from the eighteen species of modern penguins.*

Continue, *Researchers like Julia Clarke and Ali Altimanaro build on data sets like this to try to figure out how penguins of today are connected to penguins of the past.*

3. Explore a set of heritable body structures and behaviors for modern penguins.

15 MIN

Materials: *Reference: External Structures and Behaviors Key*, 1 strip of penguin stickers, 1 blank sheet of 8.5" x 11" paper, *Data Strips: External Structures in Modern Penguins and Pedro*, *Data Cards for Modern Penguins and Pedro* (optional), 1-2" ball of sticky putty (optional), 1 sheet of chart paper (optional), tape (optional)

Explore a set of penguin body structures for which scientists have gathered data. Display **slide F.** Say, *Here is a subset of some of the heritable structures and behavior data Dr. Sara Bertelli collected for modern penguins. There is also information about Pedro for some of these characteristics. For example, in the podcast, we heard about evidence that Pedro had scale-like feathers, which you can see is the first body structure listed. This table shows nineteen external body structures and behaviors in five different groups.*

Show **slide G.** Say, *For each body structure or behavior, there are different possible variations found in the modern penguins, which will be shown with this table in a key I will pass out. For example, for head plumes, there are penguins that have head plumes and there are penguins that do not. So, the variations in this body structure will be reported as either present—noted in the key with a number one—or absent—noted by a zero. You can see on the slide examples of penguins with and without a plume.*

***Supporting Students in Engaging in Analyzing and Interpreting Data**

Students need to find patterns in this rather large set of data. While they have been working with progressively more complex sets of data throughout middle school, the volume of information here may still intimidate some students.

If students are struggling to group the strips, make sure they are laying them all out to view

Show **slide H**. Say, *Other external body structures and behaviors may have more than two variations possible. For example, for the color of the top of the feet, there are four different variations found in penguins: dark coloration, pinkish coloration, orange coloration, or whitish coloration. These are just two examples of the type of structure and behavior variations you will see in the key for these nineteen different heritable external body structures and behaviors.*

Additional Guidance

Students will need to use the idea that the penguin structures included in the lesson are related to genes, but they may try to extend the idea that they developed in the *Muscles Unit* to conclude that variations between penguin species are caused by having different alleles. This has the potential to be confusing because terms used to describe and compare different individuals of the same species of penguin (e.g., traits, alleles, different versions of specific genes) are not used to describe and compare the differences between species of penguins. When comparing across species, we use the broader terms *body structures* and *behaviors*. Occasionally, we also broadly use the term *characteristic*. If students use the term *trait* instead of body structure, behavior, or characteristic, it is not important to correct them at this point.

If students are attempting to use alleles to explain differences among species of penguins, agree that there are small differences regarding the genes, and those differences cause the traits of individual penguins to be different, but reinforce the idea that we are comparing different species of penguins not different penguins of the same species.

Also, you may remind students that many of the characteristics we are looking at depend on more than one gene, so it would be too complicated to try to keep track of all the alleles involved.

Sort penguins based on external structure and behavior data. Display **slide I**. Say, *Let's look for any similarities and differences of these heritable structures and behaviors across all the different species of penguins of today and Pedro. I first will distribute data strips to you that show for each penguin species the number of the variation it has for particular external body structures and behaviors. You can use the key I will also give you to help you know what the variations are. You will have time to work in pairs to sort the strips based on the variation numbers. There is no right or wrong way to sort these data strips. The goal is to get more familiar with the data and start to identify some similarities and differences of penguin structures and behaviors.*

Assign students to work in pairs to organize data based on external structures. Distribute *Reference: External Structures and Behaviors Key* to every student. Distribute one set of *Data Strips: External Structures in Modern Penguins and Pedro* to each pair and have them begin sorting the data.*

As students are working in pairs, circulate and listen to discussions to capture ideas that will be useful to build on during the class discussion. If students are only discussing the structures and behaviors in terms of the numbers that indicate the variation type, occasionally ask, *What does that mean in terms of how the penguin looks or acts?* to help students recognize the connection between the numbers and the external structures and behaviors.

Alternate Activity

After about five minutes of partner work, ask if any pairs also want the *Data Cards for Modern Penguins and Pedro*. If so, distribute the cards to them along with a 1" ball of sticky putty for breaking into pieces and using to secure each data strip to the edge of its corresponding data card if they wish.

simultaneously. There are many structures and behaviors that are shared, so encourage them to notice the *differences* first, and then they can look for the *shared differences*, i.e., things that are similar among them but different from the rest of the penguin groups. For example, it isn't necessarily productive to focus on the external body structures and behaviors that are shared by all the penguins (like scaly feathers), so have them focus on differences and then find out who shares those same differences.

Additional Guidance

If students are struggling to go back and forth between the key and the data strips, have them first organize just by looking among the numbers on the strips. Then, encourage them to return to the key and discuss what the numbers mean in terms of body structure and behavior variation.

After students work with the data strips for about ten minutes, ask them to pause their sorting work.



Announce that you will now distribute a set of 19 penguin stickers and a blank sheet of 8.5" x 11" paper. Show **slide J**. Say, *Prepare the blank paper as shown in the slide to record what patterns you notice.* Each student will get their own set of stickers to add to their paper as a way to record how they clustered and organized the penguin data so far. Tell students that they have 3 more minutes to finalize their sort and record their groupings.

Remind students to annotate the groupings of penguins as well as to include notes about the similarities and differences that informed each grouping.

If students feel like they do not have enough time, reassure them that there is no right or wrong way to sort the penguins at this point and that the goal is to simply to start to find some similarities and differences of penguin structures and behaviors. Assure them that they will have more time to look at the data. If students spend extra time with the data strips at this point, they may no longer be interested in the data strips when they look at them again, both later in this lesson and in Lesson 3. Students should keep the paper with annotated grouping of penguins for the following discussion. After the discussion, they can be collected as an assessment.

Alternate Activity

If penguin stickers are not available, there are several other ways students can record their ideas.

- Give each pair of students a piece of chart paper on which to sort the penguin data strips into groups and record their organization by attaching the data strips to the chart paper with tape or sticky putty. Students can annotate directly on the chart paper. If you choose this method, you will need to make extra copies of the data strips so you have enough sets available for each class of students.
- Students may take a photo of the annotated arrangement of their data strips on their desktop or table and share it with their teacher for printing, then they can attach the printout in their science notebook.

- Students can take a photo of their annotated arrangement and transfer the information in the photo to their notebook outside of class time or as part of home learning.

Assessment Opportunity

2.A.1 Analyze and interpret data to find patterns across heritable body structures and behaviors among different species of modern penguins and an ancient penguin.

What to look for: Students do not need to have sorted the penguins in any particular way or found a specific pattern. Rather, look for students to have clearly organized the penguins based on some individual body structures or behaviors (or a combination of those) to demonstrate that they have been able to analyze the data in order to identify some patterns in the external structures and behaviors of penguins.

What to do: If there is no clear distinction between groups of penguins that students create, respond with questions such as the following: *Are some of these penguins more similar than others? In what ways? How can that be shown through organizing them?* Keep note of students who struggled to find patterns and organize the penguins on day 1 so you can visit them while sorting on day 2 to ask similar questions and monitor their progress.

4. Share noticings of penguin similarities and differences. 8 MIN

Materials: science notebook, paper with annotated grouping of penguins (completed in the last activity)

Share ideas about penguin similarities and differences we noticed. Show **slide K.** Give students a minute or two with their partners from the previous activity to consider the questions on the slide:

- 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?

Bring students back together and say, *Let's share some of what we noticed when we sorted the data strips.*

Suggested prompt	Sample student responses
What penguins did you and your partner notice were similar?	*Emperor and king penguins share the same variations for all these structures and behaviors except one.* *Others like macaroni, southern rockhopper, and royal have all the same structures and behaviors in common.* *Erect-crested, snares, and northern rockhopper also have all the same structures and behaviors in common.*

Suggested prompt	Sample student responses
OK, so those groupings of penguins matched for all the structures and behaviors we compared in the data strips. Does that imply that they have every single heritable characteristic in common? Remember that we looked at only a subset of the heritable structures and behaviors that scientists Julia, Ali, and Sara use to look for these sorts of connections.	*(Accept all responses.)*
Did they look identical in the sticker images or the data cards from Lesson 1, if you remember the images in those?	*No.*
What are two species of penguins that are pretty different?	*(There are multiple possible answers, for example, Galápagos and Emperor.)*

Have students put their names on their paper with annotated grouping of penguins and collect the papers.

Motivate the need for an additional set of body structures. Say, *We compared external structures and behaviors among different species of modern penguins. We also compared external structures in modern penguins to Pedro.*

Suggested prompts	Sample student responses
Do we feel better prepared to explain where modern penguins came from and ancient penguins like Pedro went?	*We saw some similarities between some modern penguins and Pedro, but it does not seem like enough information to help us know where modern penguins came from and where ancient penguins went.*
Are there other data that could help us better understand?	*We need more information about heritable characteristics of Pedro and any other ancient penguins.*
There were a lot of question marks on the data strip for Pedro. Why do you think there wasn't more information about Pedro?	*We know from what Dr. Clarke said that if we look for fossils, it's very rare to find evidence of features like feathers because they are rarely preserved. Her team was lucky with Pedro.*
What parts of an ancient penguin like Pedro might be more likely to be preserved?	*Their bones.*

Connect to prior work with internal heritable traits work in the *Muscles Unit*. Say, *In addition to heritable structures that are external, we've previously studied some internal structures that we know are largely heritable too. In the Muscles Unit you figured out that some aspects of musculature and bones are heritable. While muscles don't preserve well in fossils, bone structures do. Let's orient ourselves to some of the bone structures in penguins and other animals that Dr. Bertelli and other researchers have determined are largely heritable.*

5. Orient to skeletal structures.

4 MIN

Materials: None

Orient students to the skeletal structures for the penguins. Spend only 30-45 seconds on each of the next five slides for this orientation. Say, *Let's look at some of the heritable skeletal structures for the penguins that we have internal structure variation data for.* Present **slide L.** Say, *One of the structures listed here is the shape of the tip of a penguin's beak. We also analyzed data on this structure earlier in the external structures data set. But we did not already analyze other, nearby internal heritable structures, like the shape of the side of its skull.*

Additional Guidance

The depressed part of the skull pointed out on **slide L** is called the *temporal fossa.* Medical terms and Latin names like this are not used in the student resources. They have been replaced with alternate descriptions using less-precise but more commonly encountered words. If you are curious about the Latin or scientific names for some of these structures, further detail is provided in the teacher reference *Extended Key for Penguin Structures and Behaviors*.

Present **slide M.** Say, *We also have data about structures related to the shoulder blade. This image shows where the shoulder blade bone is located in both a penguin and in us humans. You can also try to feel the surface of your shoulder blade on your own body if you wish. Notice how the position of that bone changes as you move your arm in different ways.*

Present **slide N.** Say, *You will also see data about structures in the leg and foot, specifically variations in the kneecap, lower leg bone, and upper foot. This image shows where some of these bones are located in a penguin and in us. It's easy to feel your kneecap and upper foot; those bones are pretty close to the surface in our bodies.*

Present **slide O.** Say, *We also have variation data about a bone called the humerus. This image shows where this bone is located in us and in penguins. The humerus is the bone in the upper part of our arm. Our biceps muscles are on one side of the bone and our triceps muscles are on the other. These muscles attach to other bones in the arm, too. Other muscles also attach the humerus to the shoulder blade and other bones in our chest and back.*

Present **slide P.** Say, *Remember that the numbers represent variations in the particular body structure. For example, for the structure of the "size of the projection on the shoulder blade where the biceps are attached," a zero means "greatly expanded" and a one means "moderately expanded." So this part of the bone is going to be wider here for some penguin species than others.* Use the slide image and red arrows to demonstrate what is meant by expansion of projection of this part of the shoulder blade.

6. Record new questions.

4 MIN

Materials: 1 sticky note, *Reference: External Structures and Behaviors Key*, *Data Cards for Modern Penguins and Pedro*, *Data Strips: External Structures in Modern Penguins and Pedro*, 1" ball of sticky putty

Capture new questions as exit tickets. Show **slide Q**, pass around a sticky note pad for each student to take one note, and say, *Next time, we'll look at these internal body structure variations in modern penguins and Pedro. Before we do, record on the sticky note any new questions you have along with your name.*



Prepare data strips and data cards for the next class. After students have had 3 minutes to record their questions, ask students to do the following:

- Remove any sticky putty from the data cards and data strips.
- Secure the entire set of data strips together with a binder clip.
- Secure the entire set of data cards together with a binder clip.
- Turn these in along with *Reference: External Structures and Behaviors Key* to reuse with the next class.

Collect students' sticky notes to formatively assess the questions students are raising at this point in the lesson. If you haven't already done so, also collect the paper on which students recorded the structure and behavior patterns earlier in the lesson. Be prepared to return the sticky notes to students for the beginning of day 2.

Assessment Opportunity

2.B.1 Ask questions about ancient ancestors of modern penguins based on close analysis of patterns in the body structure and behavior data for modern penguins and Pedro; describe the type of data that would be needed in order to answer some of these questions.

What to look for: Look for a line of new questions emerging from the sources of data they investigated today, including any of the following ideas:

- how similar internal structures are in the penguins (or in other organisms)
- how internal structures might be related to function
- how the patterns in the internal structures they have in common could help us figure out which species of penguins may have had a common ancestor

Note that students will likely describe how examining bone structures across different species of penguins will help them make progress on some of these questions on day 2.

What to do: If you see no internal structure-related or bone-related questions, it is appropriate to leave a question on the sticky note such as this: Did you have any questions based on what you think might be similar or different in the shape or size of internal structures in different species of penguins?

End of day 1

7. Share new questions with whole class.

5 MIN

Materials: sticky note with their questions from day 1

Share new questions with the whole class. Have students retrieve the sticky note they turned in last time on which they recorded their new questions at the end of day 1. Present **slide R**. Summarize by saying, *Last time, we looked at external structure and behavior variations in modern penguins and Pedro.*

Allow students a minute or two to look back at their questions. Then ask students to share their responses to the following questions that are listed on the slide:

- 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?

8. Explore heritable internal structures for modern penguins and Pedro. 15 MIN

Materials: 1 strip of penguin stickers, science notebook, *Reference: External Structures and Behaviors Key*, *Reference: Internal Structures Key*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data Cards for Modern Penguins and Pedro* (optional), 1" ball of sticky putty (optional)

Prepare to explore a set of heritable internal structure data for modern penguins. Display **slide S.** Say, *Let's look for any connections across the different species of penguins for these additional data about internal structures that we introduced to you last time. We'll look at all the modern penguins and Pedro.*

Additional Guidance

Students may ask about how you measure the bones of a living penguin. In the case of modern species of penguins, scientists often take bone measurements from penguins that have recently died. So these measurements are still from modern species of penguins, but those individual penguins are no longer alive.

Sort penguins based on internal structure data. Ask students to turn to the next two blank pages of their science notebook. Show **slide T.** Say, *You will have 12 minutes to work with a partner to analyze and sort the data. Prepare these pages in your science notebook to record the patterns you notice.*



Hold up one of the data strips as an example. Say, *You will see that the data strips are folded in half so that you can start the sorting based on only the internal structures data first. This is the side that says "internal" by the species name. You may also notice that the internal structures are coded with double letters whereas the external structures we saw last time have single letters. Keep the "internal" side of the strips facing you to start with as you sort and organize the penguins to find patterns in the internal structures data.*

After you've sorted based on these internal structures data, you can unfold the data strips to look at the external data from last time in combination with the set of internal data. See if you notice any new patterns.

When you have analyzed enough data to sort the penguins into groups, raise your hand to ask for another set of penguin stickers to use in your notebook to make an annotated record of how you sorted them. Remember that we may not all end up with the same way of sorting, and that is OK. Having a variety of ways the data are analyzed can help us learn more.

Assign students to work in pairs to organize data based on internal and external structures. Distribute to each student one copy each of *Reference: External Structures and Behaviors Key*, *Reference: Internal Structures Key*, and to each pair the folded data strips from

Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro. As students are working in pairs, circulate to listen in for ideas that will be useful to build on during the class discussion. Give the class time updates so that they can begin finalizing their sort and placing their stickers in time to finish within the time window. Students will have another opportunity to sort these data, so avoid data fatigue by working within a limited time frame for this sort. If students feel rushed, assure them that they will have more time with the data strips in the next lesson.

While students are working, they may again request the penguin data cards from Lesson 1. If so, distribute the cards and sticky putty and encourage students to attach their data strips to the penguin data cards with the sticky putty.

9. Conduct a Building Understandings Discussion to share patterns and make predictions. 15 MIN

Materials: science notebook

Share patterns and ideas that were noticed during the sorting activity. Bring students together and ask them to share what they noticed when they sorted the data by internal structures as well as what they noticed when they unfolded the data strips and also looked at the external data.

Suggested prompts	Sample student responses
What patterns emerged as you and your partner began sorting the data strips based on only internal structure data?	*Some species of penguins share a lot of identical variations across all these internal structures.* *The modern ones fall into three groups that share all the same internal structures. One group is emperor and king. A second group is African, Magellanic, Humboldt, and Galápagos. And the third group is the rest.*
Did the penguins in these groups also tend to share external structures and behaviors in common too, like the feather and nesting you looked at earlier?	*Yes.*

Connect patterns to ideas of inheritance and ancestry. Present **slide U**. Ask students to work with their partner to discuss the three questions posed on the slide for three minutes and then discuss these as a class.

1. What are two species of penguins that have the same variations in common for almost all the heritable body structures you compared?
2. Where did these penguins inherit their body structures from?
3. Why would they have so many heritable body structures in common?

Suggested prompt	Sample student responses
What are two species of penguins that have the same variations in common for almost all the heritable body structures you compared?	*Emperor and king.* *African and Magellanic.* *Magellanic and Humboldt.* *Humboldt and Galápagos.*

Suggested prompts	Sample student responses
Where did these penguins inherit their body structures from?	*From their parents.*
And where would their parents have inherited them from?	*From their parents, the grandparents of the current generation.*
Why would they have so many heritable body structures in common?	*Maybe they are part of the same family of penguins, just different parts of the family, like distant cousins.* *Maybe they had an ancestor in common at some point in the past, like a great-great-great grandparent.* *Maybe their environments are very similar or were very similar in the past.*

10. Make a claim about Pedro and modern penguins.

5 MIN

Materials: *New Questions and Ideas for Data We Need*



Reflect on whether Pedro could be an ancient ancestor of any modern penguins. Distribute *New Questions and Ideas for Data We Need*. Say, *We had raised the idea before about what the ancient ancestors of the modern penguins might have looked like. And, we've wondered how Pedro might be connected to modern penguins. So do you think Pedro could be an ancient ancestor of any of the modern penguins? Why or why not?* Show **slide V.** Say, *Record your thinking on the handout.*

Assessment Opportunity

2.A.2 Analyze and interpret data to find patterns across heritable body structures and behaviors among different species of modern penguins and an ancient penguin.

What to look for: The questions on *New Questions and Ideas for Data We Need* are "Do you think Pedro could be an ancient ancestor of any of the modern penguins? Why or why not?" You will look for the following on the student handouts you collect at the end of this day:

- Any claim is acceptable (e.g., Pedro is an ancestor, is not an ancestor, is related in some other way to modern penguins or other ancient penguins, and so forth).
- Justification should include citing patterns in the heritable body structure data:
  - Pedro's entire set of known body structure variations doesn't match any of the modern penguins.
  - If students say he is not related (or not an ancestor), they should discuss the amount of body structure variation that would need to match or be similar enough in order for them to be related. Ideally, students may also raise a potential problem with this logic, since it implies that you can only be related if you match on every or most heritable characteristic, *but* there are examples in humans or cattle (from the *Muscles Unit*) that they know about that refute that.

- If they say he is related or might be related, they should discuss how that is possible given he has so few body structure variations in common with any modern penguins and include some kind of connection between the number of characteristics in common and relatedness (e.g., might be a distant ancestor because distant ancestors might be less like future generations than more-immediate ancestors).

What to do: If they don't cite evidence based on the body structure variation data in the strips, then ask this general question on the handout: *What particular patterns in the body structures that you compared led you to make this argument?*

11. Navigation

5 MIN

Materials: *Reference: External Structures and Behaviors Key*, *Reference: Internal Structures Key*, *New Questions and Ideas for Data We Need*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data Cards for Modern Penguins and Pedro*, 1" ball of sticky putty



Record questions to navigate to the next lesson. Present **slide W.** Have students record on *New Questions and Ideas for Data We Need* their new questions and ideas for data we need to answer some of the questions.

Prepare data strips and data cards for the next class. Ask students to do the following:

- Remove any sticky putty from the cards and strips.
- Refold (and paper clip, if they were used) the data strips from *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*.
- Secure the entire set of data strips together with a binder clip.
- Secure the entire set of penguin cards together with a binder clip.
- Turn these in along with *Reference: External Structures and Behaviors Key* and *Reference: Internal Structures Key* to reuse with your next class.

Collect *New Questions and Ideas for Data We Need* to formatively assess the questions students are raising at this point in the unit and what claims they made about Pedro. When you return it to students next time, have them trim it and tape it into their notebook so they have a record of this thinking.

Assessment Opportunity

2.B.2 Ask questions about ancient ancestors of modern penguins based on close analysis of patterns in the body structure and behavior data for modern penguins and Pedro; describe the type of data that would be needed in order to answer some of these questions.

What to look for: Look for any line of new questions that emerge related to how similar internal structures are in the ancient penguins (or in other organisms). This implies the need for comparing the same sort of data next time that they looked at today, but for more ancient fossils.

What to do: If you see no internal structure-related or bone-related questions, it is appropriate to leave a question on the handout, such as this: What sort of questions do you have that could help connect Pedro and modern penguins? How might exploring data for those body structures help answer your questions?

ADDITIONAL LESSON 2 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.8.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.

In this lesson, students collaborate with a partner to analyze data about internal and external body structures of penguins. The partners must discuss the data as they compare them, expressing their own ideas and building on their partner's ideas. At several points in the lesson partnerships then also share their findings with the whole class.

LESSON 3

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

Previous Lesson

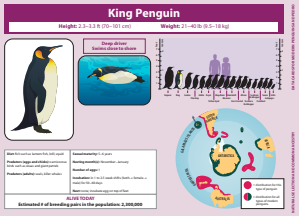
We analyzed data on a set of heritable body structures and behaviors in modern penguins to look for patterns and infer connections among them (and Pedro). We developed questions of how heritable bone structures would compare between these penguins and ancient penguin fossils other than Pedro.

This Lesson

Investigation

2 DAYS





We analyze data tables of bone-related structures for ancient penguin fossils and modern penguins and develop a timeline-based representation of the patterns in the data. We analyze images, maps, and descriptions of the environments of where these fossils formed.

Next Lesson

We will revise our initial explanation to account for the patterns in the data from the previous lessons. We will still have several candidate ideas for what might be causing these patterns. We will compare variation data for body structures of the penguin fossils we have and modern penguins. We will revisit our Driving Question Board and our list of related phenomena and decide to investigate connections among other ancient and modern organisms.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6



What Students Will Do

3.A Develop and use a timeline of a large data set to identify patterns in variations in body structures found in different penguins across different points in time.

3.B Analyze and interpret data from data tables, images, maps, and descriptive text to identify patterns of similarities and differences in variations in body structures, environments, and geographic locations of ancient penguin fossils across time.

What Students Will Figure Out

- None of the ancient penguins have all the same body structure variations in common with any modern penguins.

- Ancient penguin fossils tend to have more body structure variations in common with each other the closer they are in time. Modern penguins have more body structures in common with less-ancient penguin fossils than with more-ancient ones.
- The overall size of many but not all ancient penguins was larger than the largest modern penguins; the beak size and shape of many ancient penguins was longer and/or more curved than modern penguins.
- Earth's climate, the positions of the continents, and sea levels have changed many times over the last 60 million years.
- Ancient penguins lived in some of the places modern ones do. Some of the other organisms that lived in these areas have changed over time.

Lesson 3 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Share questions from the previous class and discuss how fossil data could help answer some of those questions.	A-B	poster from Lesson 2 with sticky note question
2	19 min	**EXPLORE BONE DATA FOR ANCIENT AND MODERN PENGUINS** Analyze data sets describing characteristics of bones from both modern and ancient penguins to identify any patterns between them. Share the patterns noticed regarding connections among the bone structures of ancient and modern penguins.	C-D	*Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data strips for ancient penguin fossils*, *Reference: Internal Structures Key*, *Extension: Data strips for more-incomplete ancient penguin fossils* (optional), 1 scissors (optional)
3	8 min	**MAKE PREDICTIONS** Make predictions about the ages of the fossils analyzed in the previous activity.	E	*Data strips for ancient penguin fossils*
4	13 min	**ORGANIZE THE DATA BY TIME PERIOD AND LOOK FOR CONNECTIONS** Organize the fossil data from the previous activity by time period and look for connections to patterns in the body structure variation data.	F-H	*Data strips for ancient penguin fossils*, *Reference: Internal Structures Key*, timeline made from *Timeline Sections*, 1 piece of poster paper, 1 roll of transparent tape, 1 rubber band, 4 colored pencils or crayons or markers in these colors: purple/ pink/ blue/ yellow *End of day 1*
5	8 min	**PARTICIPATE IN A GALLERY WALK** Review and record patterns in ancient penguin body structures related to time.	I	class's set of the timeline-organized data strips on poster paper collected from the previous class meeting

Part	Duration	Summary	Slide	Materials
6	5 min	**PREPARE TO ANALYZE FOSSIL DATA CARDS** Orient to the types and positions of information on the fossil data cards.	J-K	*Maps of Earth's Surface Over the Last 50 Million Years*, *Ancient Penguin Data Cards*, 1 modern penguin card from *Data Cards for Modern Penguins and Pedro*
7	17 min	**EXPLORE THE FOSSIL DATA CARDS INDIVIDUALLY AND IN A GROUP** Identify different factors by which to organize cards and look for patterns in traits. Then organize cards using different traits and observe and discuss related patterns in traits.	L	*Ancient Penguin Data Cards*, timeline poster, timer, DQB, Ideas for Future Investigations and Data We Need poster
8	5 min	**COMPLETE INDIVIDUAL EXIT TICKET TO SUMMARIZE PATTERNS FROM PENGUIN DATA CARDS AND STRIPS** Synthesize information on an exit ticket about newly and previously observed patterns.	M	*Ancient Penguin Sorting Exit Ticket*, *Ancient Penguin Data Cards*
9	8 min	**TAKE STOCK OF WHERE WE ARE** Share the patterns we noticed regarding connections among the characteristics of ancient penguins and identify areas of our Penguin Timeline model that we can start to fill in based on these patterns.	N	*Ancient Penguin Data Cards*, Penguin Timeline, chart paper, markers
10	2 min	**NAVIGATION**	O-P	*Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?* (optional), rubber band, timeline-organized data strips on poster paper, *Maps of Earth's Surface Over the Last 50 Million Years*, *Ancient Penguin Data Cards*

End of day 2

Lesson 3 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Maps of Earth's Surface Over the Last 50 Million Years* • *Ancient Penguin Sorting Exit Ticket* • *Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?* (optional)	• *Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro* • *Data strips for ancient penguin fossils* • *Reference: Internal Structures Key* • *Extension: Data strips for more-incomplete ancient penguin fossils* (optional) • 1 scissors (optional) • timeline made from *Timeline Sections* • 1 piece of poster paper • 1 roll of transparent tape • 1 rubber band • 4 colored pencils or crayons or markers in these colors: purple/ pink/ blue/ yellow • *Ancient Penguin Data Cards* • timeline poster • rubber band • timeline-organized data strips on poster paper • *Maps of Earth's Surface Over the Last 50 Million Years*	• poster from Lesson 2 with sticky note question • class's set of the timeline-organized data strips on poster paper collected from the previous class meeting • 1 modern penguin card from *Data Cards for Modern Penguins and Pedro* • timer • DQB • Ideas for Future Investigations and Data We Need poster • Penguin Timeline • chart paper • markers

Materials preparation (75 minutes)

Online Resources



Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

These are nonconsumables that you collect and reuse in all your classes:

- Gather a set of the *Data Cards for Modern Penguins and Pedro* (in case students want to reference modern penguins at any point) from Lesson 1 for every pair of students in your largest class. These should still be binder-clipped together.
- Gather the preprinted color copies of the *Ancient Penguin Data Cards* to have one set for every group of 3 students in your largest class. If you do not have preprinted copies of *Ancient Penguin Data Cards*, print one color copy for every 3 students and then cut the copies into half-page cards. If possible, print on cardstock and/or laminate. Use a binder clip to keep each set of these together. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally.
- Optional: Make a color copy of *Extension: Data strips for more-incomplete ancient penguin fossils* for each pair of students in your largest class. Cut the strips out of these and clip each set of strips together with a binder clip. Since these are supplementary material for students who are interested, it is recommended that you collect and reuse these for all your classes if you choose to selectively distribute them to groups that request them.
- Consider laminating these cards and strips since you will reuse them for each class you teach and can keep them year to year.
- Gather the preprinted color copies of *Maps of Earth's Surface Over the Last 50 Million Years* from your kit, or print and laminate one color copy of *Maps of Earth's Surface Over the Last 50 Million Years* per student in your largest class.

These are consumables to prepare:

- Print black and white copies of *Data strips for ancient penguin fossils* and *Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro* for every pair of students in every class. Decide if you think you will have time in class to have students cut their own strips at the start of the activity. If not, cut the strips ahead of time. After they are cut, use a binder clip to secure each set. Students will use these to build their poster.
- Your kit will contain enough color copies of the three sections of *Timeline Sections* for every 3 students in 6 classes of 30. If you do not have the materials kit or have more students, print one color copy of *Timeline Sections* for every 2 groups (of three) in your classes. Cut out the two identical sections from every sheet. Tape the three different sections of the color timeline together for each group. Students will be using these to build their poster.
- Print black and white copies of *Reference: Internal Structures Key* for every pair of students (which is how they are initially used). Students may wish to use these in the construction of their posters (which will be done in groups of 3 students), so this printing is treated as consumable. Note that students also used *Reference: Internal Structures Key* in Lesson 2, where they were nonconsumables; save those to use again when you teach the lesson in the future.
- Prepare 1 sheet of poster paper and 1 rubber band for every 3 students.

Be sure you have materials ready to add the word *extinction* to the Word Wall. Do not post this word on the wall until after your class has developed a shared understanding of its meaning.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

The body structure variation data used in this lesson were compiled and merged from two resources.

- the supporting online material published along with *Fossil Evidence for Evolution of the Shape and Color of Penguin Feathers*, published 12 November 2010 in *Science*, DOI: 10.1126/science.1193604
- the appendix published along with Paleogene equatorial penguins challenge the proposed relationship between biogeography, diversity, and Cenozoic climate change. Published July 2007 in *Proceedings of the National Academy of Sciences*, *104*(28): 11545-11550; DOI: 10.1073/pnas.0611099104

Both of these databases were used by Dr. Julia Clarke (one of the scientists interviewed in Lesson 1) and her collaborators to look for connections between modern penguins and extinct penguin fossils. A subset of this much larger data set the scientists used in their published paper was selected for students to use in this lesson to make the data analysis task accessible for students. The selection of the 17 sets of bone-related traits that are included for students to analyze are ones that met these 3 criteria: (1) the body structure and related variations could be described relatively concisely and accurately for students without using Latin names, (2) many of the ancient fossils had measured values (data) for that trait, and (3) the structure-function relationships in the variations of those traits would be relatively easy to hypothesize. For this last reason variations in the shape of the beak, wing bone (humerus), leg bone (femur), and shoulder blade were chosen rather than traits related to hip or spine bones. For a reference that compares both the Penguin Taxon and common names, please see *Penguin Taxon vs. Common Name or Nickname*.

The data set students will be working with in *Data strips for ancient penguin fossils* references only 13 additional ancient penguins (beyond Pedro) from the larger data sets described above. The large data sets described above contain more types of fossils, but ones that provide a very limited amount of body structure variation data due to relatively incomplete fossils (e.g., one or two bones). This is why they were excluded from *Data strips for ancient penguin fossils*. Some students may wonder whether the data set they are given to work with represents all known ancient penguin fossils. If students raise this question, tell them it does not, but it does represent the ones for which scientists had relatively complete body structure variation data (more than 3 values for the 17 bone-related structures under consideration). Those that had only two or three values for the structures are included in a supplemental material—*Extension: Data strips for more-incomplete ancient penguin fossils*—in case you want to provide an optional, additional resource to students who ask for it. Even with this reduction in data, students will still be working with a large data set to identify temporal and spatial relationships (32 data strips, 13 of which have 17 variables on them and the rest of which have 36 variables on them). This type of large data set analysis work is a key element of engaging in analyzing and interpreting data and looking for patterns at the middle school level.

The data cards students use in day 2 of this lesson contain a lot of complex information, including global maps, descriptions of the fossil site(s), and local and global environmental conditions, as well as images showing the recovered fossil parts and an artist's reconstruction of the entire penguin's body shape. Students will be working with similarly formatted data cards in Lesson 5, but for different organisms. In that lesson, the task will be more rigorous because students will need to describe structures and variations they see in bones (and shells) of those organisms themselves rather than receiving data that are already organized into categories.

The global maps on the data cards show shifts in the continents and mountain ranges. Students should be familiar with the ideas of geologic time scale, rock strata, and land masses changing position on Earth due to plate movement over time from their prior work in *Unit 6.4: What causes Earth's surface to change? (Everest Unit)*.

Students will have developed understandings around shifts in global average temperatures and corresponding changes in precipitation from their prior work in *Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)*. However, in that unit they only investigated climate level changes over hundreds of years, not millions.

Where We Are NOT Going

Some of the color-coded time periods on the timeline correspond to what would be considered multiple geologic epochs (e.g., yellow = the holocene, pleistocene, and pliocene epochs combined). Knowing the names of the periods and when they occured is not the focus of this lesson. The term *time period* (rather than *geological period*) is used to refer to the color-coded parts of the timeline. Each fossil penguin data card includes a corresponding description of Earth's climate trends and a map representative of continents and mountain ranges based on plate reconstructions for the time period when that ancient penguin is determined to have lived.

Students will work with both the moderns and ancient penguin data cards again in Lesson 13. At that point they will do more than look for patterns across them. They will use them as a source of evidence for arguments about proposed lines of descent and common ancestors. However, students will not do that in this lesson. If some students start to propose possible lines of descent or common ancestors in their interpretation of the data, that is fine, but be sure that your reactions to these ideas do not broadcast whether such inferences are or are not supported by the data. Take the stance of "we are looking for correlations first" in order to refine our ideas about possible causes of the connections we notice among the penguins.

Likewise, if students start introducing words such as *adapt* or *evolve*, you might suggest that they add questions about those words to the DQB. Continue to encourage students to look for correlations at this point because many of them will not be ready to explore any proposed mechanisms until they first become more familiar with the data they are trying to explain. That is the focus of this lesson—finding patterns in the fossil versus modern penguin data that beg explanation.

As in the previous lesson, students will need to use the idea that these traits are related to genes. However, students may try to extend the idea that we developed in *Unit 8.5: Why are living things different from one another? (Muscles Unit)* that different alleles are what is leading to different expressions of a trait. If students establish this thinking, it could be confusing for them as they learn more about the details of genetics in the future because that language (to describe the changes in sequence) is not used when we start comparing organisms that are different species. If students are attempting to make these connections, you can agree that there are small differences regarding the genes that lead to trait variations, but instead of discussing this at the gene versus allele level, guide students to use the broader terms *body structures* or *behaviors* to compare the traits of different organisms. In reality the trait-level differences are often not due to changes at the sequence level (which would result in a new allele), but instead are due to changes in the timing of the expression of the gene during development, which is far outside of the scope of this grade band.

LEARNING PLAN FOR LESSON 3

1. Navigation

5 MIN

Materials: science notebook, poster from Lesson 2 with sticky note question

Share questions from the previous class meeting. Present **slide A**. Remind students that during the last class they recorded questions (on *New Questions and Ideas for Data We Need*) after considering some of the data they had investigated. Ask students to share some of these questions.

Suggested prompt	Sample student responses
What were some of the questions you recorded last time after examining the data?	*How do bone structures of other penguin fossils compare to Pedro?* *How big were other ancient penguins?* *How many species of ancient penguin fossils have been found?* *How old are other penguin fossils, and what part of the world were they found in?* *Are there fossils that have more body structure variations in their bones in common with modern penguins than Pedro does?* *Do all ancient penguins look different from the penguins of today?*

Say, *In our very first lesson we drew or described what we thought other ancient penguins besides Pedro might have looked like. Scientists make those sorts of drawings using measurements of fossil bones. We developed these questions after comparing some of the body structure variations in bones for modern penguins and Pedro. Scientists have recorded and published these data on the other penguin fossils they have discovered too.*

Present **slide B**. Discuss the question on the slide as a class.

Suggested prompt	Sample student response
How could analyzing these data from fossils of other ancient penguins help us make progress on some of our questions?	*We can sort the data like we did last time and look for connections between different penguins to see how many, if any, body structures they have in common with one another and with the penguins of today.*

Additional Guidance

Looking at fossils of other ancient penguins or having questions about whether there are other ancient penguin fossils besides Pedro are ideas that have appeared from students on Driving Question Boards from the pilot of this unit.

If these questions have also appeared on your Driving Question Board, you may want to take a brief moment to reference that connection for students. Establishing regular connections to questions (or categories of questions) on the Driving Question Board is one important way you can support coherence for students. Likewise, following the most proximal line of questions that has emerged from sensemaking in recent class discussions also supports this coherence.

2. Explore bone data for ancient and modern penguins.

19 MIN

Materials: *Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data strips for ancient penguin fossils*, *Reference: Internal Structures Key*, *Extension: Data strips for more-incomplete ancient penguin fossils* (optional), 1 scissors (optional)

Prepare students to look for patterns in bone data. Organize students into pairs. Say, *In addition to Pedro, we have bone structure data for thirteen other species of ancient penguin fossils. These are from fossil sites where scientists found more than just a few bones of the penguin and therefore can provide a more complete set of the type of body structure data we compared last time.*

Some students may ask whether the data set they are working with on *Data strips for ancient penguin fossils* has data from all the penguin fossils ever found. If so, see the related equity support in the sidebar.*

Uncover patterns in the data from ancient and modern penguins. Say, *Similar to what we did last time, let's use data strips to look for any patterns in the same heritable bone traits that we looked at last time, but this time let's look for them across all the different ancient and modern penguins together. Remember, the ancient penguins have a black background at the top of their strip, and this time the modern ones have a red or gray one* (depending on whether you are looking at color-print versions or grayscale). *We will do a second pass on these data in a bit, at which point we can record the patterns we notice. For this first pass though, let's just focus on talking through the different patterns we are finding with our partner.*

Present **slide C**. Review the instructions on the slide.

- 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.

Distribute to each pair of students a set of data strips from *Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro* and from *Data strips for ancient penguin fossils* along with *Reference: Internal Structures Key*. If you did not cut the strips ahead of time and have time in class, have students cut out their own strips before they begin working with them. Tell students that they do not need to figure out every pattern in the strips but just look for 1-2 patterns in body structure variations across the penguins, and we will put the pieces together as a class in a few minutes.

*** Attending to Equity**

Universal Design for Learning—Extension Opportunity: If students ask whether the data set they are working with on *Data strips for ancient penguin fossils* represents data from *all* the penguin fossils found so far, say, *No, there are more, but they are relatively incomplete, often just one or a few bones, and therefore harder to interpret.* You can then offer those students an opportunity to analyze these as well, if they are interested. This data set is on *Extension: Data strips for more-incomplete ancient penguin fossils*. But encourage those students to work with the data set on *Data strips for ancient penguin fossils* first and then, after they find a set of patterns in these, add the more-incomplete data set from *Extension: Data strips for more-incomplete ancient penguin fossils*. For some students, working with this additional data set may support the *relevance* of the task by

Additional Guidance

If students struggle going back and forth between the key and the data strips, have them first organize just by looking for similarities of the numbers in the strips. Then, encourage them to return to the key and discuss what the numbers mean in terms of body structures.

Share the patterns that students noticed. Display **slide D**. Ask student pairs to summarize their choices and reasons for any patterns they noticed in the bone structures of the ancient and modern penguins. While sharing, walk around the room and listen for patterns such as the ones below.

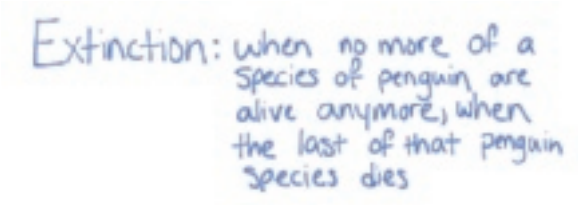
- Some of the modern penguins have all the same body structures or behaviors as other modern ones.
- None of the modern penguins has a corresponding ancient fossil that has all the same body structures in common with it.
- Some ancient penguins have a lot of structures in common with the modern penguins, some more than others.
- Some ancient penguins have a different number of structures in common with other ancient penguins.

Ask some of the students you heard discussing these patterns to be ready to share their thinking with the whole class. While sharing, students may refer to *Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data strips for ancient penguin fossils*, and *Reference: Internal Structures Key*.

either (a) increasing the cognitive demand and therefore increasing the challenge of the data analysis or (b) providing them a larger and therefore more-comprehensive sample of the types of fossil data that paleontologists use.

Additional Guidance

It is likely that at some point in this lesson's discussions students will bring up the idea of extinction, possibly that some penguin species have gone extinct or are not existing anymore. When this happens, capitalize on the moment and **add a co-constructed definition for *extinction* to the Word Wall**. Their co-constructed definition might be something like "when no more of a species of penguin (or other organism) are alive anymore" or "the last of that penguin species dies." Students will continue to build science ideas around extinction throughout the remainder of the unit as they further explore the fossil records of penguins and other organisms.



3. Make predictions. 8 MIN

Materials: *Data strips for ancient penguin fossils*

Make predictions about the ages of these fossils. Say, *We looked at data from a lot of penguin fossils. The ages of these fossils are not all the same. Some are from within a few million years of when Pedro died, which was about 36 million years ago, while some are tens of millions of years older, and some are tens of millions of years younger. Let's make some predictions.* (Refer to *Data strips for ancient penguin fossils*.) *Which of these ancient penguins would you expect to be the fossils that are more ancient than Pedro? Which of them would you expect to be the fossils that are less ancient than Pedro? We'll make some predictions individually before we share our ideas with a partner.*

Present **slide E**. Have students individually follow the directions on the slide for a minute or two.

- 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).

Then have students meet with a new partner to discuss their predictions for another minute or two. When you assign new partners, advise students who relocate to leave all the strips at their current spot and work with the strips at their new spot. Say, *Talk with your partner about what you think. Be sure to discuss why you think some penguins are likely to be more or less ancient than others*.

Ask some students to share their predictions or their partner's predictions and why they made them. Here are some anticipated student responses:

- The ones that have the most body structure variations in common with Pedro might be the ones from closest to around 36 million years ago.
- The ones that have more body structure variations in common with the ones today might be the ones that are younger than Pedro.
- The ones that have few body structure variations in common with Pedro and very, very few traits in common with the ones of today may be the more ancient ones.
- There is no way to tell for sure since body structure variations could have come from anywhere over that long a time.
- Their differences in body structure variations could be because of where they lived rather than when they lived, so we can't tell.
- I really don't know … I am curious to see.

4. Organize the data by time period and look for connections.

13 MIN

Materials: *Data strips for ancient penguin fossils*, *Reference: Internal Structures Key*, timeline made from *Timeline Sections*, 1 piece of poster paper, 1 roll of transparent tape, 1 rubber band, 4 colored pencils or crayons or markers in these colors: purple/ pink/ blue/ yellow

Introduce the timescale for the fossil data. Present **slide F**. Say, *The fossils you have analyzed were formed at various points in time in the past. The timescale shown here represents different periods of time during which they may have formed. The square dot on the purple bar of the scale represents the time when Pedro was alive. How many millions of years ago was that?* Students will say, "36 million years ago."

Color code the data strips by time period. Present **slide G**. Organize students into groups of three. Distribute colored pencils (or crayons or markers). Have students use the slide as a reference to color code the white rectangle on the bottom of each ancient fossil data strip to reflect the time period that species of penguin was living.

Compare the age of the fossils. Show **slide H**. Distribute to each group a copy of the timeline made from *Timeline Sections*, tape, and a piece of poster paper. Tell students the timeline can be taped to the poster and that *Data strips for ancient penguin fossils*, *Reference: Internal Structures Key*, can be annotated after they finalize their organization of the strips. Say, *You have plenty of space on this large paper to work together to find patterns and compare the structures that the ancient penguins*

have in common or not within their same time periods and across time periods. Once you have your strips organized, tape them down and annotate your data for future reference. I will also take a look to see what patterns you have found in this large data set.

Have students use the remaining time to organize the strips, observe any patterns of traits that emerge, discuss their organization, tape them to their poster, and annotate their poster to show any connections they noticed across the time and structure data. Remind students that they do not need to find every pattern in the strips but just look for 1-2 patterns in body structures across the penguins, and we will put the pieces together as a class next time.*



Assessment Opportunity

Building towards: 3.A Develop and use a timeline of a large data set to identify patterns in variations in body structures found in different penguins across different points in time.

What to look and listen for

- Placement of the following groups of penguins over the corresponding horizontal, color-coded section of their timeline
- Clustering based on number of body structure similarities in the purple time period
  - *P. gunnari* and colossus together (All known body structures are in common for which values were measured.)
  - *P. devriesi* and *W. tuatahi* separated from *P. gunnari* and colossus
- Clustering based on number of body structure similarities in the pink time period
  - different number of body structures in common between Simpson's and Lopdell's versus Simpson's and Lowe's
- Clustering based on number of body structure similarities in the blue time period
  - Tiny rower and slender-footed together (All known body structures are in common for which values were measured.)
  - *Pa. antarcticus* near slender-footed and *S. urbani* and tiny rower (one structure is different between each of these) but further away from tiny rower
  - *S. urbani* further away from tiny rower than other two (slender-footed and *Pa. antarcticus*)
- Clustering based on number of body structure similarities in modern penguins
  - major clusters by number of internal body structures in common
  - possible minor clusters by number of external body structures or behaviors in common

What to do: If students simply arrange the strips in order by time and not by body structure patterns as well, emphasize that organizing by time is a good first step. Then encourage students to next look for body structure patterns both among the penguins in a given time period and in penguins across time.

Additional Guidance

If students ask what the first initial stands for in the penguin names, it is OK to recognize that these are used to help identify the different species of penguins. It is not necessary in the middle school grade band to distinguish genus and species. Later in the unit, during Lessons 4 and 13, when discussing individual populations of penguins breeding, students will co-construct the meaning of *species* as a class.

*** Supporting Students in Engaging in Analyzing and Interpreting Data**

In this process students are developing and using graphical displays of a large data set to identify temporal relationships. The size of this data set (32 data strips with 17 or 36 variables on each one) and the suborganization of groups within the data set make this a challenging data (re) organization and analysis task. It is well aligned to elements of the practice of analyzing and interpreting data in the middle school grade band. Students will need to work with these data again in Lesson Set 3 to make evidence arguments for lines of descent and common ancestors. This lesson provides an opportunity for students to develop fluency in working with these sorts of data in this way that they will need to leverage in those later lessons.

Roll up and collect student posters. Once students are done, distribute a rubber band to each group to use for securing their poster after rolling it up. Remind students to put their group member names on the outside of the poster before saving them for next time.

End of day 1

5. Participate in a gallery walk.

8 MIN

Materials: science notebook, class's set of the timeline-organized data strips on poster paper collected from the previous class meeting

Prepare the posters for a silent gallery walk. Distribute the group posters from last class and/or lay them out on tables before class so students can do a gallery walk of at least two posters during this activity. Present **slide I**. Review the directions on the slide.

Do a silent gallery walk. Have students bring their Progress Tracker and circulate individually to two posters to record what patterns they notice in the body structure data. One of the posters can be their own if they wish.

Assessment Opportunity

Recall that Progress Tracker entries should not be scored or graded because doing so would invalidate their purpose—to be a safe space for students to process and record their thoughts honestly and without worry about evaluation. At the end of this lesson, students will complete a reflection on their Progress Tracker entry and other ideas they have built in this lesson. You can collect that reflection as a formative assessment; see the related assessment guidance callout box for 3.B at the end of day 2 of this lesson.

Transition to the next activity. Say something like, *Now that you have had a chance to compare the patterns you found with your classmates' ideas about body structures, let's continue to explore this question of how ancient and modern penguins might be connected. Some of you wondered about where these ancient penguins were living and what their environment was like at the time, so I have some additional data about that for us to investigate.*

6. Prepare to analyze fossil data cards.

5 MIN

Materials: *Maps of Earth's Surface Over the Last 50 Million Years*, *Ancient Penguin Data Cards*, 1 modern penguin card from *Data Cards for Modern Penguins and Pedro*

Introduce the new types of maps students will see on the new data cards of Pedro and ancient fossils. Say, *We have additional data for these penguin fossils that may help us find other connections. Let's look at the new types of data that are on a different version of penguin data cards. One important difference is the maps on the cards. Instead of a view of the Southern Hemisphere looking down on the South Pole like on the Data Cards for Modern Penguins and Pedro* (hold up one of the modern penguin cards)*, you will see a map that displays a different view of the land on Earth at that point in time when that penguin lived. Let's take a look at what those maps show.*

Display **slide J**. Say, *These are two of the maps you will see on the cards. The left map is what you will see for any ancient fossil from the purple time period. That map shows what scientists have determined the positions of the continents, coastlines, and ice cover were on Earth for about the middle of that time period. The maps for the pink and blue time periods will also be*

for the middle of those time periods. But the yellow time period will show the map of Earth from 21,500 years ago, which is during the last ice age. The last ice age ended 11,700 years ago, which is very close to the end of the yellow time period.

Additional Guidance

Some students may comment on the apparent shifts in the positions of continents or apparent changes in ocean water levels. If they do, this is an opportunity to have them briefly recall what they learned about plate tectonics in *Everest Unit* and/or temperature changes in *Droughts and Floods Unit* to propose possible explanations for the differences they see on the maps. However, the key reason for using these different maps is to provide a line of evidence for eventually claiming that the environment conditions are changing over time both locally and globally. So it is not critical for students to raise connections to prior units at this time.

Orient to the new types of data on the new data cards of Pedro and ancient fossils. Display **slide K**. Say, *Now we'll take a look at the other types of data you will see on the Ancient Penguin Data Cards.*

Organize students into the same groups of 3 they worked in on day 1. Distribute a copy of *Maps of Earth's Surface Over the Last 50 Million Years* to each student and a set of *Ancient Penguin Data Cards* to each group. Have students divide up the 14 fossil data cards as evenly as possible among their team members. Give students a minute to orient themselves to the layout of these fossil data cards. Help them locate and identify the information on the new data cards using the prompts below and **slide K** as a common reference, pointing to a part on the slide to indicate the location of the corresponding piece of information.

Suggested prompts	Sample student responses
Where can we find the bone structure data for this fossil?	*Along the left edge of the card.*
Where can we find information on where the bones of this fossil were found?	*In the left white box and on the map.*
Where can we find information about when this individual penguin lived and died?	*On the timeline at the bottom of the card.*
What other general information can we determine from this fossil data card?	*What the overall environment of Earth was like compared to today.* *What other organisms lived in or near the location where this fossil was formed and at that time.* *How big the penguin was, its height and weight.* *Some of the specific bones, out of the entire skeleton, that were found.* *An artist's reconstruction of what the overall body silhouette looked like and how that compares to other ancient penguins.*

Say, *Notice that there are now fourteen penguin silhouettes in the blue box. These are different silhouettes than you saw before. These silhouettes are artists' reconstructions of the overall body size and shape of these ancient penguins, which are the same ones that are on the data strips on your timeline posters.*

7. Explore the fossil data cards individually and in a group. 17 MIN

Materials: *Ancient Penguin Data Cards*, timeline poster, timer, DQB, Ideas for Future Investigations and Data We Need poster

Connect to the Driving Question Board. Walk over to the DQB and the Ideas for Future Investigations and Data We Need poster and ask students if they see any questions or ideas for investigations that these cards could provide information about. There are likely to be many that match the data on these cards.

Individually explore a subset of fossil card data. Say, *These cards provide us with a lot of new information about these ancient penguins. We already organized information about them by time, and we've already organized them by their body structures on the data strips. Let's now try to organize them in different ways using some of this new information.*

Individually sort cards. Display **slide L**. Set the timer for 4 minutes. Have students individually sort their subset of 4 or 5 fossil data cards based on a factor of their choice, but not by time or bone-related body structures. After they sort one way, they should find two other, different ways to re-sort the cards. They can keep their previously built timeline poster on the table as a reference for all group members, if they wish.*

Sort cards as a group. Cue students to start the group work. Refer to **slide L**. As students are working, listen for groups to be finding patterns that link body structures with the other factors they used to organize their *Ancient Penguin Data Cards*, such as geographic location or climate features. Group members can record patterns on a piece of paper or in their science notebooks.

*** Supporting Students in Engaging in Analyzing and Interpreting Data**
This 4 minutes of individual exploration gives students an opportunity to first orient themselves to the format of the complex set of information on a subset of the cards before working with the larger set of data.

8. Complete individual exit ticket to summarize patterns from penguins data cards and strips. 5 MIN

Materials: science notebook, *Ancient Penguin Sorting Exit Ticket*, *Ancient Penguin Data Cards*

Use an exit ticket to reflect on patterns in the data. Present **slide M**. Have students individually complete *Ancient Penguin Sorting Exit Ticket* using what they just figured out from the *Ancient Penguin Data Cards* sort and what they wrote in their Progress Tracker during the gallery walk. Allow students to keep *Ancient Penguin Data Cards* close by as a reference when completing *Ancient Penguin Sorting Exit Ticket*.



Collect student exit tickets to review before next class. Review students' *Ancient Penguin Sorting Exit Ticket* as a formative assessment. These will give you important information about the types of ideas you can draw on in the next lesson.

Additional Guidance

In this unit are many formal exit tickets at the end of lessons. Since this unit calls for fewer Progress Tracker entries than other units have, consider returning the exit tickets to students and having them adhere them to the Progress Tracker section in their science notebook as a record of what they have figured out. However, the Progress Tracker may be used at teacher discretion during any lesson to help students process their thinking individually and in a space that will not be evaluated for a grade.

Also, students' thinking during the data analysis and organization on day 1 was likely more focused on small details (such as naming specific penguin species and structures) whereas in today's work with the fossil data cards and in this reflection students are connecting those details to make generalizations and bigger-picture comparisons of ancient, less ancient, and modern penguins.

Assessment Opportunity

Building toward 3.B Analyze and interpret data from data tables, images, maps, and descriptive text to identify patterns of similarities and differences in heritable body structure variations, environments, and geographic locations of ancient penguin fossils across time.

What to look and listen for

- None of the ancient penguins have all the same body structure variations in common with any modern penguins.
- Ancient penguin fossils tend to have more body structure variations in common with each other the closer they are in time.
- Modern penguins have more traits in common with less-ancient penguin fossils than with more-ancient ones.
- The overall size of many but not all ancient penguins was larger than the largest modern penguins; the beak size and shape of many ancient penguins was longer and/or more curved than modern penguins.
- Penguins living at different times experienced differences in Earth's climate, the positions of the continents, and sea levels.
- Ancient penguins lived in South America, Antarctica, and New Zealand. Depending on where the penguins lived and when they lived there, the other organisms that lived in these areas varied.

What to do: Since students have built towards this lesson-level performance expectation in their Progress Tracker and in *Ancient Penguin Sorting Exit Ticket* at two different points in the lesson, you should expect to see many of the patterns listed above. If any students neglect to mention an entire category of patterns, such as any based on shared traits or time or geography, leave a sticky note on their exit ticket for the student to respond to. Include both a noticing and a wondering on this note. In your noticing, emphasize the category of patterns that the student already noted. In your wondering, raise a question related to the category of patterns you would like them to consider further. For example, *I noticed you found many patterns in how the traits of penguins compared across time. This was very interesting. I have a question. Did you find any patterns in the traits of the penguins compared to where they lived?* Make sure to provide time in an upcoming class for students to respond to this feedback.

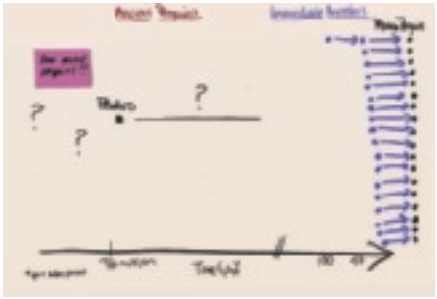
9. Take stock of where we are. 8 MIN

Materials: *Ancient Penguin Data Cards*, Penguin Timeline, chart paper, markers

Share findings in a whole-group discussion. Display **slide N**. Ask student groups (from the last group work of sorting data cards) to share with the class the connections they discovered. With each idea that is shared,

ask other groups to weigh in on whether they found similar connections in the data. Here are some anticipated responses:

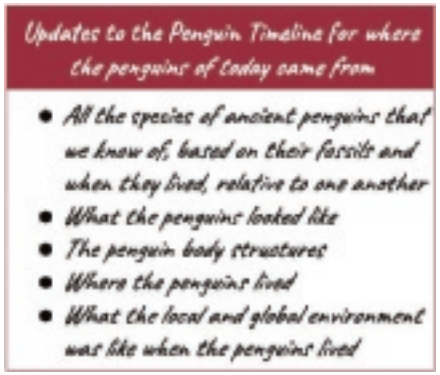
- There are only three major sites for all these fossils: Peru, New Zealand, and Antarctica. These are some of the places where penguins are found today.
  - Traits may (or may not) be related to this.
- The global environment has changed over time in million-year time frames.
  - Earth was warmer and wetter long ago.
- The local environment has differences by site, e.g., what other things lived there.



Motivate the need to organize as a class all these data in a way that helps address the questions that led us here. Say, *So if we are thinking that maybe where something is living is connected to the traits of that thing due to some sort of connections among what else lives there, what the local environment is like, and/or what the global climate is like, then let's look back at our initial consensus model to see whether it captures all these possible connections.*

Consider how we should update the Penguin Timeline. Facilitate a Building Understandings Discussion to recall the goal of the Penguin Timeline and to identify the gaps in it we can now fill in. Title a sheet of chart paper with "Updates to add to consensus model". As you are facilitating the discussion, add the information that students describe.

Suggested prompts	Sample student responses
What were we trying to show and/or explain in this timeline model when we first developed it?	*Where the penguins of today came from.*
What do these arrows between the dots on the right side of our model represent?	*The arrows represent lines of descendents from a group of ancestors to modern penguins.*
What do the question marks in the model represent?	*Gaps or uncertainty in which penguins lived when and what those penguins looked like.*
What could we add to this model now?	*All the species of ancient penguins that we know of, based on their fossils and when they lived relative to one another.*
What other information about these ancient penguins do we know now that we think is important to keep track of on this model?	*What they looked like.* *Their body structures.* *Where they lived.* *What the local and global environment was like when they lived.*



Save the ideas captured on a piece of chart paper to have ready when you begin class next time. Say, *This is a lot that we discovered that we do not have on our Penguin Timeline yet. Before moving on to new investigations, let's plan to update this model next time we meet so that it captures all the important discoveries we have made. That will allow us to have one common, public record of what we agree on to refer to going forward. Let's plan to meet in our Scientists Circle next time to work on updating this model together.*

10. Navigation

2 MIN

Materials: science notebook, *Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?* (optional), rubber band, timeline-organized data strips on poster paper, *Maps of Earth's Surface Over the Last 50 Million Years*, *Ancient Penguin Data Cards*

Connect to the Driving Question Board. Say, *Next time, we will also take stock of the questions on our Driving Question Board and the ideas for investigations to determine which we've made progress on. I can see one line of questions on our Driving Question Board that is about how scientists or artists determine what an ancient penguin looked like considering no one has ever seen one alive before.**

Alternate Activity

If you do not have any questions on your DQB related to how scientists and artists visualize ancient organisms, you should make *Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?* an optional home-learning opportunity for interested students (not the whole class). If you choose to do this, modify **slide P** by adding the word "optional" to the "Home Learning" box.

Say, *In this lesson, we looked at some really specific data that scientists measured from the bones of fossils they found. But we also saw drawings of entire penguins that no one has ever seen alive. How is it possible to make a drawing of an entire organism that we've never seen with our own eyes based on just what you would measure from some bones? Maybe you already have some ideas about how that is possible.*

Show **slide N**. Say, *Take a moment to 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? If after talking with a partner you feel you have an answer you are satisfied with, great. If you aren't sure or are kind of curious to learn more about this, I have an optional reading available that will explore this question further. You can take a copy of it on your way out of class.*

Read one or more of those questions out loud. Then say, *Let's explore that further in a reading that you will do as home learning. Before you look at that home-learning reading, talk with a partner about how scientists might decide what an ancient penguin looked like using the data they have available from the fossil.*

Show **slide O**. Have students 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?

Present **slide P** to introduce the home-learning assignment and distribute *Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?*.

Collect nonconsumables and posters. Have each group clip together their set of *Ancient Penguin Data Cards*. Collect these sets of cards and the *Maps of Earth's Surface Over the Last 50 Million Years* to reuse in your next class. Have each group roll up their poster again, with their names visible on the outside, and secure it with a rubber band for easy collection and storage. They will be used again in Lesson 13.

*** Attending to Equity**

Universal Design for Learning: Use the provided *Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?* to maximize student *relevance* in their instructional experiences. Determine how to use it based on the questions that are on your Driving Question Board or that you heard students raise in these first three lessons. If there is a question about how one can determine what an ancient penguin (or other organisms) looked like, this reading is designed to answer it.

If your students have raised this sort of question, refer to their specific question(s) as suggested here. If they haven't raised this question yet on their own, it is recommended that you either skip the assignment of the home-learning reading or offer it as an optional enrichment opportunity for interested students. For the latter, an alternate framing for introducing the reading as an optional activity is described in the related teacher support box.

ADDITIONAL LESSON 3 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

When they read *Reading: How do scientists use fossils to figure out what an organism that lived millions of years ago may have looked like?*, students are prompted to summarize two central ideas about the text:

- 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 they can make based on the data they have?

This reading directly relates to the wonderings many students have when they work with fossil data in this unit.

LESSON 4

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

Previous Lesson

We analyzed data tables of bone-related structures for ancient penguin fossils and modern penguins and developed a timeline-based representation of the patterns in the data. We analyzed images, maps, and descriptions of the environments of where these fossils formed.

This Lesson

Putting Pieces Together, Problematizing

2 DAYS



Data source: Paleobiology Database (2021)

We revise our initial explanation to account for the patterns in the data from the previous lessons. We still have several candidate ideas for what might be causing these patterns. We compare variation data for body structures of the penguin fossils we have and modern penguins. We revisit our Driving Question Board and our list of related phenomena and decide to investigate connections among other ancient and modern organisms.

Next Lesson

We will investigate various organisms to see if the patterns of connections between ancient and modern organisms are similar to penguins. We will sort data cards for ancient and modern horseshoe crabs, horses, and whales to see what patterns of similarities and differences exist in their body structures. We will discuss whether and how the patterns we notice in their body structures might be connected to where they live(d) or when they live(d). We will confirm that similar kinds of relationships exist in ancient and modern horseshoe crabs, horses, and whales as well as in penguins.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

4.A Develop an explanation based on preliminary evidence to illustrate that changes over time occur in the existence, diversity, and disappearance of different kinds of penguins throughout history.

4.B Develop an explanation that predicts what the variation in a chosen body structure or behavior of Galápagos penguins and king penguins looks like at different scales (between species versus between individuals within a population).

What Students Will Figure Out

- Some species (one or multiple) of ancient penguins must have produced the 18 lines of descendants that are alive today. We think we are missing the fossils of penguins from long ago that are more similar to or identical to the ones of today.
- If penguins have been changing over many generations, we suspect that these different species of penguins live(d) in different places. We think this because the penguins that live in different places have different body structure variations that could help them survive better in that environment.
- We establish that a sample of one penguin fossil might be representative, on average, of the entire population at that time, but there is variation among individuals within a population. Since there are not very many penguin fossils available, we want to look at fossils of other organisms.

Lesson 4 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Reorient to our unit questions. Turn and talk to review previous groupings of penguins to prepare to organize all the penguins and to identify new questions.	A	"Updates to add to the consensus model" class list from Lesson 3, Penguin Timeline from Lesson 1 (optional)
2	15 min	**DEVELOP CONSENSUS FOR PENGUIN GROUPINGS** Develop as a class a consensus representation of penguin groupings which will be our Penguin Timeline with Cards.	B	Penguin Timeline with Cards
3	20 min	**DEVELOP AN EXPLANATION BASED ON EVIDENCE** Use evidence from the penguin groupings to add to, change, or create an explanation based on evidence for the connections between ancient and modern penguins.	C-E	*Three Explanations,* 1 scissors, transparent tape, 3 sheets of chart paper, markers
4	5 min	**ANALYZE OUR EXPLANATIONS** Review our explanations with a critical eye to identify holes or missing evidence.	F-H	*Word Wall Image for Population,* chart paper, markers
				End of day 1
5	5 min	**DISCUSS POPULATION VERSUS INDIVIDUAL** Review why use of population versus individual matters for our explanations and missing data.	I	
6	5 min	**LOOK AT ANCIENT PENGUIN FOSSIL DATA** Examine the number of samples that exist for each species of penguin fossil we have looked at.	J	*Reference: Analyzing and Interpreting Fossil Data*

Part	Duration	Summary	Slide	Materials
7	5 min	**HOLD A BUILDING UNDERSTANDINGS DISCUSSION** Participate in a Building Understandings Discussion to surface the idea that individuals that belong to the same population share a set of common body structure variations.	K-M	*Reference: Analyzing and Interpreting Fossil Data*
8	15 min	**CONTINUE THE BUILDING UNDERSTANDINGS DISCUSSION** Continue the Building Understandings Discussion to revisit the idea that there is variation in traits between individuals of a population.	N-S	*Exit Ticket - Trait Variation,* king and/or Galápagos card from *Data Cards for Modern Penguins and Pedro* from Lesson 1, Penguin Timeline with Cards
9	15 min	**NAVIGATION** Revisit our related phenomena and Driving Question Board to see if we can apply what we are figuring out about penguins to other organisms.	T-U	1 copy of the Ideas for Future Investigations and Data We Need poster from Lesson 1, Related Phenomena chart from Lesson 1, 1 copy of the typed DQB (optional), 1-2 3" x 3" sticky notes, chart paper titled "DQB questions we have answered"
				End of day 2
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 4, students are ready to read Student Reader Collection 1 and then respond to the writing exercise.		Student Reader Collection 1: *Earth's Long Life Story*

Lesson 4 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Three Explanations* • 1 scissors • transparent tape • *Reference: Analyzing and Interpreting Fossil Data* • *Exit Ticket - Trait Variation* • 1 copy of the Ideas for Future Investigations and Data We Need poster from Lesson 1 • Related Phenomena chart from Lesson 1 • 1 copy of the typed DQB (optional) • 1-2 3" x 3" sticky notes	• king and/or Galápagos card from *Data Cards for Modern Penguins and Pedro* from Lesson 1	• "Updates to add to the consensus model" class list from Lesson 3 • Penguin Timeline from Lesson 1 (optional) • Penguin Timeline with Cards • 3 sheets of chart paper • markers • *Word Wall Image for Population* • chart paper • chart paper titled "DQB questions we have answered"

Materials preparation (20 minutes)

Online Resources 

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make 1 copy of the Ideas for Future Investigations and Data We Need poster from the end of Lesson 1 for each student so that they can add it to their science notebook. This may be a printed photo of the poster itself or a typed list of the ideas on the poster.

Optional: Type the questions from the Driving Question Board into a document that can be printed if you think that will allow them to see the questions more clearly to evaluate them. Make 1 copy of the typed DQB for each student.

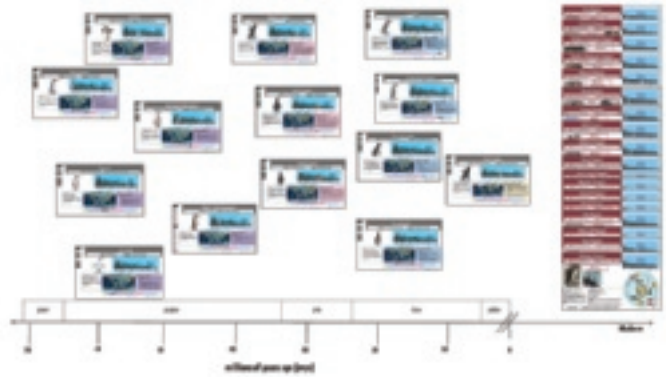
Prepare the handouts:

- Print 1 copy each of *Three Explanations* and *Exit Ticket - Trait Variation* for each student.
- *Reference: Analyzing and Interpreting Fossil Data* is included in the References section of the student edition. But if you want to provide it as a handout as well, print 1 copy per student.
- Have the king and Galápagos penguin cards from *Data Cards for Modern Penguins and Pedro* ready for students to reference.

Prepare for the Penguin Timeline with Cards:

- Designate a large space on a whiteboard or a bulletin board to organize the *Data Cards for Modern Penguins and Pedro* and *Ancient Penguin Data Cards* into an initial layout on the timeline. Make sure there is enough vertical space

to fit all 18 of the modern penguin cards on it. An example of how to organize this space is shown here. It is OK that the details of the cards in the image are indistinct; it is intended simply to help get a sense of the scope of the whole layout.



- Add small pieces of painter's tape to each card of one full set of *Data Cards for Modern Penguins and Pedro* from Lesson 1 and one full set of *Ancient Penguin Data Cards* from Lesson 3. You can set aside the duplicate Pedro card, as you will not need two of those on the timeline.
- Post the penguin cards on the board by time period groups, but not organized in any other way yet.
- Mark a timeline along the bottom of your board space from 70 million years ago to the present. You may choose to color code the time periods to coordinate with the penguin data cards as shown in *Timeline Sections*.

Prepare to update the Word Wall:

- Print one color copy of *Word Wall Image for Population* to add as a reference to your Word Wall during the appropriate point indicated in the lesson.
- Have materials ready to post the word *fossil record* to the Word Wall, and be prepared to repost the word *trait* from *Muscles Unit* or create a new card for that word, if needed.
- *Optional:* On a separate sheet of paper to add to the Word Wall, list one or more examples of samples that students collected in investigations and activities (related to CCSS.MATH.CONTENT.7.SP.A.1) that they engaged in during their math classes in the prior year (7th grade). Talk to your 7th grade math teachers ahead of time to find out specific examples to cite.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, we are putting together into three mini explanations a series of science ideas developed over previous lessons. The science ideas include the following:

- Different species of organisms in the fossil record: There are different species of things that lived long ago than are alive now.
- Environmental change: Ecosystems can change over time. Earth was different in the past than it is now.
- Heritability of trait variation: Some aspects of trait variation are heritable, even in cases where there are aspects of it that are influenced by the environment.
- Fossil record sequence: New things do not come out of nowhere; they must have come from something slightly different in the past through a line of direct descendants.
- Extinction: When the environment changes, some species of organisms disappear from Earth.

This lesson will leverage student reasoning about samples and populations that relies on ideas that they developed in CCSS 7th grade math. In that grade they used random sampling to draw inferences about a population. As part of this work (CCSS.MATH.CONTENT.7.SP.A.1) they developed the understanding that statistics can be used to gain information about a population by examining a sample of the population and that generalizations about a population from a

sample are valid only if the sample is representative of that population. Coordinate with your 7th grade math teacher(s) to find out specific examples of simulations or data sets students worked with to generate statistics inferences based on random sampling they carried out on a larger population that you can reference in your discussions.

In this lesson we again surface the importance of thinking about whether what we are seeing and describing is applicable at a population level versus an individual level. It is important to keep pressing on the idea (that we carried over from *Unit 8.5: Why are living things different from one another? (Muscles Unit)*) that trait variation exists between individuals in the population. Students will need to look for evidence of this in Lesson 7, and in Lesson 8 they will need to include those data as part of the mechanisms they use to describe how natural selection happens (specifically, that selection will act on the individual phenotypes, but we can only see the effects of this process at the population level as the proportion of individuals in a population with a certain trait changes over time).

Students know, from *Muscles Unit* and from observations of photographs of individuals within populations of modern penguins, that there is also some level of individual trait variation in the population. While we don't see many examples of individual trait variation in the fossil record, this may be explained due to the small sample sizes we have since we are more likely to see this type of variation if we have a sample of many different individuals from the same population.

In this lesson, students will continue to use the language of "trait variation" (that they know from *Unit 8.5: Why are living things different from one another? (Muscles Unit)*) as they begin to focus on individuals within a population. Previously in this unit, students had been more explicitly examining and describing body structure variations (not traits) because they were comparing different species of penguins.

Where We Are NOT Going

In this lesson, we define *population* as "a group of the same species of organism in an area." This use of "species" in the definition is a step toward deepening our understanding of the word, on which we will continue to build in Lesson 13. However, note that the larger set of mechanisms that drive speciation events are not developed until high school.

In this lesson, we will not stress the idea of limiting a population to a geographic area since our focus is on understanding whether an individual or small sample can represent a population.

It's OK if students suggest ideas about individuals rather than populations changing over time. Figuring out the distinction of what is changing will be the focus of Lesson 6 and beyond. While you can ask for clarification on whether students are suggesting one versus the other (or maybe both), avoid indicating whether either or both possibilities seem more reasonable at this point.

LEARNING PLAN FOR LESSON 4

1. Navigation

5 MIN

Materials: science notebook, "Updates to add to the consensus model" class list from Lesson 3, Penguin Timeline from Lesson 1 (optional)

Reorient to the unit questions. Gather students in a Scientists Circle as they enter the room. Display **slide A** and remind students that we started our investigation by wondering whether Pedro, the large penguin fossil found in Peru, could be connected to modern penguins. In Lesson 1, we identified two important subquestions: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from?

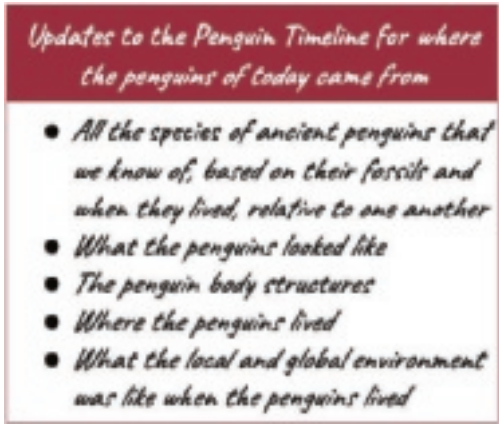
Say, *We've analyzed a lot of penguin data to figure out if Pedro could be connected to modern penguins and to help us answer these two subquestions. As we've made progress, we're beginning to think about the connections between modern and ancient organisms in new ways.*

Recall where we left off last time. Refer to the chart paper list you created in Lesson 3 of updates to add to the consensus model. Give students a moment to talk with a partner, referring to their science notebooks as needed, about the following question on **slide A**:

- What evidence do we have for one or more of these updates we plan to make to our model?

After a moment of partner talk, say, *We will use that evidence during our work today.*

Remind students to the goal of today's work. Say, *As a class, we are going to try to come to an agreement about how to best represent our current thinking about the connections between the penguins. We will create a public record of our penguin groupings.*



Additional Guidance

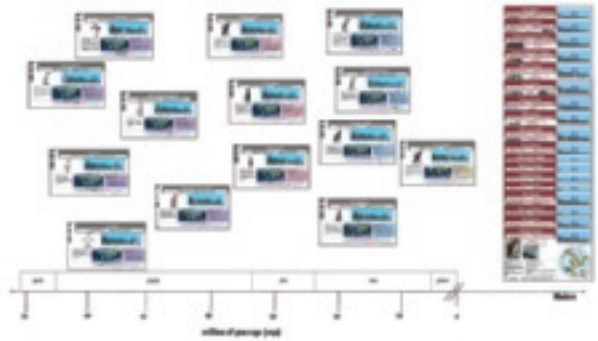
If you think it would benefit your students to recall the representations in the Penguin Timeline from Lesson 1, facilitate a conversation to contextualize the following in that model:

- Point out that the dots to the immediate left of the far-right dots for modern penguins each represent at least two parents in the population before the modern penguins' generation, which we know must have been the case because some parents reproduced sexually and successfully raised an offspring. Since the current population sizes for modern penguins are in the thousands, we can assume there were many parents in the previous generation.
- A dot therefore implies a population greater than one individual.
- Each arrow in the timeline model represents all the mating events that produced offspring that became part of the next generation.
- The dot on the left side of an arrow therefore represents all the individuals in that generation (of parents of the generation represented by a dot to the right of an arrow) along with any others that are still alive from the prior generation.

2. Develop consensus for penguin groupings. 15 MIN

Materials: science notebook, Penguin Timeline with Cards

Additional Guidance



Please note that the Penguin Timeline with Cards developed in this lesson is not a replacement for the original Penguin Timeline developed in Lessons 1-3. Keep the original Penguin Timeline available in the classroom to refer to in Lesson 6.

Facilitate a Consensus Discussion. Present **slide B** and launch the discussion by saying, *I got us started by putting the penguin cards on the board according to the corresponding time periods they are from.*

Tell students that we will use the following process to reach consensus:

- One student proposes a potential penguin grouping and justifies the grouping decision with evidence.
- Other students agree, disagree, or propose a modification to the grouping (based on evidence).
- Repeat this process until all the penguins are grouped in a way that the class can agree on (for now).

Key Ideas

Purpose of this discussion: Come to consensus on the groupings for ancient and modern penguins

Listen for these ideas:

- Penguins that are closer in time to one another share more body structure variations in common.
- We can group penguins based on a variety of different body structure variations, and the groupings slightly change depending on what we prioritize.
- None of the penguins we grouped together exactly match.

Have students share suggestions for how to group the penguins. It may help to offer sentence starters such as, "I think we should have a grouping for X, Y, and Z penguins here because (give evidence for why they go together)." As students share their proposed arrangement, move the penguin cards to the proposed grouping or have students move the cards. Then invite all students to agree or disagree with the proposed grouping using thumbs up, down, or sideways (not sure). Students may also suggest a modification supported by evidence. If there are disagreements, work through them and move the penguin cards accordingly. It may help to suggest that some penguins can be placed between groupings if the class cannot agree on a single grouping for a species. Continue, having another student propose another grouping; work through 2-3 options for groupings.

Initiate a Turn and Talk: *We have seen a couple of groupings. Talk with your partner about which grouping you think best describes what is going on with the penguins across time.* Listen for students to use evidence of body structure variation to justify their choice of grouping.

Bring the class back together to wrap up the discussion and arrange the cards in the grouping the class is most in agreement with. Work together to summarize the choice the class made by facilitating a discussion using these prompts.

Suggested prompts	Sample student responses
What evidence did we, as a class, use to make this grouping?	*We decided to group based on _____ (body structure variation).* *We used evidence of _____ from the ancient and modern penguins.*
Looking at our consensus grouping across time, what do you notice?	*None of the structures exactly match across time.* *Our consensus grouping shows both similarities and differences in body structure variations.* *Penguins closer in time to one another have more body structure variations in common.*

Additional Guidance

There are many ways to group and regroup these penguins. Consider referencing the idea that biologists do exactly this work in an effort to develop an explanation from the data they collect. The goal here is twofold: to get to an arrangement that (1) shows similarities and differences in body structures and (2) shows that the structure variations are more similar the closer in time the penguins are to each other.

3. Develop an explanation based on evidence.

20 MIN

Materials: science notebook, *Three Explanations*, 1 scissors, transparent tape, 3 sheets of chart paper, markers

Reorient to our original goal. Say, *When we first started this unit, we decided to see if we could figure out where all the ancient penguins went and where all the different species of modern penguins came from. We have made a lot of progress on these questions, so let's revisit them to see if we can add to, change, or create new explanations in response to each question. Let's think about these questions one at a time.*

Distribute *Three Explanations* and have students trim and tape it into their notebook. Tell students that we will be using this handout to keep track of our ideas.

Stop and jot ideas about "Where did all the ancient penguins go?" Project **slide C** and tell students that we are going to start by thinking about the question "Where did all the ancient penguins go?" Give students a minute to look back at their materials from Lesson 1. Then instruct students to take three minutes to jot down their ideas to answer the question in the "Explanation" section on *Three Explanations*. Remind them to include a description of the sources of evidence that currently support their explanation, or if they don't have any evidence, then they should include a description of the type of additional data they would need to support or refute their explanation.



Lead a mini consensus discussion about "Where did all the ancient penguins go?" Have students share their ideas about this question. As the class agrees upon key ideas, record the ideas on a piece of chart paper titled "Where

did all the ancient penguins go?" Students should add any new ideas they hear to their *Three Explanations* handout. As students share their ideas, prompt them to back up their ideas with evidence.

Key Ideas

Purpose of this discussion: To take stock of the progress we have made in answering the question "Where did all the ancient penguins go?" even though we still have areas of uncertainty and we need additional evidence.

Listen for these ideas:

- The ancient penguins could have completely died off or gone extinct, possibly because of an environmental change. Our evidence is as follows:
  - Modern penguins have different body structure variations from ancient penguins (the structure variations are so different that the ancient and modern penguins are all different species).
  - The environments and climates the ancient penguins lived in are significantly different from the environments modern penguins live in today.
- We need additional evidence from penguins in the time period between ancient and modern penguins.
- Optional: Some lines of descendants from one or more groups of ancient penguins could have changed so much that they were no longer recognizable as that same type or are now a different species. They could have somehow changed into modern penguins. *Note: Do not push at this time for everyone to agree on the idea of the penguins changing. We have not approached change yet, and we do not have a mechanism to explain it until we figure out natural selection. This is an intended area of uncertainty at this point in the unit even if students bring it up as a possible mechanism.*

Stop and jot ideas about "Where did all the different species of modern penguins come from?" Project **slide D** and transition to thinking about the question "Where did all the different species of modern penguins come from?" Give students a minute to look back at their initial explanations from Lesson 1. Then instruct students to take three minutes and jot down on *Three Explanations* their ideas about this question. Remind them to add evidence that currently supports their explanation or, if they don't have any evidence, they should include a description of the type of additional data they would need to support or refute their explanation.

Lead a mini consensus discussion about "Where did all the different species of modern penguins come from?" Have students share their ideas about this question. As the class agrees upon key ideas, record the ideas on a piece of chart paper titled "Where did all the different species of modern penguins come from?" Students should add any new ideas they hear to their *Three Explanations* handout. As students share their ideas, prompt them to back up their ideas with evidence.

Key Ideas

Purpose of this discussion: To take stock of the progress we have made in answering the question "Where did all the different species of modern penguins come from?" even though we still have areas of uncertainty and we need additional evidence

Listen for these ideas:

- At least one species of ancient penguins has descendents that are alive today. The modern penguin(s) that are directly descended from an ancient penguin(s) don't look exactly like fossils we've seen yet because we haven't found all the fossils of all the penguins there ever were.
    - Our evidence for this is that we know some traits are heritable and in modern penguins we can see direct descendants. We can assume the fossils we looked at also had direct descendants.
- We need additional evidence or more fossils from related penguins.
- Optional: The modern penguins could have come from some species of ancient penguin(s) that changed so much that they were no longer recognizable as that species of penguin. *Note: Don't assume that the entire class is in agreement on "change" yet if the class isn't pushing for it now.*

Stop and jot ideas about "Why are there similarities and differences in the body structures of modern and ancient penguins?" Project **slide E** and transition to thinking about the question on the slide. Give students a minute to look back at their previous two mini explanations and take three minutes to jot down on *Three Explanations* notes about the question on the slide.

Lead a mini consensus discussion about "Why are there similarities and differences in the body structures of modern and ancient penguins?" Have students share their ideas about this question. As the class agrees upon key ideas, record the ideas on a piece of chart paper titled "Why are there similarities and differences in the body structures of modern and ancient penguins?" Students should add any new ideas they hear to their *Three Explanations* handout. As students share their ideas, prompt them to back up their ideas with evidence.

Key Ideas

Purpose of this discussion: To come to consensus on the progress we have made in answering the question "Why are there similarities and differences in the body structures of modern and ancient penguins?"

Listen for these ideas about why penguins might share similar body structure variations:

- Because they lived around the same time.
- Because penguins share(d) common environments.
- They are ancestors, related somehow, e.g., distant cousins.
- Our evidence includes our penguin cards showing penguins that share body structure similarities.

Listen for these ideas about why penguins have different body structure variations:

- environment changes or differences such as climate; availability and distribution of food, water, shelter; type and number of predators; availability of mates; disease or absence of disease
- changes in genes (mutations)
- something that happens within the individual in response to the environment
- something that happens to some or all the members of the population or group of penguins within a lifetime or over multiple generations

Listen for these ideas about why penguins have different body structure variations:

- something that time causes (e.g., long periods of time always lead to some change, change is constant)
- something that is random
- Our evidence includes our penguin cards with penguins that have differences in body structure variations.

Other ideas to listen for

- We need to examine additional evidence of penguins that lived between modern and ancient penguins.
- We need to examine additional evidence of penguins who lived in different environments.
- Optional: The species of different penguins might be slowly changing over time.

Assessment Opportunity

Building towards: 4.A Develop an explanation based on preliminary evidence to illustrate that changes over time occur in the existence, diversity, and disappearance of different kinds of penguins throughout history.

What to look and listen for: Students should include the following ideas in their explanations:

1. Some ancient penguins and all their descendants either died off and disappeared entirely or their descendants became a different species of penguin.
2. At least one species of ancient penguins has descendents that are alive today. This species of penguins can be similar to one of the fossils that we have seen or not because maybe we haven't discovered their fossils yet.
3. Different species of modern penguins must have descended from different lines of penguin ancestors that stretch back many, many generations.
4. Other possible ideas are listed in the key ideas callout above.
5. Students cite a line of evidence from the penguin cards and prior groupings for one or more of their explanations or identify holes in their explanations that require additional evidence to support.

What to do: If students don't have a version of ideas 1-3 above, you could include those statements as three separate claims on a single sheet of paper for students to evaluate and ask them whether they agree or disagree with each claim and why. If students don't have any of the other possible ideas referenced in the key ideas callout, that is fine. You will look for a version of these ideas when students develop revised explanations in Lesson 6. If students don't cite any evidence as described in idea 5, remind them to include at least one new line or type of evidence that they would need to either support or refute their ideas for at least one of their explanations.

4. Analyze our explanations. 5 MIN

Materials: science notebook, *Word Wall Image for Population*, chart paper, markers

Analyze explanations to identify holes and evidence still needed. Display **slide F** and say, *We used a lot of evidence from our penguin cards to support our explanations, and I also heard from you that we need more evidence. Let's quickly capture in one place the additional evidence we think we need.*

Add headings to two columns on chart paper: "Additional evidence we need" and "How this evidence will help us". Lead a discussion to surface the missing pieces of evidence in the explanations and record students' ideas on the chart paper.

Key Ideas

Purpose: To identify the weaknesses in our current explanations in order to identify additional information or evidence that we need to strengthen our explanations

Listen for these ideas:

- Some species (one or multiple) of ancient penguins must have produced the 18 lines of descendants that are alive today. This means that either some of those ancient penguins changed somehow over many generations or we are missing the fossils of penguins from long ago that are more similar to or identical to the ones of today.
  - If penguins have been changing over many generations, we suspect that these different species of penguins live(d) in different places from one another. We think this because penguins have different body structure variations that help them survive better in the specific environment where they live.
  - If there were ancient penguins that were more similar to or identical to the modern ones, we need more fossil data to support or refute that possibility.

Use prompts such as the following to uncover what other evidence we need.

Suggested prompts	Sample student responses	Follow-up question
Looking back at our three explanations. What evidence are we missing or do we think we need to support our explanations?	*We would like to see more fossils of ancient penguins.* *We want to see more data and fossils for penguins that lived between ancient and modern penguins.* *We want to examine data of penguins that lived in different environments.*	
Why is this evidence important for our explanations?	*This is important because for some ancient penguins we only have one fossil and we are missing data for penguins between ancient and modern penguins.*	*How does the lack of fossils influence the kinds of conclusions we can draw from our groupings?*

Suggested prompt	Sample student responses	Follow-up question
How does the lack of fossils influence the kinds of conclusions you can draw from your groupings?	*We can draw only limited conclusions about ancient penguin populations.* *Since we have bones from only one, individual penguin, we aren't sure if that penguin is representative of the other penguins from that population or if that penguin was somehow very different from the other penguins.*	*How do the number of fossil occurrences we have for each species of ancient penguin influence the strength of the claims we can make about what was typical in that population?*

Lead a discussion to surface how this evidence will help us fill in the holes in our explanations and add ideas to the chart under the column, "How this evidence will help us."

Suggested prompt	Sample student responses
Where are there holes or missing evidence in our explanations?	*For some species of ancient penguins there was only one fossil found, so for those we aren't sure if these fossils are representative of their whole penguin population that lived at that time.* *We still aren't sure why there are so many different kinds of penguins living today.* *Maybe there are better records out there to help us think about this since we don't have that many penguin fossils.*

Discuss *population*, *sample*, and *individual*. As students are discussing how this evidence will help us, listen for references to groupings or populations of penguins.

Add *Word Wall Image for Population* to the Word Wall to represent the differences among an individual, a sample, and a population. The provided image contrasts the word *individual*, which refers to a single living organism, with an example of a *sample* (many Adélie penguins are in the photo, but not the entire population). Because we cannot usually collect data for every single individual in a population, we take a sample. A sample is a random smaller group chosen to represent the characteristics from a whole population.

Take this opportunity to also remind students that a *population* is a group of the same species of organism in an area. This use of "species" in the definition of *population* is a step toward deepening our understanding of the word, on which we will continue to build as the unit continues.

Word Wall Image for Population

This photo includes a large **sample** of Adélie penguins, but it does not show the entire population. A sample is a random smaller group chosen to represent the characteristics from a whole population.



Additional Guidance

If your students experienced *Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit)*, you might remind them that they studied various populations of orangutans in that unit, and they defined *population* as "a group of the same kind of organism in an area." Since we are discussing so many different species of penguins and other

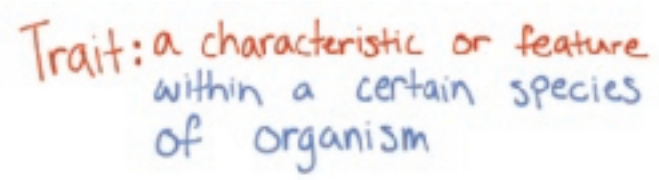
organisms in this unit, we are saying "species" instead of "kind." We will continue to build on our definition of *species* in Lesson 13.

In this lesson, we will not stress the idea of limiting a population to a geographic area since our focus is on understanding whether an individual or a small sample can represent a population.

Underneath *Word Wall Image for Population* add another sheet of paper that lists the word *sample* again along with a description of one or more examples of samples that students collected in investigations and activities that they engaged in during their math classes in the prior year (7th grade). Thinking about samples and populations builds on ideas that students developed in 7th grade math when they used random sampling to draw inferences about a population. As part of this work (CCSS.MATH.CONTENT.7.SP.A.1) they developed the understanding that statistics can be used to gain information about a population by examining a sample of the population and that generalizations about a population from a sample are valid only if the sample is representative of that population.

Clarify our definition of *trait* from *Muscles Unit*. Display **slide G**. Say, *Something else to keep in mind when we talk about different groups of organisms like penguins is how we talk about their characteristic features when we are comparing them. We know that within a certain species of organism, there are differences in their traits. For example, we see the top two animals are cattle, and we see there is variation in the coat color trait for each of these individuals. The animals in the bottom row are African buffalo. There is also variation in the coat color trait between these two individuals. When you look at cattle and African buffalo, they share many body structures. For example, they both have four legs and they both have horns. However, there are some key differences in body structures that only the cattle share with one another and not with buffalo and also that only the buffalo share with one another and not with cattle.*

Display **slide H**. Say, *So, we've been using the terms "body structures" or "behaviors" to compare different species of organisms. For example, the king penguins at the top of this slide differ from the Galápagos penguins shown on the bottom in several of their body structures. The king penguin has orange feathers on its head and neck as well as bright orange on its beak, while the Galápagos penguin has black bands on its chest and pink markings on its beak. We can't compare variation in these traits between an individual king penguin and an individual Galápagos penguin because they do not share those same structures (in this case, types of markings). Among several king penguins, however, we can see variation in the brightness of the orange feathers or beak traits, and among several Galápagos penguins we can see differences in the patterns or thickness of the banding trait or the amount of pink on the beak trait. So, let's repost "trait" to our Word Wall and update the definition a little bit. We had "trait: a characteristic or feature", and let's add "within a certain species of organism."*



End of day 1

5. Discuss "population" versus "individual".

5 MIN

Materials: None

Discuss "population" versus "individual" with penguin example. Show **slide I**. Say, *In the last class we added "population", "sample", and "individual" to our Word Wall. We also identified that we would like more fossil data because we aren't sure if the fossils that have been found are representative of all the penguin populations that lived long ago. Let's discuss an example of this. Think back to one of the 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?

Give students 3 minutes to turn and talk with a partner about these questions. Ask students to share their ideas with the whole class, then follow up with a prompt to elicit any direct evidence to support either claim.

Suggested prompt	Sample student responses	Follow-up question
Do you think penguin body structure variations were typical for the entire population of penguins that they belonged to when they were living, or do you think those variations were unique to that one individual who happened to get preserved as a fossil?	*Probably the population.* *Maybe it's unique to that individual in a few cases, but that seems unlikely across all the cases we look at.* *If we had a lot of fossil samples from the same site, we would know for sure.*	*So do we have direct evidence for either of these possibilities?*

Say, *Let's look at some additional data for the penguins and see if we can figure out if we have evidence that a body structure variation found in a fossil could represent a body structure variation found in the population.*

6. Look at ancient penguin fossil data.

5 MIN

Materials: *Reference: Analyzing and Interpreting Fossil Data*

Present penguin fossil summary data. Present **slide J**. Say, *Each single fossil that was found came from a single individual. As we have talked about, that individual must have been from a larger population of penguins that was living around that place and around that same time. Let's see what conclusions we can draw about the trait variations of that larger population of penguins based on this data table.*

Distribute *Reference: Analyzing and Interpreting Fossil Data* or direct students to it in their student editions. Give students 30 seconds to orient to the data table, specifically the first two columns.

Additional Guidance

If students ask how we know an ancient penguin was part of larger population that lived around the same time, suggest that we at least can claim that it came from two parents, which makes for a population of at least three penguins of its species (if not more) that lived within a few years of when it died (based on the typical lifetime of a penguin).

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
P. devriesi	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%
S. urbinai	4	100%
W. tuatahi	4	100%
Colossus	7	100%
Gunnari	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.

Ask the following questions to help students interpret the first two columns in the table on **slide J**.

Suggested prompts	Sample student responses
For what species of ancient penguin have the most individual fossils been found?	*Gunnari.*
How many individual fossils of this species of penguin did they find?	*Eleven.*
For some of these species of ancient penguins, scientists have found only one individual. How many species of penguins have only one individual fossil? Which ones?	*Seven.* *Water king/Pedro, P. devriesi, Harris', Simpson's, Lowe's, Lopdell's, giant spear-billed.*

Connect to the work of Julia Clarke and Ali Altamirano. Say, *So for some of these species of penguins, there was more than one individual found. In cases where we have only one or a few individual fossils found for a species of penguins, scientists like Dr. Clarke and Señor Altamirano assume there are more at the site where the original fossil or fossils were found.*

Scientists would often like to go back and hunt for more fossils in the same location, but that process takes a large amount of time and money and isn't likely to be very productive without a clear clue of where another penguin fossil might be, like the foot bone sticking out of the ground for the one that Señor Altamirano originally found.

Introduce the idea of making inferences about populations based on samples. Say, *So let's consider what we can infer about a population when we have data on only a small sample of individuals from that population.*

7. Hold a Building Understandings Discussion.

5 MIN

Materials: *Reference: Analyzing and Interpreting Fossil Data*

Surface ideas about variation to contrast variation we see among different species of penguins and that we see among individuals in the same population. Show **slide K**. Say, *Let's look at the whole table now. For the seven species of penguins listed here at the bottom of the table, scientists have discovered more than one fossil occurrence of each species. And in the right column, we have data showing that within each of those species of penguin 100 percent of fossils discovered have the same humerus bone structure variations.*

Show **slide L**. Ask students to turn and talk with a partner for three minutes to interpret the data table. Then ask students to share their thinking with the whole class.

Suggested prompts	Sample student responses
Think back to the penguin cards. How would you describe what the right column's data mean?	*Scientists compared the body structure variations for the humerus bone, and they were all the same for each of those species of penguins.* *For example, for the tiny rower penguin there are three fossils, and all three of those fossils had humerus bones with similar curvature, width, shape, and the other variations in our data set.*
What do you notice? What is the entire data table telling us?	*I notice that because we only have one fossil for some ancient penguins, we don't know if other fossils of that kind of penguin have the same body structure variations in the humerus bone.* *But we can see that for all the kinds of penguins that we have multiple individual fossils for, they all shared the same body structure variations in the humerus bone.*

Show **slide M**. Say, *Scientists have looked at other body structures besides the humerus bone and found similar patterns. They compare all the bone structures they can from the penguin fossils. This can include measurements related to the shape of the bones in its beak, skull, shoulders, kneecaps, legs, toes, spine, and hips. In every case where they have fossilized bones for more than one individual, the body structures of all the individuals can be compared. The table on this slide indicates what percent of the body structures for which there is available measurement data from each penguin species had a matching body structure variation in all fossils found.*

Continue, *If someone found another* Urbinai *penguin fossil from the same place and the same time as the* Urbinai *penguin fossils that have been found so far, what percent of body structure variations would you expect it to have in common with those fossils already found*? Students will likely say, "100 percent."

Consider the effect of sample size on certainty. Use prompts such as these to push on whether this is really a large-enough sample to be completely certain that 100 percent of the characters would be the same.

Suggested prompts	Sample student responses
We have only a few samples to base our claim on either way. Can we ever be completely certain of the body structure variation of a population based on the individuals in a sample?	*No.*
If we had more individuals in our sample, how would that affect our certainty of what is likely typical about the population they came from?	*It would increase the certainty.*

8. Continue the Building Understandings Discussion. 15 MIN

Materials: *Exit Ticket - Trait Variation*, king and/or Galápagos card from *Data Cards for Modern Penguins and Pedro* from Lesson 1, Penguin Timeline with Cards

Work with examples where sample sizes are larger. Show **slide N**. Say, *We looked at all our ancient penguins and we decided we could be more certain about making claims for what is typical for a given body structure in that population if we had more data. And we do have more data for our modern penguins.*

Go over to the Penguin Timeline with Cards you created in this lesson and focus the students' attention on the modern penguin cards. Say, *How does the sample size of each species of penguin here compare to the sample sizes of the ancient penguins we just looked at?*

Students should say the sample size is much larger and since these penguins are still alive we could get even more of this evidence, such as whenever a penguin died or maybe we could x-ray them to see their bones.

Additional Guidance

Students may be surprised there are not even more modern penguins in each of these samples. You might point out that the researchers gathering these data were specifically focused on penguins in the wild (not in zoos or other captive settings) and that finding humane ways to gather skeletons could be difficult, since one of the main reasons penguins die is because they are eaten by another animal.

Say, *Let's take a look at some body structure data for our modern penguins. In this table, we see that scientists looked at 34 body structures in the humerus bone, such as curvature, width, and shape, and 31 body structures in the skull, beak, and jaw bones. They documented how many times they found a variation that differed from the rest of the sample.*

Species of penguin	Number of specimens examined	Humerus Bone (34 body structures total measured)	Skull, Beak, and Jaw (31 body structures total measured)
		Number of body structures that differed from other penguins of the same species	
Emperor	23	1	1
King	9	0	0
Chinstrap	4	0	1
Gentoo	10	0	3
Adélie	19	0	0
Yellow-eyed	3	0	0
Southern rockhopper	5	0	1
Macaroni	9	0	0
Northern rockhopper	4	0	0
Fiordland	8	0	1
Snares	4	0	0
Royal	4	0	0
Erect-crested	14	0	0
Little	6	0	0
African	18	1	0
Magellanic	18	0	0
Humboldt	7	0	0
Galápagos	10	0	0

Data from: Ksepka, D. T., Bertelli, S., & Giannini, N. P. (2006). The phylogeny of the living and Fossil Sphenisciformes (penguins). *Cladistics*, *22*(5), 412–441. https://doi.org/10.1111/j.1096-0031.2006.00116.x and Ksepka, D. T., & Clarke, J. A. (2010). The basal penguin (aves: Sphenisciformes) perudyptes devriesi and a phylogenetic evaluation of the Penguin Fossil Record. *Bulletin of the American Museum of Natural History*, *337*, 1–77. https://doi.org/10.1206/653.1

Additional Guidance

The focus of this discussion is to recognize what we know about current populations (that even in large sample sizes from one species of penguin there is very little variation in body structures) and use that information to extrapolate to ancient penguin populations—if we are comparing two fossils and we see differences between their body structures, they are very likely different species even though we do not have many examples to investigate.

Ask students to take three minutes to turn and talk with a partner about what they notice in this data table. Then, lead a discussion to interpret this data table using prompts such as those shown here.

Suggested prompts	Sample student responses
So what is this table telling us?	*There is not much variation in these body structures for each species of penguin.*
(If needed, continue …) Even though the sample sizes available for us to study in these modern penguins are usually larger than for many of the ancient penguins, do we find a lot of variation between individuals within a population with regard to these particular body structure variations?	*Out of 34 body structures for the humerus and 18 species of penguins, only two variations in two penguins total showed differences between individuals.* *Out of 31 body structures for the skull, beak, and jaw we see only seven times where variations differed between individuals in a population, and those examples were not all in the same species of penguin.*
These data come from many penguins, and, as you pointed out, there are not many differences. Based on these data, is it common to see differences between individuals in a population at the body structure level for the humerus, skull, beak, and jaw?	*No, even when there are more penguins to look at, we don't commonly see differences in body structures between individuals in a population.* *As long as they are the same species of penguins, they will have the same body structure variations.*
For example, these scientists observed the humerus bones of 19 Adélie penguins and saw no variation in any of those 34 body structures for any of those penguins. What does that tell us about the amount of variation that is likely to occur in these body structures in a population?	*There won't be much variation.* *If it's the same species of penguin, we can expect it to have those same body structure variations.*

Suggested prompts	Sample student responses
How does seeing these data about modern penguins help us learn something different than what we learned when we looked at the number of samples we have for ancient penguin fossils?	*There were only a few species of ancient penguins that had more than one individual in the sample, and we saw that all the body structure variations measured were the same for each species.* *The sample sizes are larger for many of the modern penguins, and we see that there is occasionally variation within the same species of penguin, but it is rare.*
I hear you saying that we have several examples of modern penguins whose body structures do not vary within their species. What does that make you think about the fossils we have of ancient penguins? *Even if there aren't always as many examples to look at, do you think there would be much variation in the body structures of each ancient species?*	*I think we can expect that a fossil probably represents the body structure variations that species of penguin usually had.* *We would not expect to see much variation at all in the body structures of the same species of ancient penguins.*
These body structures we looked at are all internal. What other things did we examine initially when we were grouping our penguins?	*There were also external structures like feathers and toenails.* *We also looked at behaviors, like nest building.*
Do you think we would see differences between any penguins in a population if we looked at those external structures and behaviors?	*There would probably be a couple variations in those structures or behaviors like we saw with the internal structures, but not many.* *It seems likely that within a certain species of penguin, they would have the same internal and external body structure and behavior variations.*

Move to identifying body structures or behaviors that show variation between individuals within a population. Show **slide O**. Say, *OK, we agree that for each species of penguin, there are body structure and behavior variations that make it that species, that every penguin of that species shares. But we have evidence from the Muscles Unit that within a population of the same species of organism, there can be variation between individuals. Is that true for penguins? Let's take a look at a couple of modern penguins to see if we can identify any body structures or behaviors where we would expect to see variation between individuals in the same population. Where do we see a range of data on these cards?*

Distribute the king and Galápagos cards from *Data Cards for Modern Penguins and Pedro* or have students find those cards in their student editions or refer to the images on the slide. Ask students to find a new partner to turn and talk with and give them two minutes consider the questions on the slide:

- 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?

Bring the class back together for a discussion.

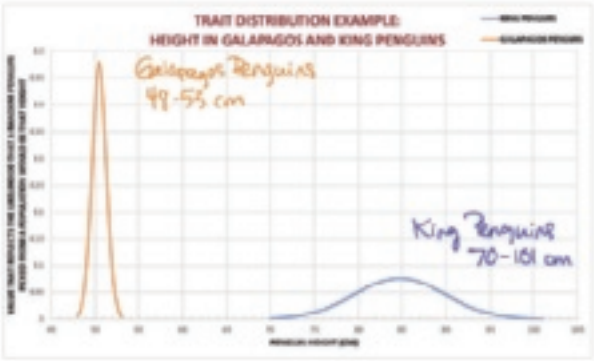
Suggested prompts	Sample student responses
What are some of the penguin body structure or behavior variations represented on these cards?	*Height.* *Weight.* *Diving depth.* *Where they swim.* *What they eat.* *Age of sexual maturity.* *Nesting months.* *Length of incubation.* *Type of nest (for Galápagos penguins).* *Number of eggs (for Galápagos penguins).* *Maybe there are also slight coloration differences in their beaks, feet, or feathers or differences in the feather patterns, like the banding.*
Which of these body structures or behaviors would be easiest for us to see variation in if we wanted to compare penguins within a population?	*Height.* *Weight.* *Nesting months.* *Maybe there are slight coloration differences in their beaks, feet or feathers or differences in the feather patterns (like the banding).*

Focus on a specific body structure to examine the range of trait variation. Show **slide P** and say, *Let's take a moment to focus on penguin height. This is a body structure that is quite different between king penguins and Galápagos penguins, and one that's easy for us to see and compare.*

Suggested prompts	Sample student responses
Can we comfortably say that all adult king penguins are taller than all adult Galápagos penguins? What evidence from the cards supports your claim?	*Yes, there is a big enough gap between the two ranges that they probably don't overlap.* *The tallest Galápagos penguin is still way smaller than the shortest king penguin.*
OK, so even though we can use height as one of the defining body structures of king penguins—we call them tall—and of Galápagos penguins—we call them short—these body structures aren't just as simple as tall versus short, right?	*Yes, there is variation in both kinds.* *The range of height given for king penguins is 2.3 to 3.3 feet.* *The range of height for Galápagos penguins is 1.6 to 1.8 feet.*
Is there evidence that there is variation in height between individuals in a king penguin population? What about in a Galápagos penguin population?	
When a range is reported, what does that actually mean? Do you think that there are an equal number of penguins of different sizes across the reported range?	*It's like the histograms we used in the Muscles Unit—they usually made a bell-shaped curve with more individuals in the middle or typical part of the range and fewer individuals on the extreme ends.*
Or do you think the tallest and shortest ever found get reported as the upper and lower limits to the range, but most of the population is somewhere in the middle of the height range?	*There are probably more average-sized penguins.* *It sounds like what we figured out about human limb length in the Muscles Unit: There are people who are 7 feet tall, but they are rare; the same is true for very short people. It is more common to see a person with a height somewhere in the middle.*

Examine two populations to help understand the connection between range and variation. Show **slide Q** and say, *This graph shows the results of measuring many, many Galápagos and king penguins.*

Give students a moment to orient themselves to the graph, then say, *We see that there is a really high chance* (refer to the peak of the Galápagos penguin height distribution curve) *that any random Galápagos penguin we pick up and measure would be right around* (point and trace down from the peak of the curve to the *x*-axis, where you will read the height) *51 centimeters. You can see there is a much lower chance of picking a random Galápagos penguin from a population and measuring it to find it is either 48 or 53 centimeters—and it would be very unlikely to find a penguin with a height outside of that range. In fact, out of the many measurements scientists have collected, they found that 99.7 percent of all Galápagos and king penguins fall within these ranges*. Point to the end points of the curves for both the Galápagos penguin height and the king penguin height to illustrate the range of heights where we find 99.7% of all penguins.

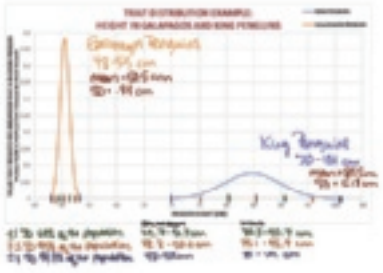


Additional Guidance

You may choose to discuss the meaning of each curve and why they look so different. Galápagos penguins are more likely to be the same height as one another than king penguins are—there is a very high likelihood that a random Galápagos penguin would be the average Galápagos penguin height. But in king penguins the variation is more spread out—you will have a greater chance of finding a wider variety of heights in king penguins. (This larger range exists in king penguins because female king penguins are a bit smaller than male king penguins.)

Alternate Activity

Highly interested students may challenge using the word "all" when referring to all adult king penguins being taller than all adult Galápagos penguins, even after examining the distribution of variation in each population. If so, you might take a moment to discuss how scientists come up with the ranges of height that are listed (even though the statistics involved are beyond what we need to know for this lesson). Optional **slide R** illustrates this idea using normal distribution graphs. Make this a quick overview as students will likely not encounter standard deviation in their math classes until they get to high school. Show **slide R** and say, *This type of graph is known as a normal distribution. Graphs like this are a special way to show the probability that a penguin we pick at random will be any given height on the curve that you would like to test. The graph was created by finding the mean of the penguin heights (which is at the center or top of the curve) and finding a statistic measuring how spread out the other measurements in the sample are from the mean, which is called the standard deviation. Scientists use the number of standard deviations from the mean to have a certain level of confidence that a random penguin would fall within these ranges. You can see there is a much lower chance of the random penguin we measure being on either end of the ranges. About 67 percent of all individuals will fall between one standard deviation of the mean, 95 percent will fall between two standard deviations of the mean, and 99.7 percent of all penguins fall between three standard deviations from the mean. The likelihood that the king penguin and Galápagos penguin heights*



would overlap with this much of a gap, (point to the space between the two curves on the graph) *and taking these probabilities into account, is really, really unlikely. So for the purpose of our investigation it is OK to use "all".*

Reflect on trait variations in an exit ticket. Show **slide S**. Say, *So height is an example of a body structure for which there is a lot of variation across the different penguin populations. Of course you could probably think of other examples too where a lot of variation can be seen in a body structure or behavior, even when the general body structure or behavior is considered "the same" for a population.*



Distribute *Exit Ticket - Trait Variation*. Ask students to complete the exit ticket: 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 words and/or pictures to share your thinking.

Assessment Opportunity

Building towards: 4.B Develop an explanation that predicts what the variation in a chosen body structure or behavior of Galápagos penguins and king penguins looks like at different scales (between species versus between individuals within a population).

What to look for: Students should include the following ideas in their predictions:

- At different scales of penguin groups (between species versus between individuals within a population of a species), the variation we are accounting for is different.
- Within a population of the same species of penguin we can also look at variation within a trait (a body structure or behavior that species has)—this variation makes individuals within a population different from one another.
- We look at variations of body structures or behaviors that are shared among all individuals in a species of penguin, and we look for differences in these variations of body structures or behaviors between different species of penguins.

What to do: If students are struggling with differentiating the between-species and within-population variations, use the height example as a comparison and walk them through the sequence of thinking for comparing height, then ask the students to do the same for the structure they chose. Two good options to steer students toward are weight and incubation time.

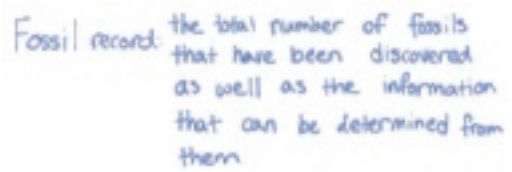
The reason this distinction is important to establish now is that eventually we need to figure out that some individuals will have variations that make them more successful (at getting resources, escaping predators, attracting mates, and so forth) under certain conditions compared to other individuals in the same population with different variations.

9. Navigation

15 MIN

Materials: science notebook, 1 copy of the Ideas for Future Investigations and Data We Need poster from Lesson 1, related phenomena chart from Lesson 1, 1 copy of the typed DQB (optional), 1-2 3" x 3"sticky notes, chart paper titled "DQB questions we have answered"

Summarize our progress thus far. Display **slide T**. Say, *We revised our explanations and we talked about what additional data we need and how that could strengthen our explanations. I heard many of us mention that we do not have very many fossils of ancient penguins and there is a gap between the fossils we have and the modern penguins we have examined. When we look at ancient fossils and gather information from them, like we have done in this unit so far, we are looking at the fossil record.*



Add *fossil record* to the Word Wall. Add to the Word Wall the phrase "fossil record." A suggested definition is "the total number of fossils that have been discovered as well as the information that can be determined from them".

Use related phenomena to determine what we should investigate next. Say, *OK, we said that we needed more data from the fossil record. We know that scientists have unfortunately not found very many ancient penguin fossils; and we have already looked at all the penguin data we have until scientists find more. However, we had some ideas in Lesson 1 about phenomena related to Pedro.*

Point students to the related phenomena chart from Lesson 1. Prompt students to turn and talk with a partner about these questions:

- How we could 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?

Bring the class back together and ask each pair to share one idea about how related phenomena could help us with either of these goals.

Revisit the Driving Question Board to answer questions.* Show **slide U**. If using, distribute to each student a typed copy of the DQB. Students may refer to this list and/or the classroom DQB. Invite them to select one question from it that they feel they have made progress on. Students will likely select a penguin-specific question. Prompt students to develop a short answer to the question based on their work in Lessons 1-4. They should write the question they chose on one sticky note and their answer on a second sticky note of a different color if possible. Then they should attach these together and stick them on chart paper (for their class) titled "DQB questions we have answered."

Alternate Activity

The protocol students follow here to answer questions from the DQB is written assuming the teacher has more than one section of this class and the DQB is a compilation of the questions from all sections. This is why the students are asked to rewrite the question on a new sticky note. If you have only one section of the class or have a separate DQB for each class, the students can use the sticky notes from the DQB and will only need one additional sticky note to answer the question. Then they can attach the sticky note with the answer to the question on the DQB.

Revisit our Ideas for Future Investigations and Data We Need. Distribute a copy of this poster for each student to add to their science notebook. Then ask students to evaluate the list of investigation ideas by putting a check mark next to each idea for an investigation that we have pursued in some way or made some progress on. If time is short, all or

*** Attending to Equity**

Universal Design for Learning: The goal in this sort of activity is to help students recognize that the work the class has done so far has made substantial progress on the class's questions and ideas for investigations and data needed to answer these questions. Such self-reflection helps reinforce a sense of agency and *relevance*.

Based on results from the pilot of the unit, it is anticipated that at this point in the unit, students will check off about half or more of the ideas for investigations and data they brainstormed in Lesson 1. If you don't have time for this activity in this lesson, it is recommended you do it as the first activity of the next class meeting before resuming the outline in the learning plan in the *Teacher Guide* for Lesson 5.

part of this reflection task can be assigned as home learning. **Conclude the lesson by looking forward to the next lesson.** Refer to the definition of *fossil record* added to the Word Wall. Say, *OK, so we've explored some of the fossil record, but we've only been looking at the penguin-related part of it. It sounds like it would be really productive to check out some other species of living things found in the fossil record to see if we can find some patterns that are more complete than those we found for penguins. Let's pick up there next time.*

ADDITIONAL LESSON 4 TEACHER GUIDANCE

Supporting Students in Making Connections in Math

CCSS.MATH.CONTENT.7.SP.A.1: Understand that statistics can be used to gain information about a population by examining a sample of the population; generalizations about a population from a sample are valid only if the sample is representative of that population. Understand that random sampling tends to produce representative samples and support valid inferences.

Ideas related to what can be inferred about a population from a sample are leveraged in the discussions in this lesson. In particular, the relative uncertainty based on a very small sample size (e.g., one or very few occurrences in the fossil record for any species of ancient penguin) drives the need for additional evidence and motivates looking at patterns of character traits in populations of organisms other than penguins in Lesson 5. We are not addressing statistics specifically; this is a connection to 7th grade math that students may make when the class is considering the kinds of conclusions they can draw from their groupings. Referencing students' prior-grade work and understanding about samples and populations can help support cross-curricular coherence for students.

SCIENCE LITERACY: READING COLLECTION 1

Earth's Long Life Story

1 **Picturing the Fossil Record**
2 **Gone but Not Forgotten**
3 **Carbon 14's Disappearing Act**
4 **Living Things**

Literacy Objectives

- ✓ Summarize key points related to fossils, extinction, and how species are related.
- ✓ Organize text details related to a metaphor of a layer cake.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 1–4.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a graphic organizer relating the science to a layer cake.

Instructional Resources

Student Reader



Collection 1

Science Literacy Student Reader, Collection 1
"Earth's Long Life Story"

Exercise Page



EP 1

Science Literacy Exercise Page
EP 1

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 1: How could penguins and other things living today be connected to the things that lived long ago?
- Lesson 2: How similar or different are different species of penguins?

Standards and Dimensions

NGSS

Disciplinary Core Idea LS4.A: The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth. (MS-LS4-1)

Science and Engineering Practice: Analyzing and Interpreting Data

Crosscutting Concepts: Scale, Proportion, and Quantity; Patterns

CCSS

English Language Arts

RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

Math

CCSS.MATH.CONTENT.6.RP.A.1: Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote candidate A received, candidate C received nearly three votes."*

- Lesson 3: How do the body structures of other ancient penguins compare to modern penguins?
- Lesson 4: Why are there similarities and differences in the body structures of modern and ancient penguins?

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

fossil record **mass extinctions**

species **taxa**

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

homeostasis **isotope**

phylogenetic tree **radiocarbon dating**

radiometric dating **sedimentary rock**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

Exercise Page



EP 1

2. Preview the assignment and set expectations. (Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Natural Selection and Common Ancestry unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *First, you will interpret a diagram showing geologic time periods in Earth's history and the record of fossils of organisms that lived in each period.*
  - *Next, you'll read about the top five mass extinctions in Earth's history, when they took place, and some hypotheses about what caused them.*
  - *Then, talking carbon atoms will explain to you how scientists compare the proportion of one type of carbon atom to another type to deduce the age of fossils. While atoms don't really talk, the rest of the science is all true!*
  - *Finally, you'll read a photo essay that will have you ponder the meaning of "life."*
- Distribute Exercise Page 1. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a graphic organizer that uses the metaphor of a layer cake to relate the selections in this collection.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
Where in Earth's crust are the oldest sedimentary rock layers compared to the youngest layers?	*They are below the younger layers, deepest underground.*
What was the fate of 99% of the species that have ever existed on Earth?	*They went extinct.*
What does the ratio of carbon 14 to carbon 12 isotopes in a fossil reveal?	*how old the fossil is*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
How do scientists figure out which extinct species are related to species living today?	*They look at their heritable traits, such as body structures.*
In class we learned that Pedro the penguin lived 36 million years ago. How do you know scientists did not figure this out using radiocarbon dating?	*because radiocarbon dating only works for fossils that are up to 50,000 years old*
What does a phylogenetic tree show?	*It shows which species share similar genetic information.*

- Refer students to the Exercise Page 1. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
- *The writing expectation for this assignment is to draw a graphic organizer to communicate something you learned from each of the four readings.*
- *Notice that the title of the page is "Earth's Life Story Layer Cake." For each reading, write a sentence about how the layer cake metaphor works to explain the science.*
- *Don't worry about what your classmates are writing. Just use your creative thinking.*
- *Make sure to write your own words about what you learned, instead of copying text from the reading.*
- *If you write the statements first and then draw boxes around them, your design may be more effective.*
- *Color choices are up to you, but you might want to use colors to suggest your favorite flavor of cake and icing!*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page



EP 1

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise. The reading begins with a somewhat complex graphic showing the geologic timescale related to the fossil record. The reading ends with another complex graphic, a phylogenetic tree. Encourage students to spend as much time "reading" the graphics as reading the text.

Pages 4–13 Suggested prompts	Sample student responses
What is the general purpose of the first selection, "Picturing the Fossil Record"?	*It explains what the fossil record is and how scientists interpret it to describe the history of life on Earth.*
Diagrams showing geologic time and the fossil record can be difficult to interpret. What did you find challenging?	*The layers don't seem to be in proportion to the number of years shown by the labels.* *The names of the eons and eras are hard to say and remember.* *The pictures of the fossils don't have names, so you just have to compare the pictures.*
What is the name of the era in which Pedro the penguin lived? Explain how you know.	*the Eocene, because that era was from 33.9 to 55.8 million years ago and Pedro was dated to 36 million years ago*
What evidence from the fossil record supports the idea that the trilobites were a very successful group of living things?	*the fact that their fossils can be seen in rocks representing 240 million years of Earth's history*
Summarize the data shown in the circle graphs.	*They show that mass extinctions have ranged from wiping out from 75 to 96 percent of all living species.*
What is the general purpose of the second selection, "Gone but Not Forgotten"?	*It describes the five biggest extinctions in Earth's history.*
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first article displays and names all of the eras and eons in Earth's history. The second article details the locations on the graphic where the biggest mass extinctions occurred.*
What fact or idea from this selection most impressed or surprised you?	*Mass extinctions seem to be a regular "thing" on Earth.* *Tyrannosaurus lived ONLY 65 million years ago. It's not that long compared to the age of Earth.* *The ancestor of mammals looks like a reptile.*
Summarize the causes of mass extinctions.	*They are caused by climate change, changes in sea level, volcanic eruptions, wildfire, moving continents, asteroid crashes, and unknown causes.*
What is the general purpose of the third article, "Carbon 14's Disappearing Act"?	*It explains how the ratios of different isotopes of carbon in nature can be used to calculate the approximate age of fossils.*

Student Reader



Collection 1

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

SUPPORT—Refresh students' understanding of percentages as describing part-whole relationships. Point out that a circle graph is a good way to visualize parts to whole. The entire circle is the whole and the colored section of the whole shows what part, fraction, or percentage visually.

CHALLENGE—If students are interested in learning more about isotopes and subatomic particles, point them to videos on these topics. Challenge them to assemble the most interesting facts in an infographic to share with other students.

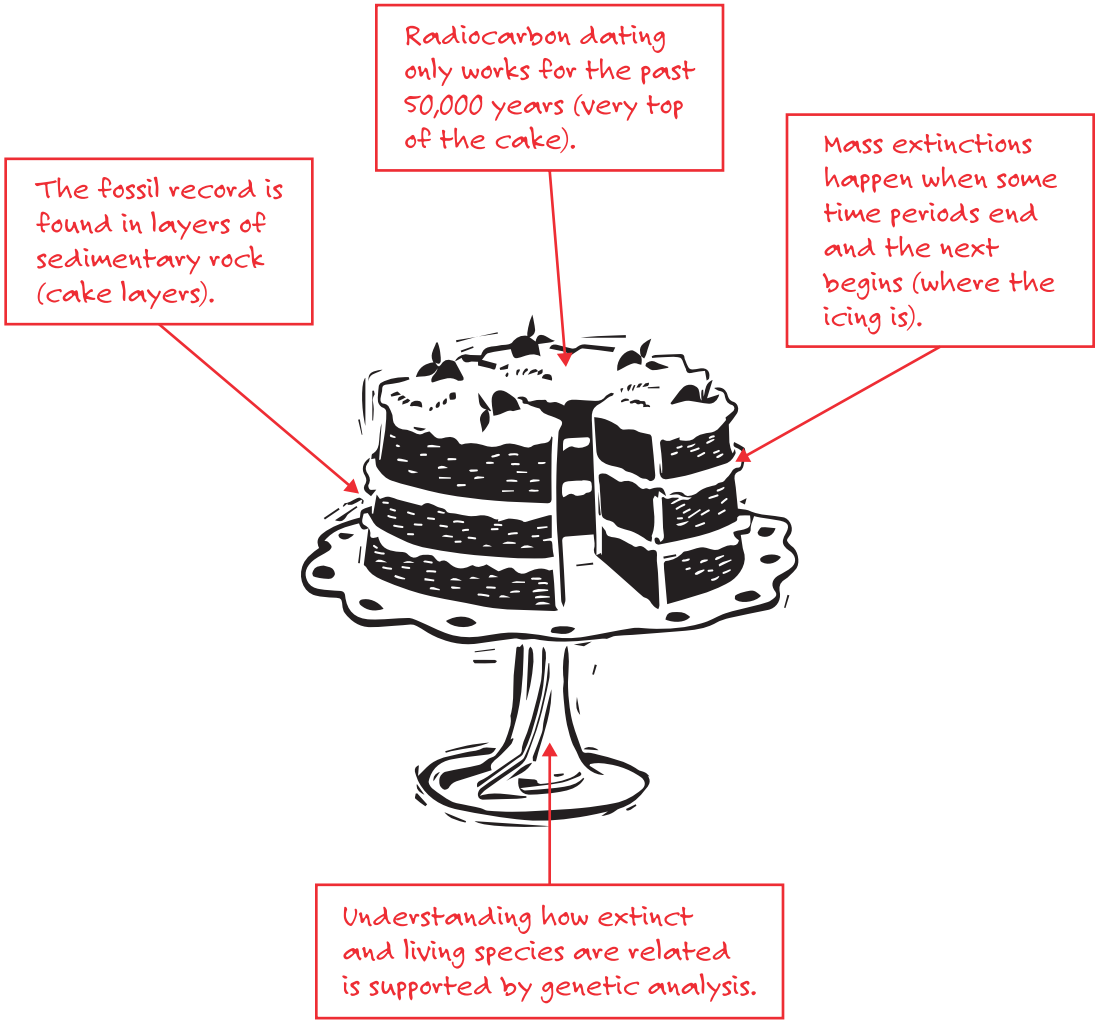
Pages 4–13 Suggested prompts	Sample student responses
The title of this selection talks about "disappearing." What, exactly, disappears?	*A neutron seems to disappear when it changes into a proton.* *A carbon 14 isotope disappears when it changes into a nitrogen 14 isotope.*
What questions do you have about atoms and isotopes after reading this selection?	*Does every kind of atom have isotopes or just carbon atoms?* *Is the radioactivity from carbon 14 isotopes dangerous to people?* *What about electrons? Do they have anything to do with one isotope changing into another?*
What is the general purpose of the fourth article, "Living Things"?	*It defines "living" by listing traits to look for and explains how living things are classified.*
What does it mean for a human body to maintain homeostasis?	*keeping its temperature around 98 degrees F* *getting food particles to cells that need them* *getting oxygen to cells and carbon dioxide out of the body* *getting water to places that need it and getting rid of excess water*
What can you learn about taxa by looking at the graphic on pages 12 and 13?	*which animal groups are parts of the same taxon and how those taxa are related*
How does this selection build on our class discussions of how scientists decide what species are related?	*In our class discussions, we learned that species are classified by their structural characteristics and behaviors. In this selection, we learned that they are also classified by how similar their genes are.*
The graphic in this selection is a type of tree diagram. How did it get its name?	*It looks a little like a tree that was cut down with the branches and twigs still connected.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 1, students should, following a template, draw a graphic organizer showing how the idea of a layer cake is related to each of the four readings in Collection 1. Look for evidence that students understand that the cake, with its layers, is a metaphor for the history of life on Earth. A sample completed organizer is shown below, but students may cite other examples from the readings.

Earth's Life Story Layer Cake



Use the rubric provided on the Exercise Page to supply feedback to each student.

Online Resources

EXTEND—Students may prefer to use a free online drawing or mind mapping tool or app to create their graphic organizer. Note that some tools require an email address to get started. Before using with students, preview the tool or app to determine that it conforms to your school's internet-use policies.

LESSON 5

How might other living things be connected to ancient organisms?

Previous Lesson

We revised our initial explanation to account for the patterns in the data from the previous lessons. We still had several candidate ideas for what might be causing these patterns. We compared variation data for body structures of the penguin fossils we have and modern penguins. We revisited our Driving Question Board and our list of related phenomena and decided to investigate connections among other ancient and modern organisms.

This Lesson

Investigation

2 DAYS



Whale: US NOAA - PD

We investigate organisms other than penguins to see whether the patterns of connections between ancient and modern organisms that we saw with penguins also occur in other types of organisms. We sort data cards for ancient and modern horseshoe crabs, horses, and whales to see what patterns of similarities and differences exist in their body structures. We consider and discuss whether and how the patterns we notice in their body structures might be connected to where they live(d) or when they live(d). We confirm that similar kinds of relationships exist in ancient and modern horseshoe crabs, horses, and whales as well as in penguins.

Next Lesson

We will argue in support of claims for how modern organisms are connected to ancient organisms through a line(s) of descendants. We will propose possible explanations for those connections. We will add new questions to our Driving Question Board related to possible mechanisms causing this change.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

5.A Analyze and interpret data from images to identify patterns of similarities and differences in modern organisms and the fossil record and use the patterns to look for relationships between ancient and modern organisms.

5.B Respectfully provide and receive critiques about models of the similarities and differences (patterns, stability, and change) in some of the body structures of organisms observed over time and in different environments based on evidence from the fossil record.

What Students Will Figure Out

- The structures of some other living things today (like whales, horses, horseshoe crabs) look similar to but not exactly like the most similar-looking fossils we can find.
- Sometimes, but not always, there are noticeable differences in specific body structures (limbs, skulls, teeth, shells). Sometimes, but not always, there are changes in overall size of the organism.
- The further back in the fossil record we go, the more pronounced those structural differences are (and the less horseshoe crab-like, horselike, whale-like that type appears to be).
- Sometimes, but not always, body structures of organisms seem to match the environment in which they live(d) (e.g., teeth or limbs adapted for forests or grasslands).

Lesson 5 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION: WHAT'S OUR QUESTION?** Recall what we figured out in our previous lesson and motivate the need to look at data from other organisms.	A	
2	20 min	**SORT ORGANISMS BY BODY STRUCTURES** Work in small groups to sort organisms by body structure similarities and differences and to create a model representing those patterns.	B	*Day 1: Horseshoe Crab Data Cards* or *Day 1: Horse Data Cards* or *Day 1: Whale Data Cards*, 3" x 3" sticky notes (several per group)
3	15 min	**COMPLETE A GALLERY WALK TO COMPARE MODELS** Observe how groups that have the same organism decided to organize their cards. Identify additional data needed to better understand the patterns in similarities and differences of the organisms' body structures.	C-D	1 set of stickers that corresponds to the organism data the student has been working with, 3" x 3" sticky notes (several per group), model prepared by students in previous activity
4	5 min	**MAKE A PREDICTION** Take a poll on predictions about how *where* and *when* organisms live(d) might be connected to how similar they are based on their body structures and discuss reasons with a partner.	E-F	
				End of day 1
5	5 min	**SHARE PREDICTIONS** Share reasons for predictions about how *where* and *when* organisms live(d) might be connected to how similar they are based on their body structures.	G-I	*Patterns for My Organism: _____*, *Maps of Earth's Surface Over the Last 50 Million Years*, *Maps of Earth's Surface 150 and 100 Million Years Ago* for horseshoe crab groups only, *Day 2: Horseshoe Crab Data Cards* or *Day 2: Horse Data Cards* or *Day 2: Whale Data Cards*

Part	Duration	Summary	Slide	Materials
6	10 min	**SORT ORGANISMS BASED ON WHEN THEY LIVED OR WHERE THEY LIVED** Examine whether patterns of the environment where the organisms live(d) or patterns of the time when the organisms live(d) seem to help explain patterns of body structures in their organisms.	J-M	*Patterns for My Organism: _____*, *Maps of Earth's Surface Over the Last 50 Million Years*, *Maps of Earth's Surface 150 and 100 Million Years Ago* for horseshoe crab groups only, *Day 2: Horseshoe Crab Data Cards* or *Day 2: Horse Data Cards* or *Day 2: Whale Data Cards*
7	10 min	**SHARE PATTERNS** Share findings in a Scientists Circle with the other groups that have been examining the same organism.	N	*Patterns for My Organism: _____*
8	9 min	**CREATE A CONSENSUS MODEL** Work together in small groups to create a consensus model showing students' understanding of how their organisms are connected across time and environments by their body structures.	O	*Patterns for My Organism: _____*, 1 set of stickers that corresponds to the organism data the student has been working with, *Maps of Earth's Surface Over the Last 50 Million Years*, *Maps of Earth's Surface 150 and 100 Million Years Ago* for horseshoe crab groups only, *Day 2: Horseshoe Crab Data Cards* or *Day 2: Horse Data Cards* or *Day 2: Whale Data Cards*
9	9 min	**EXPLAIN YOUR ORGANIZATION IN JIGSAW GROUPS** Share and critique the models students developed in the last activity during a jigsaw activity in groups of three students who worked on different organisms.	P-R	*Guiding Questions to Compare Our Models*, *Peer Feedback Guidelines*
10	2 min	**NAVIGATION** Articulate answers individually to the last two questions on *Guiding Questions to Compare Our Models* to identify remaining questions about patterns of connections between ancient and modern organisms.	S	*Guiding Questions to Compare Our Models*

End of day 2

Lesson 5 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • 1 set of stickers that corresponds to the organism data the student has been working with • *Patterns for My Organism: _____* • *Guiding Questions to Compare Our Models* • *Peer Feedback Guidelines*	• *Day 1: Horseshoe Crab Data Cards* or *Day 1: Horse Data Cards* or *Day 1: Whale Data Cards* • 3" x 3" sticky notes (several per group) • model prepared by students in previous activity • *Maps of Earth's Surface Over the Last 50 Million Years* • *Maps of Earth's Surface 150 and 100 Million Years Ago* for horseshoe crab groups only • *Day 2: Horseshoe Crab Data Cards* or *Day 2: Horse Data Cards* or *Day 2: Whale Data Cards*	

Materials preparation (30 minutes)

Online Resources 

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Day 1

- **Group size:** 2-4 students
  - It is important to have equal numbers of groups for each of the organisms (horseshoe crab, horse, and whale) and to have at least two groups working on each organism (i.e., a minimum of 6 groups per class).
- **Setup for cards**
  - Gather your color copies of *Day 1: Horseshoe Crab Data Cards*, *Day 1: Horse Data Cards*, and *Day 1: Whale Data Cards*. If you do not have the materials kit, print them in color on cardstock, if available. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally. Print sets of organism cards and their cover sheets from *Day 1: Horseshoe Crab Data Cards*, *Day 1: Horse Data Cards*, and *Day 1: Whale Data Cards*. Cut each set into half-sheet cards. Each set will have a cover sheet explaining common characteristics. You will need two or more sets for each organism (horseshoe crabs, horses, and whales): one set for each group that is working on that particular organism. Make enough sets for groups in your largest class.
  - You may choose to laminate the cards. Clip the cover sheet and all cards for the same organism together in sets. These are nonconsumables that you will collect and reuse in all classes.
- **Setup for stickers**
  - Gather the preprinted color copies of the *Horse Stickers, Horseshoe Crab Stickers*, and *Whale Stickers* from your kit. Or, if you do not have premade stickers from the materials kit, print each type of stickers in color onto a letter-sized sheet of ¾" x ¾" square labels using a zero-inch margin. Print sufficient copies of so each student can have two sets of stickers. (Note that each student will need one set of stickers for their organism for this day 1 activity and one set of stickers for their organism for an activity on day 2 in this lesson. There are 8 sets of stickers per sheet, so each sheet is enough for 4 students).
  - Cut sets of stickers from each sheet for easy distribution to students.

- If stickers are not available, there are a few other ways students can record their ideas.
  - You can print the *Horse Stickers, Horseshoe Crab Stickers*, and *Whale Stickers* files onto regular copy paper, and students can cut the images into individual squares and tape the arrangement of their organisms into their notebook. Note that this will take longer.
  - Students may take a photo of the arrangement of their data cards on their desktop or table, print it out (sharing with their teacher if needed), then attach the printout in their science notebook.
  - Students can take a photo of their arrangement and transfer the information in the photo to their notebook outside of class time or as part of home learning.
  - Students can make a sketch or diagram of their card arrangement directly in their science notebooks.
- **Other materials**
  - 3″ × 3″ sticky notes, about a dozen per student group
- **Storage:** Store cards in sets using resealable plastic bags or plastic tubs for future use. Store any unused stickers along with the cards.

Day 2

- **Group size:** At first, students will be in the same groups of 2-4 as on day 1. Then later in the day they will reorganize into new, jigsaw (mixed) groups of 3 students each (1 student for each organism).
- **Setup for cards:**
  - Gather from your kit or print in color all data cards from *Day 2: Horseshoe Crab Data Cards*, *Day 2: Horse Data Cards*, and *Day 2: Whale Data Cards*. You will need two or more sets for each organism (horseshoe crabs, horses, and whales): one set for each group that will be working on that particular organism. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally. Make enough sets for groups in your largest class. Cut each set into half-sheet cards. You may choose to laminate these cards, also.
  - Clip the cover sheet and all cards for the same organism together in sets. These are nonconsumables that you will collect and reuse in all classes.
- **Other materials**
  - Print one copy of *Patterns for My Organism:* _____ and one copy of *Guiding Questions to Compare Our Models* for each student.
  - Have available one set of relevant *Horse Stickers, Horseshoe Crab Stickers*, or *Whale Stickers* for each student (see information about these stickers day 1's setup).
  - Each group will need to be able to access a class copy of *Maps of Earth's Surface Over the Last 50 Million Years* from Lesson 3.
  - Each group working with horseshoe crabs will need access to a copy of *Maps of Earth's Surface 150 and 100 Million Years Ago*, either in the student edition or as handouts which can be reused for all classes.
  - *Peer Feedback Guidelines* in student editions or printed as handouts to collect and reuse in each class
  - *Patterns for My Organism:* _____

- *Guiding Questions to Compare Our Models*
- *Maps of Earth's Surface Over the Last 50 Million Years* (from Lesson 3)

- **Storage:** Store card sets using resealable bags or plastic tubs for future use.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students dig more deeply into analyzing data to look for patterns of body structures and variations in those body structures among ancient and modern organisms of the same type. Students will identify body structures and body structure variations in fossils. They will explore how similarities and differences in those body structure variations relate to time (when and how close together in time organisms lived) and location (where geographically and in what local environment organisms lived). Students will investigate three types of organisms other than penguins to look for generalizable patterns of connections that occur in all organisms. They will find and describe patterns and relationships between ancient and modern organisms that may or may not reflect the commonly understood evolutionary relationships.

In this lesson, students are still describing patterns and connections between organisms. We are not yet focusing on changes in the distribution of traits in populations of descendants over time. Many students, however, are likely to suggest this idea themselves by this point in the unit, and that is fine, but do not confirm or deny it for them. This lesson lays the groundwork for Lesson 6 where students will propose the possibility of changes in populations happening over time, and then they will investigate, find evidence for, and confirm that idea as the unit continues.

This lesson also provides several opportunities for students to engage in discussions to build understandings and discuss their findings with others that are often led by the teacher in a whole-class group. However, since this is the end of 8th grade and students have had many experiences with these kinds of discussions, the teacher releases that responsibility to students in this lesson, and they hold these discussions in small groups of peers without the teacher's direct leading.

Where We Are NOT Going

Throughout this lesson, students will be talking about patterns and possible relationships of those patterns to time and environment. However, they will not articulate whether those patterns indicate any kind of evolutionary or ancestry-based relationships. The focus is on the data they have rather than on what it implies about connections between ancient and modern organisms. They will be looking only at patterns of similarities and differences and patterns of time and location. Though these patterns could be assembled to create an argument supporting changes in body structures through a line of ancestry over time, that does not happen in this lesson. Instead, students work in this lesson to gain a deep understanding of the data and the patterns that will then be used later to support such an argument.

At this point, students still might hold Lamarckian ideas that individuals might change over their lifetime and pass on those changes in traits to offspring. Also, students might have partial understandings about differences between traits in individuals versus differences between trait distributions of populations. These ideas are still OK at this point. In the next lesson, students will get an opportunity to revise and refine their ideas. And, in the second lesson set (Lessons 7-10) the class focuses on figuring out what is actually changing over time (populations rather than individuals).

LEARNING PLAN FOR LESSON 5

1. Navigation: What's our question?

5 MIN

Materials: None

Revisit previous learning. Display **slide A**. Ask students to turn and talk and recall what we figured out in our previous lesson. Then bring the class back together for a discussion.

Suggested prompt	Sample student responses
What did we figure out in our last lesson?	*There seem to be similarities connected to when penguins lived in time, but we don't know why that is.* *If the penguins are connected by ancestry, we aren't sure why they don't still look the same.* *We know Earth has changed over time and the climate was different at different times, but we don't know how or if that's connected to why ancient and modern penguins are different.* *We want to know if this pattern works for more than just ancient penguin populations. Is there more information for different kinds of ancient and modern organisms?*

Summarize by saying, *After our last lesson, we were thinking that populations of organisms could be connected by similarities in their body structures. We ended the class by reviewing our DQB and noticed that we had some questions about whether the patterns we see in penguins hold for other organisms, like those from our list of related phenomena. Let's see if we can figure out if what happened with the penguins was unique or if we see similar patterns in other organisms.*

Suggested prompt	Sample student responses
How could looking at data from other ancient and modern organisms help us answer our questions?	*We could see if other organisms have similar or different body structures compared to species similar to them that lived long ago.* *We could see how the body structures changed over time.* *We could see if there are changes in the size of structures or whether the structures are there at all.*

Say, *Let's do that by looking at some additional examples of both ancient and modern organisms just like we did with the penguins. We will not have time to look at all of the exact organisms we listed on our related phenomena, but we have substantial data sets for three organisms that might be similar to some we have on our list.*

2. Sort organisms by body structures.

20 MIN

Materials: *Day 1: Horseshoe Crab Data Cards* or *Day 1: Horse Data Cards* or *Day 1: Whale Data Cards*, 3" x 3" sticky notes (several per group)

Introduce the sorting activity. Display **slide B**. Say, *We're going to divide into small groups which will each focus on data from different kinds of ancient and modern organisms of the same type. Our goal is to organize them according to how similar or different they are. Before we do this let's recall some understandings about the nature of science: science knowledge is cumulative, and many people from many generations and nations have contributed to science knowledge. When we are working with these data today, no single group will have the whole picture or all the answers. Instead, each group will have a piece of the puzzle we can put together later to get a clearer picture of what might be going on with how ancient and modern organisms are connected.**

Organize students into at least 6 groups with at least 2 groups for each of the 3 organisms (2 groups for horseshoe crabs, 2 groups for horses, 2 groups for whales).*

Additional Guidance

Later in the lesson, groups working on the same organism will pursue different lines of investigation and then compare their findings, so it is necessary to have more than one group per organism. Also, to facilitate an activity on day 2, be sure there are the same number of groups for each organism, i.e., 6 groups (2 for each kind of organism), 9 groups (3 for each kind of organism), or 12 groups (4 for each kind of organism). This way, experts on each of the three organisms can convene in mixed jigsaw groups on day 2 to report their findings. The number of students per group may range from 2-4 so that you can compose these groups.

Discuss how this work of image sorting is creating a model. Use prompts such as the following to consider the modeling we're doing in this lesson (and unit).

Suggested prompts	Sample student responses
We'll have groups working with horseshoe crabs, whales, and horses today. What is the question we're trying to answer as you analyze the data we have about these modern and ancient organisms?	*How are the ancient and modern organisms connected?* *What do they have in common or what's different?*
Like we did with the penguins, I have data cards for various species of these ancient and modern whales, horses, and horseshoe crabs. How will you use those cards to help you answer your question about how they're connected?	*We can sort the cards into groups like we did with the penguins.* *We can organize the cards based on features they have in common, like similar body structure variations, when they lived, or where they lived.*

*** Supporting Students in Engaging in Analyzing and Interpreting Data**

Remind students here about the nature of science, especially around the understanding that science is a way of knowing. Science knowledge is cumulative, and many people from many generations and nations have contributed to science knowledge. When students are doing this activity it is not expected that students get a "right answer" or that any group or student has all the answers. This is a great opportunity to stress the ideas of collective knowledge and that we need everyone in the class to work together since this is such a large data set.

*** Attending to Equity**

Emerging Multilingual Learners: Students will work with these groups for several activities in this lesson that involve thinking and rethinking. It may be helpful to intentionally put together emerging multilingual students with peers whose English language development is similar to theirs. As students sort cards to show connections, encourage them to express their reasoning using both linguistic and nonlinguistic modes such as drawings, symbols, and gestures.

Suggested prompt	Sample student responses
I hear you saying you plan to develop a model similar to what we have started for our penguins. We have been making sense of how the ancient and modern penguins are connected, and we're using the way we have sorted or grouped the data cards to illustrate that thinking. How will the way you organize your data cards today also be a model?	*We will be organizing our data cards to show our ideas about how those ancient and modern animals are connected.* *The way our cards are organized will represent our thinking about the patterns—of similarities and differences we find.*

Let students know that the ancient organism data cards they will examine show bones or other structures that have been fossilized. Review the directions shown on **slide B**.

Additional Guidance

Each card set includes a list of characteristics that define each of the organisms: horseshoe crabs, whales, and horses. This list is provided simply to support students as they begin to look for similarities and differences among the species of that organism.

Work in small groups to organize the data cards. Distribute *Day 1: Horseshoe Crab Data Cards*, *Day 1: Horse Data Cards*, and *Day 1: Whale Data Cards* to the appropriate groups, along with sticky notes. Circulate among the groups as they work. Students should create a model based on similarities and differences in body structures and lay it out on their table as they sort. Students might choose to sort their organisms in a line or in multiple clusters. They should use sticky notes to label the body structures and variations they used to sort their organisms.*



Assessment Opportunity

Building towards: 5.A.1 Analyze and interpret data from images to identify patterns of similarities and differences in modern organisms and the fossil record and use the patterns to reconstruct relationships between fossil (ancient) and extant (modern) organisms.

What to look and listen for: Circulate as students work to formatively assess students' identification and use of patterns to sort ancient and modern organisms based on their body structures. Different groups may have focused on different body structures and noticed different patterns that led to different organizations. Listen for these general ideas:

- The structures of some living things today look similar to but not exactly like the most-similar-looking fossils we can find.
- Sometimes, but not always, there are noticeable structural differences.
- Sometimes, but not always, there are differences in overall size of the organism.

Look for students to sort and arrange their specific organism data cards based on the following body structures and variations:

- horseshoe crabs: shape of shell, position of eyes, number of spines

* Supporting Students in Developing and Using Patterns

If students are struggling to identify body structures and/or variations on which to base their sorting, help them to think more deeply with probing questions such as these:

- What do you notice about your organisms overall?
- What parts of your organisms are you able to examine?
- What features do you notice about the ___ (legs, skulls, shells) of your organisms?
- What are the structures that all species have in common for your organism?

If students are struggling to get started, ask them to look for one characteristic that will allow them to divide their organisms into two groups. Prompt them to continue dividing into subgroups based on similarities in body structures.

- horses: number and size of toes, shape and size of teeth
- whales: presence or size of hind limbs, presence or absence of teeth, short or long skull, position of blow hole on skull

What to do: If students are struggling to identify patterns among the organisms, help them focus specifically on the structural body structures they've identified as important. Ask them to verbally explain or to show you visually what is similar and what is different among the organisms. Prompt them to group together things they'd describe as mostly similar and divide into separate groupings those things they'd describe as mostly different.

You may also choose to assess student understanding when students use stickers to record in their science notebooks the patterns they found after the gallery walk and discussion in the next step.

3. Complete a gallery walk to compare models.

15 MIN

Materials: science notebook, 1 set of stickers that corresponds to the organism data the student has been working with, 3" x 3" sticky notes (several per group), model prepared by students in previous activity

Do a gallery walk around models of the same organism. Display **slide C**. Have students title a page in their science notebook: "Organizing (name of organism) by body structures". Below that they should draw a Similarities and Differences T-chart.

Say, *You're going to take a look at how other groups that worked with the same organism decided to organize their cards. As you look at their models, record how they did their organizing and how it is similar to or different from how your group organized the organism cards*. Allow students to circulate around the room and take a quick look at the models of any other groups working with their same organism. Students should record in their science notebook the similarities and differences in other groups' organizations compared to their own. If students have a critique or question to leave for the models they visit, have them write it on a sticky note, citing the pertinent evidence from their own sort to support their critique or question.

After 3-4 minutes, have students go back to their original group and discuss what they recorded during the gallery walk and make any desired adjustments to their own model.

Say, *Consider the critiques others left on your model and critique your own work now that you've seen how other groups organized the same data. As you adjust your group's model, support any changes you propose by telling your group the relevant evidence you noticed from viewing other groups' models.**



Circulate through the groups to listen to their conversations. Pass out additional sticky notes if needed.*

Assessment Opportunity

Building towards: 5.B.1 Respectfully provide and receive critiques about models of the similarities and differences (patterns, stability, and change) in some of the body structures of organisms observed over time and in different environments based on evidence from the fossil record.

*** Supporting Students in Engaging in Analyzing and Interpreting Data**

This activity gives students multiple opportunities to refine their thinking through small-group discussion and metacognition about what patterns of similarity and difference in body structures exist among ancient and modern organisms as they consider how their group's thinking compares to that of others. As students are discussing what similarities and differences they noticed about how other groups organized organisms, ask them to consider how their thinking may have changed or been confirmed based on similarities and differences among different groups' analyses.

What to look and listen for: By this final unit of 8th grade, students should be very familiar with classroom norms that guide respectful conversations. Closely listening and trying to make sense of their peers' ideas should be a well-established practice in small-group argument sharing. Though students are not yet building mechanistic explanations, they should be supporting their ideas and organizational models with patterns in the data sets that their peers shared. Students should also be posing and responding to questions to elicit additional details or to clarify the patterns in these models when there is something they don't understand.

What to do: If you see or hear students struggling to maintain a respectful tone of voice or failing to support their critiques with ideas from the data cards, point them back to the classroom norms and other expectations you have set for productive discussions. As needed, provide sentence starters such as those from the *Communicating in Scientific Ways* poster from Lesson 1. You might also use sentence starters such as these: "I see …", "I notice …", "The reason I think my evidence supports my claim is because …", and "The model shows that …."

Display **slide D**. Distribute to each student the appropriate set of stickers from *Horse Stickers*, *Horseshoe Crab Stickers*, or *Whale Stickers*. Students should use stickers of their organisms to individually record in their science notebook their revised model along with explanatory notes so they can revisit their thinking on day 2 and later in the unit. This is similar to what they did in Lesson 2.

Additional Guidance

If you do not have stickers to support students in recording their ideas, see the alternate ideas suggested in the Materials Preparation section, such as having students sketch in their notebook or take a photo of their arrangement of cards and labels. If students take photos, you might consider having them upload the photo files using a digital tool such as Google Jamboard so they can revisit their work and compare their work to other groups.

After students have added stickers to their notebook, say, *Based on our work today, we have some ideas about connections among organisms based on their* body structures. *Think about what other information you might want to examine to help us refine our thinking and understand what the patterns we noticed might mean. Record these ideas in your notebook and be ready to share your thinking with the class in a few minutes.*

Invite students to share some of the ideas they recorded in their science notebook.

Suggested prompts	Sample student responses	Follow-up question
Now that we have some ideas about how connected our organisms might be based on their body structures, what other information do we need to better understand the patterns we noticed? Did we have other information about the penguins that we might want about the horseshoe crabs, horses, and whales to refine our thinking?	*We should look at where they live or lived to see if they group together that way, like the penguins seemed to.* *We should look at when the organisms lived to see if they group more closely if they lived more closely in time, like the penguins seemed to.*	*It sounds like we should look for other connections in geographic location and in time.*

* Supporting Students in Engaging in Argument from Evidence

As students discuss what they noticed and make adjustments to their organizational models, everyone should share ideas and ask questions of their group members to understand their thinking. Students should respectfully ask probing questions. Provide sentence starters to help students understand the thinking and ideas of their group members:

- Why do you think _____?
- Can you explain why you think these two organisms are more similar/less similar?
- Can you show us what evidence from the card supports your idea?

4. Make a prediction.

5 MIN

Materials: science notebook

Make predictions based on location and time. Say, *Let's try analyzing our data on these organisms in a different way—looking for some of the patterns we looked for in our penguin data. Before we do, let's make a couple of predictions.* Show **slide E**. Give students a half minute to read through both questions to get ready to take a poll. Then poll the class on the following two questions, having students show their response with a thumb up, down, or sideways (not sure).

- Do you think that how similar organisms are (based on their body structures) will be connected to where 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?

Discuss reasons with a partner. Show **slide F**. Give students the remaining class time to talk with a partner about the reasons they made the predictions they did.

Close today's work by telling students, *Be prepared next time to share the reasons you and your partner gave for your predictions. You can record your ideas in your science notebook if that's helpful.*

Collect data cards for reuse in upcoming classes.

End of day 1

5. Share predictions.

5 MIN

Materials: *Patterns for My Organism:_____*, science notebook, *Maps of Earth's Surface Over the Last 50 Million Years*, *Maps of Earth's Surface 150 and 100 Million Years Ago* for horseshoe crab groups only, *Day 2: Horseshoe Crab Data Cards* or *Day 2: Horse Data Cards* or *Day 2: Whale Data Cards*

Share reasons for predictions from last time. Display **slide G**. Say, *Last time, we started considering how the similarities and differences in body structures of your organisms might be connected based on when or where they live or lived. Look back at your science notebook, if needed, and let's share some of those reasons with the whole group.*

Encourage students to describe their partner's reasons first before explaining how their own predictions compare and why. Accept all answers.

Prepare to sort organisms based on new information. Say, *Let's analyze more of the data set to see if they support or refute any of these predictions.*

Display **slide H**. Distribute *Patterns for My Organism:_____* to each student.

Tell students that they will be working with the group they sorted cards with in the previous class, but today we will have groups look for patterns based on either *where* the ancient and modern organisms live(d) or *when* in time they live(d) to see if either of those helps us to explain any of the similarities and differences that we noticed in body structures.

Tell students they will record the patterns they notice in the "How patterns of body structures are connected to my factor" section of the handout *Patterns for My Organism:_____*.

*** Attending to Equity**

Universal Design for Learning: These small-group discussions provide opportunities to support student *engagement* in meaningful, accountable talk by using a socially safe grouping structure. This is especially beneficial to emergent multilingual students. Allowing students to share their thinking with a small number of students before a whole-group conversation increases confidence.

Display **slide I**. Divide and assign student groups with their investigation so that for each of the three organisms (horseshoe crabs, horses, whales) there is at least one group that will be looking at the factor of *where* they live(d) and at least one group that will be looking at the factor of *when* they live(d) in time. Every group should be assigned to one investigation or the other. Have them indicate which organism and factor they'll be working on in the "My Organism" and "The factor my group investigated" areas at the top of *Patterns for My Organism:_____*.*

Alternate Activity

Examining where organisms live(d) is complex because students will need to identify similarities and differences in the local environments before they can sort organisms based on those categories. However, in the timeline groups students are matching already-described patterns in the timeline. Therefore, consider assigning an extra group for each organism to the "where they lived" investigation and having them focus only on the local environment (rather than on both the geographical and local environment aspects of where they lived).

Distribute *Day 2: Horseshoe Crab Data Cards*, *Day 2: Horse Data Cards*, or *Day 2: Whale Data Cards* to each group based on what organism they are working with. Be sure each group has access to a copy of *Maps of Earth's Surface Over the Last 50 Million Years* and that horseshoe crab groups have access to *Maps of Earth's Surface 150 and 100 Million Years Ago*.

6. Sort organisms based on when they lived or where they lived.

10 MIN

Materials: *Patterns for My Organism:_____*, science notebook, *Maps of Earth's Surface Over the Last 50 Million Years*, *Maps of Earth's Surface 150 and 100 Million Years Ago* for horseshoe crab groups only, *Day 2: Horseshoe Crab Data Cards* or *Day 2: Horse Data Cards* or *Day 2: Whale Data Cards*

Orient students to the information on the data cards. Display **slide J** and discuss as needed. The information on these data cards is organized very similarly to the cards they looked at for the modern and ancient penguins in Lessons 1 and 3. Therefore, if students are sufficiently familiar with the format of the data cards, skip pointing out the details listed here and move on to the next step (at **slide K**).

- On cards for ancient organisms, the map shows where the fossil was found or where the modern organisms live now (indicated with a white circle on the map).
- Note that for an ancient organism the map is different based on what the planet's surface looked like at the time it was alive.
- Information about the environment of Earth during the time period in which the organism lived/lives is in the "Global climate" box on the right.
- Information about the local environment in the area where the fossil was found at the time that it was alive, including what organisms we know were there at the same time, is in the white box on the left.
- The timeline is at the bottom of the card. The time when the ancient organism may have lived is indicated on this timeline.

Display **slide K** which shows an example horseshoe crab data card. Ask students, *What is different about the timeline on the horseshoe crab cards compared to the penguin cards we used in Lesson 3?*

*** Attending to Equity**
Universal Design for Learning: As a reminder, to support *representation* help students clarify the map symbols. On the maps, the blue color indicates water. The very light blue color indicates shallow seas or lakes. Deeper water is darker blue. Green or brown color indicates land. Green areas are covered with plants. Darker green indicates denser vegetation. Brown areas are drier with sparse vegetation. White areas indicate ice. During ice ages, the ice can cover large areas of land and water. Even in warmer climates, some areas, like Antarctica, may remain ice-covered.

Students should notice that the horseshoe crab timeline goes much further back in time than the timeline on the cards for the penguins (and horses and whales). Orient them to the differences in the maps by referring them to *Maps of Earth's Surface Over the Last 50 Million Years* and *Maps of Earth's Surface 150 and 100 Million Years Ago* and noting the differences in the way the land and sea appear in the different time periods.* You might ask, *What do you notice about how the world has changed since then?*

Review directions for both investigations. Display **slide L**. Remind the "where they lived" groups that they will be looking at both the geographical location and the local environment where their organisms lived, unless they have specifically been assigned to look only at the local environment. Remind the "when they lived" groups that they will be looking at both the order in which their organisms appear on the timeline as well as how close together in time they lived.

Work in small groups to sort organisms and describe patterns. Students should work together in their small groups for about 5 minutes to sort their organisms based on the factor they are investigating.

While color coding is a useful way to quickly reference the parts of the map, letter or number coding helps ensure accessibility for any student who may be color blind. Consider adding additional coding to support your students as needed.

Additional Guidance

Students may want to begin today's work with the model they developed on day 1, where they organized their organisms based on body structure similarities, and then try to figure out whether those groupings match up with any of the categories of when or where they live(d). However, it is much more fruitful if students *first* identify similarities and differences in geographical location or local environment, or order and proximity in time, and *then* look at whether any patterns of the body structures can be explained by the patterns in where or when they lived. Encourage students to take this stepwise approach.



Circulate among the groups as they work. As you move among them, encourage students to clearly articulate any patterns they notice between the factor they are investigating and the body structures of their organisms. They are working to further develop the model they began last time now that they have more data about how these ancient and modern organisms are connected. Remind students to explain to one another (or you, if you ask them directly) what evidence they have that supports the relationships they articulate. They should be able to show or describe how some specific organisms fit the patterns they are articulating.

Conduct Building Understandings Discussions in and by small groups. After students have sorted their organisms and noticed potential connections, then they should look to determine if there is any relationship to the patterns of body structures they identified or to how similar or different they think the individual organisms are based on their body structures. Their goal should be to see if any of these factors help them explain the patterns of body structures they modeled on day 1.

Key Ideas

Purpose of the Building Understandings Discussion: Students in small groups should work to agree, based on evidence, about how patterns of body structures in their organisms might be explained by patterns of where or when the organisms live(d).

Listen and look for these ideas: Students may come up with many different types of patterns showing groups or lines or branches of organisms with similar body structures connected by when or where they lived. There are no right or wrong patterns for students to notice, but it is important that they use evidence and articulate the patterns clearly. These are potential patterns students may notice:

For where they live

- Horseshoe crabs: It is hard to see patterns because their body structures are all very similar to each other. Geographically, they are spread out all over the world, so there's no real pattern there. Their local environments are all exactly the same: tidal marine areas of shallow seas. So maybe their similar body structures match their similar local environments.
- Horses: Geographically there's no real pattern except it's weird that the ancient ones are all in the Western Hemisphere and the modern ones we looked at are in the Eastern Hemisphere. The patterns of having pointier teeth and more toes seem to go with more forest areas usually. More molars and fewer toes seem to go with more grasslands. There are exceptions.
- Whales: Geographically, they're really spread out, so it's hard to tell if there's a pattern. If you look at the temperature of the ocean or the depth of the ocean, there might be a pattern with size. Warmer oceans have smaller whales. Colder oceans have larger whales. There isn't any particular pattern of where they lived connected to whether they had teeth.

For when in time they lived

- General: There aren't many clear boundaries of different body structures long ago versus more recently or for different time periods in particular. Sometimes you can notice a kind of scaling of things over time (getting bigger or getting smaller, or going from more toes to fewer). Size changes over time for all three organisms. They mostly get bigger over time (with a few exceptions).
- Horseshoe crabs: It is hard to see patterns because their body structures are all very similar to each other. The size changes don't seem to follow the exact pattern of how close together they are in time, but they do get bigger overall as time goes by.
- Horses: Over time, their toes go from having multiple big ones to having multiple small ones to just one. Also, they go from having sharp, dog-like teeth to having some molars to having *big* molars over time.
- Whales: Further back in time, whales had bigger hind limbs. The more-recent fossils and the modern whales have none or practically no hind limbs. Also their front limbs seem to get a little longer over time, except for the sperm whale. The blow holes in their skulls go from closer to the front to closer to the back of the skull over time (but students might not notice this). The older ones have teeth, but since about 30 mya, some have teeth and some don't. So similarity in teeth is connected to time for the older whales but not for those in the last 30 million years.

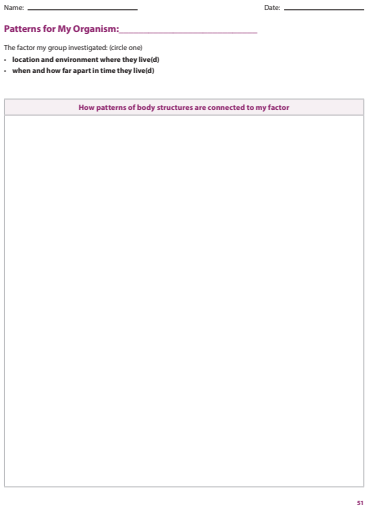
Assessment Opportunity

Building towards: 5.A.2 Analyze and interpret data from images to identify patterns of similarities and differences in modern organisms and the fossil record and use the patterns to reconstruct relationships between fossil (ancient) and extant (modern) organisms.

What to look and listen for: Circulate as students work to formatively assess students' identification and use of patterns to sort ancient and modern organisms based on their body structures and location and environment or when they lived. Different groups may have noticed different patterns that led to different organizations. See the Key Ideas box for specific ideas to listen for.

What to do: If students are struggling, then revisit the cards for their organism. Ask them questions such as, *What do you notice is similar or different in the data between _____ and _____ organisms? Do you see any possible patterns in those similarities? What about patterns in differences on the _____ data card versus the _____ data card? Do you see that anywhere else?* If needed, borrow another group's second set of cards or use an extra set to show sorting the cards in different ways to see multiple pattern possibilities.

Record with their group the patterns students noticed. Display **slide M**. After they have clarified their thinking, have students work with their group to write out how the patterns of body structures of their organisms are connected to either when or where they live(d) in the "How patterns of body structures are connected to my factor" section on their *Patterns for My Organism:*_____. They should individually list each relationship between their factor and the body structures of their organisms and number each one for reference in the next activity.


Name: _____ Date: _____

Patterns for My Organism: _____

The factor my group investigated: (circle one)

- location and environment where they live(d)
- when and how far apart in time they live(d)

How patterns of body structures are connected to my factor

51

7. Share patterns.

10 MIN

Materials: *Patterns for My Organism:*_____

Assign roles within small groups and organize into Scientists Circles. Display **slide N**. All students who investigated the same organism will gather together in a small-group Scientists Circle to share their findings with one another, compare their findings, and ask and answer clarifying questions. Therefore, there will be three Scientists Circles for the class—one for horseshoe crabs, one for horses, and one for whales—each combining both the "when" and the "where" small groups for each organism.

Within each original small group, have students quickly decide who will report the findings from their group to the others in the Scientists Circle. They may also want to assign other roles such as clarifying-question-asker or question-answerer. Then they can form a Scientists Circle with the other groups of students that investigated the same organism.

Share findings. Tell students that this is a chance for them to share their findings and listen to others' findings, not to criticize others' findings. They should be prepared to listen to other groups and ask clarifying questions. Each group should share what they recorded on their *Patterns for My Organism:*_____. Any clarifying questions from other groups should be asked and answered before the next group shares.*

As each group shares their findings, students in other groups should individually list in the appropriate space on their *Patterns for My Organism:*_____ each of the patterns reported, drawing a line under each idea and numbering it for reference. If a pattern has already been reported by another group, they can just record the reference number rather than rewriting it.

Remind students to highlight how organisms are tied to their location (or are different in different places) and listen for students to make the connection that organisms are different now than they were and so is the world they live in (the environment has changed too).

*** Supporting Students in Engaging in Argument from Evidence**

Sharing ideas clearly and persuasively is an important aspect of scientific communication, and students have experiences with respectful feedback from other units (e.g., *Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)* and *Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)*). As students are engaged in cross-team discussions, circulate and encourage presenting groups to cite evidence to support their models. Students should ask and answer clarifying questions that reveal differences in rationale between groups.

8. Create a consensus model.

9 MIN

Materials: *Patterns for My Organism:_____*, science notebook, 1 set of stickers that corresponds to the organism data the student has been working with, *Maps of Earth's Surface Over the Last 50 Million Years*, *Maps of Earth's Surface 150 and 100 Million Years Ago* for horseshoe crab groups only, *Day 2: Horseshoe Crab Data Cards* or *Day 2: Horse Data Cards* or *Day 2: Whale Data Cards*

Create a model showing how organisms are connected across time and environments. Display **slide O**. Say, *Now you're going to work together with your original group using everything you've learned to create a model that shows how you think your organisms are more closely or more distantly connected to each other. Be sure you have a reason for why you think each organism belongs where it does in your model. When you're finished, you'll split up and each of you will explain your model to students who have been working with a different organism. So, be sure to become an expert on your model.*****

Have students reassemble in their original small groups. They should work together to use all they have seen and heard in their own investigations and those of other groups to organize their data cards spatially on their table in a way that indicates their understanding of how closely or distantly connected these organisms are to each other. Tell students that they will be individually sharing their model with students from other groups who did not study this organism, so they should be sure they understand the reasons for placing each species of those animals where they are in the model. They can sort and discuss using the *Day 2: Horseshoe Crab Data Cards*, *Day 2: Horse Data Cards*, or *Day 2: Whale Data Cards* until they are satisfied with the organization of their model.

As they work, circulate among the groups and encourage them to articulate the relationships they are representing and their reasons for positioning various organisms where they put them. Encourage them to consider both when and where they live(d) as they organize their model.

Record models in science notebooks. When groups are satisfied with the organization of their model and have articulated and agreed on their reasons for organizing that way, distribute a set of stickers from *Horse Stickers, Horseshoe Crab Stickers*, or *Whale Stickers* to each group member for them to use to recreate the model across 2 new pages in their science notebook. They should make notes on those pages describing the reasons why they positioned the organisms as they did. They may want to include a hand-drawn timeline or sketch of a map as part of this copy of the model in their notebook.

9. Explain your organization in jigsaw groups.

9 MIN

Materials: *Guiding Questions to Compare Our Models*, science notebook, *Peer Feedback Guidelines*

Prepare for jigsaw discussions. Display **slide P**. Distribute *Guiding Questions to Compare Our Models*.

Organize students into mixed jigsaw groups of three students: one person representing each organism. Then, get everyone's attention and remind students about norms for giving and receiving feedback. Ask students to share ideas for which classroom norms are especially important when both giving and receiving feedback. If necessary, display **slide Q** that lists classroom norms. Allow a few students to quickly share their thinking with the class and listen for ideas such as the following:

- We critique ideas, not people.
- We listen carefully and ask questions to help us understand.

*** Attending to Equity**

Universal Design for Learning: Students may benefit from assistance with *expression and communication* by using sentence starters to help them express what they know and ask clarifying questions. Consider providing some sentence or question starters (either on chart paper posted visibly in the room or on sticky notes on student desks), such as the following:

- This pattern in _____ seems connected to this *_(body structure/body structure variation)__* because _____.
- The evidence that supports our organization is _____.
- Why did you place this organism(s) in that way in your model?
- How do you think that pattern is connected to the *__(body structure/body structure variation)*?
- How does the world as it existed when the organisms lived possibly connect to the patterns we are seeing in the organisms?

- We value that people represent their ideas in different ways.
- We challenge ourselves to think in new ways.
- We are open to changing our minds.

Say, *The ideas we are talking about are very complex. These norms are all important ways to help us learn from one another. We're learning together about what is going on with many different kinds of organisms and how ancient and modern organisms may be connected to each other.*

Provide copies of *Peer Feedback Guidelines* or direct students to their student editions to reference it during their discussions.

Share and discuss the models. Display **slide R**. Each person in the group should have an opportunity to share and explain their model to the two others in their group. Their description should focus on how and why their original group decided to organize their organisms the way they did. While one student is sharing, the others can be taking notes in the appropriate sections on *Guiding Questions to Compare Our Models* about how when or where organisms live(d) helped organize the model they are hearing about.



Name: _____ Date: _____

Guiding Questions to Compare Our Models

Discussion questions	Horseshoe crabs	Horses	Whales
How does your model incorporate when these organisms lived?			
How does your model incorporate where these organisms lived?			
What similarities did you notice across all three organisms as students shared their arguments for the patterns shown in their models?			
What new questions do you have?			

After each person has shared, have the students talk through with one another their answers to the first two questions on the handout, and jot notes as they discuss:

- How does your model incorporate when these organisms lived?
- How does your model incorporate where these organisms lived?

Circulate among the groups and encourage them to listen carefully and consider the ideas of the others in the group.

Assessment Opportunity

Building towards 5.B.2 Respectfully provide and receive critiques about models of the similarities and differences (changes) in some of the body structures of organisms observed over time and in different environments based on evidence from the fossil record.

What to look and listen for: When students are in their 3-person jigsaw groups, the focus should be on asking and answering clarifying questions that reveal the patterns they noticed and the rationale for their models. They should support their explanations using patterns in body structures connected to where and when organisms lived.

What to do: If students are struggling to articulate their models or explain why they organized them as they did, refer them to the resources they have developed: the model made with stickers in their science notebook, the information on *Patterns for My Organism:*_____, the discussions they had in their small groups.

Give students feedback on how respectfully they are asking and answering questions during the discussion. Positive feedback is especially powerful as it both encourages the student being addressed and points out a peer model of respectful exchange in a discussion.

* Supporting Students in Engaging in Analyzing and Interpreting Data

Remind students that we have figured out a lot about these organisms, but we might not have all the pieces. This is what all scientists do in their careers. This is real data. We didn't adjust or change the data to make it clear and easy to find patterns or try to fit patterns we might have anticipated. Science isn't always "clean"—it can be messy! Trying to figure out the "holes" or the as-vet-unexplained pieces is what scientists do!

10. Navigation

2 MIN

Materials: *Guiding Questions to Compare Our Models*



Record individually on the *Guiding Questions to Compare Our Models* handout students' answers to the last two questions. Present **slide S**. Direct students to work independently as they respond to these questions from the handout:

- What similarities did you notice across all three organisms as students shared their arguments for the patterns shown in their models?
- What new questions do you have?

Articulating their answers individually gives students an opportunity to think a little more deeply about how ancient and modern organisms may be connected and to articulate any questions they have. If needed, students could finish responding to these questions as home learning.

Assessment Opportunity

Building towards 5.B.3 Respectfully provide and receive critiques about models of the similarities and differences (changes) in some of the body structures of organisms observed over time and in different environments based on evidence from the fossil record.

What to look and listen for: Collect *Guiding Questions to Compare Our Models* after students have finished filling it out. In their writing, students should make specific references to similarities or differences in body structures and should explicitly refer to time and environments in their written answers. How these elements are used is less important than whether they are part of the information recorded. This is because the focus of this work is on working with ideas that other students shared in their arguments.

What to do: Provide feedback regarding the presence or absence of the specific use of similarities and differences in body structures and the presence or absence of explicit reference to time and environments in the patterns they describe. Emphasize the role that students should adopt when they realize they missed a key point that a peer made in their arguments. In particular, remind students to ask their peers for clarification and/or restating of key ideas when they realize they have a gap in their recall or understanding of one or more of the ideas a peer shared.

ADDITIONAL LESSON 5 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.8.1.D: Acknowledge new information expressed by others, and, when warranted, qualify or justify their own views in light of the evidence presented.

On day 2 of this lesson, students have two opportunities to engage in respectful feedback conversations with their classmates:

- as groups who examined similarities and differences in body structures of the same organism (horseshoe crabs, horses, or whales) come together and share their ideas and models
- when students form triads to share their thinking and models showing relationships among body structures, time in which organisms live(d), and environments in which organisms live(d) for all three organisms investigated during this lesson

By this final unit of 8th grade, students should be very familiar with classroom norms that guide respectful conversations. Closely listening and trying to make sense of their peers' ideas should be a well-established practice in small-group argument sharing. Students should be supporting their ideas and models with patterns in the data sets that their peers shared. Students should also be posing and responding to questions to elicit additional details or to clarify the patterns in these models when there is something they don't understand.

LESSON 6

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

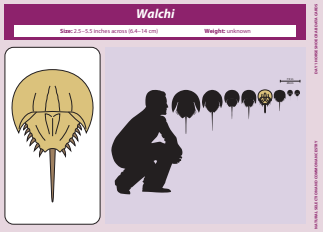
Previous Lesson

We investigated various organisms to see if the patterns of connections between ancient and modern organisms were similar to penguins. We sorted data cards for ancient and modern horseshoe crabs, horses, and whales to see what patterns of similarities and differences exist in their body structures. We discussed whether and how the patterns we notice in their body structures might be connected to where they live(d) or when they live(d). We confirmed that similar kinds of relationships exist in ancient and modern horseshoe crabs, horses, and whales as well as in penguins.

This Lesson

Putting Pieces Together, Problematizing

2 DAYS



We argue in support of claims for how modern organisms are connected to ancient organisms through a line(s) of descendants. We propose possible explanations for those connections. We add new questions to our Driving Question Board related to possible mechanisms causing this change.

Next Lesson

We will explore five cases where trait distributions in the population changed over a few generations. We will use a jigsaw strategy to analyze data from different studies on our group's assigned case. We will develop a model to explain what was causing the shift in trait distribution over time for our individual cases.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

6.A Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support an explanation for whether the types of things that lived long ago are ancestors to the modern organisms we see today (stability and change).

6.B Ask questions related to what is causing changes in a whole population of organisms.

What Students Will Figure Out

- There are clear patterns of differences in the body structures of certain types of organisms over really long periods of time (multiple generations) and across different environments.
- There must have been some population(s) of ancient organisms that had offspring that were lines of descendants that led to modern organisms.
- We don't agree on what those lines of descent were, but we have some possible candidates.
- The body structure variations are somehow changing in a line of descendants from one of the ancient populations to one of the modern ones.
- We have some different ideas about what might be causing such changes in a whole population of descendants.

Lesson 6 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	8 min	**NAVIGATION** Recall what we figured out in our previous lesson.	A-B	*Guiding Questions to Compare Our Models*
2	15 min	**CONSTRUCT AN ARGUMENT ABOUT ANCIENT AND MODERN PENGUINS** Write a new argument making a claim about how modern penguins are connected to penguins from long ago.	C-D	*"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, DQB, Penguin Timeline model from Lesson 1, markers
3	22 min	**CONSENSUS DISCUSSION ABOUT PENGUIN DESCENT** Participate in a whole-group discussion to come to consensus about whether a line of descendants exists between modern and ancient penguins.	E-F	*"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, Penguin Timeline model from Lesson 1, New Model Ideas chart, markers, DQB
				End of day 1
4	10 min	**REVISIT ARGUMENTS** Revisit arguments we put forward to support our claim about descendants and problematize ideas that need to be true if the dots do indeed connect between ancient and modern penguins.	H	*"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, Penguin Timeline model from Lesson 1, DQB

Part	Duration	Summary	Slide	Materials
5	10 min	**PROPOSE AND SHARE EXPLANATIONS** Individually record ideas that could explain how traits in an entire population of descendants could change and then share the ideas with the whole class.	I	chart paper, markers, Penguin Timeline model from Lesson 1
6	5 min	**DEVELOP NEW QUESTIONS** Jot down new questions about how traits in an entire population of descendants could change over time.	J	several 3″ x 3″ (or 3″ x 5″) sticky notes, fine-tip permanent marker
7	15 min	**SHARE QUESTIONS TO THE DRIVING QUESTION BOARD** Add new questions to the DQB and organize similar questions into groups.	K	students' completed sticky notes, several 3″ x 3″ (or 3″ x 5″) sticky notes, fine-tip permanent marker, DQB, markers, chart paper
8	5 min	**NAVIGATION** Think about how we might investigate the new questions we have.	L	Ideas for Investigations and Data We Need poster

End of day 2

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• *Guiding Questions to Compare Our Models* • science notebook • *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment* • several 3″ x 3″ (or 3″ x 5″) sticky notes • fine-tip permanent marker • student's completed sticky notes		• DQB • Penguin Timeline model from Lesson 1 • markers • New Model Ideas chart • chart paper • several 3″ x 3″ (or 3″ x 5″) sticky notes • Ideas for Investigations and Data We Need poster

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Online Resources



Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Have a half-sheet of copy paper ready to add the following phrase to the Word Wall: *line of descendants*. Do not post this phrase on the wall until after your class has developed a shared understanding of its meaning.

Prepare chart paper titled "New Model Ideas".

Make sure the DQB is accessible to students. Have 3" x 3" (or 3" x 5") sticky notes and fine-tip permanent markers available for students to add questions to the DQB.

The class will be referring back to the Penguin Timeline from Lesson 1 so you will want to be sure students can view it.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

Students will apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern and ancient organisms to infer evolutionary relationships. They will review the patterns in the anatomical similarities and differences between various organisms living today and also between extant organisms and organisms in the fossil record to enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. Though evolutionary mechanisms won't be developed until the next lesson set, eliciting initial or new candidate ideas of what is causing the apparent changes in a population over time is the focus of this lesson.

Further reflection on the fossil record patterns they analyzed previously gets students to the idea that a given type of organism doesn't come out of nowhere, they must have come from something slightly different in the past through a line of direct descendants. When we examine the fossil record we can see that organisms of the same type that existed closer in time share more similarities than organisms of that type that are separated by more time.

Students will likely surface the idea that environments change over time, and ecosystems can change over time, and/or Earth was different in the past then it is now, so there may be some connection between any of these and why these populations of organisms also seem to have changed over time.

Where We Are NOT Going

This is the final lesson in this lesson set. However, students will continue to explore evidence for common ancestry in Lessons 12-14 when they wonder where any penguins like Pedro (and/or other organisms) came from in the first place.

LEARNING PLAN FOR LESSON 6

1. Navigation

8 MIN

Materials: *Guiding Questions to Compare Our Models*

Summarize the patterns seen in the data in the previous lesson. Show **slide A**. Give students a half a minute to look back through *Guiding Questions to Compare Our Models* from the last lesson to prepare to share a statement that summarizes some of the patterns we saw across all the different types of organisms we looked at (penguins, horses, horseshoe crabs, and whales). Then have students share their responses.

Suggested prompt	Sample student responses
What were some of the patterns we saw across all the different types of organisms we looked at–penguins, horses, horseshoe crabs, and whales?	*The structures of living things today–like whales, horses, and so forth–look similar to but not exactly like the most similar-looking fossils we can find.* *In many cases, the further back in the fossil record we go, the more pronounced those differences are and the less horseshoe crab-like, horse-like, or whale-like that type appears to be.* *Sometimes but not always there are noticeable structure differences, like in limbs or skulls.* *In every case, there are changes in overall size of the organism over time.*

Pose a follow-up question. Show **slide B**. Say, *We agree we saw specific differences in the shape and size of the structures that made up the bodies of ancient whale, horse, and horseshoe crab fossils we analyzed. How do we think the similarities and differences we saw in the organisms preserved in the fossil record and in modern-day whales, horses, and horseshoe crabs are connected?*

Give students 2 minutes to turn and talk with a partner about this question.

Ask a few students to briefly share their ideas with the whole class. Then introduce the next activity by saying something like, *Let's work today to organize our claims about these connections and the evidence we have for them.*

2. Construct an argument about ancient and modern penguins.

15 MIN

Materials: science notebook, *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, DQB, Penguin Timeline model from Lesson 1, markers

Take stock of how we know the penguins of today must be connected to penguins of long ago. Display **slide C**. Say, *Let's take stock of how we know the penguins of today must be connected to penguins of long ago.* Direct students to the Penguin Timeline model from Lesson 1 to help think through this.

***Attending to Equity**
Universal Design for Learning: Allowing students to *express* their ideas using multiple modalities supports student

Suggested prompts	Sample student responses
Do we think modern types of organisms, like penguins, must have descended from other organisms, like penguins, in the past? Why?	*Yes, penguins and other organisms have to come from somewhere. If we have one penguin it had to have descended from its parents. The parents of that individual must have also come from a set of parents too and so on.*
OK, that is part of our answer to the "how" modern penguins descended from others from our Driving Question. We've shown that here on our model. (Point to where a dot on the right side of the model representing a species of modern penguin has another dot to the left of it with an arrow connecting them.) How far back does this go?	*It goes back one generation.*
What do the additional dots to the left of the first two mean?	*The model is showing it goes back at least a few generations.*

ownership of their learning by giving students choice, access, and control in navigating their own understanding around the science ideas. Use this opportunity to encourage students' *action* and *expression* by using different representations—symbols, colors, words, pictures. There will be moments throughout the unit where the class agrees on shared representations, but this is not necessary right now.

Write an argument and defend the claim about how modern penguins are connected to penguins from long ago. Show **slide D** and distribute *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*. Let students know we will use the claim they develop to share arguments in a class discussion. So, at this time, students should respond to the prompt on part 1 only.



Assessment Opportunity

Building towards: 6.A.1 Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support an explanation for whether the types of things that lived long ago are ancestors to the modern organisms we see today (stability and change).

What to look and listen for

- As students are completing their argument, circulate the room to check in to see if claims are aligned with the idea that penguins alive today descended from penguins that lived long ago and somehow the variations in their body structures have changed.
- See *Key: Argument for "How are penguins today connected to penguins from long ago?"* for further scoring guidance.

What to do

- If students are not using the idea that penguins had to come from somewhere, refer to the idea using different examples of animals coming from their parents. You could go back to the discussions in *Unit 8.5: Why are living things different from one another? (Muscles Unit)* about cattle and even the planaria (we couldn't have had two planaria if there wasn't one before them to split).
- If students are not bringing in the idea that the organisms must have changed over time, ask them to think about populations now and whether they are all the same with regard to every body structure and ask them to think about some of the body structures that show a lot of variation.

3. Consensus Discussion About Penguin Descent

22 MIN

Materials: science notebook, *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, Penguin Timeline model from Lesson 1, New Model Ideas chart, markers, DQB

Turn and talk to share claims with a partner. Show **slide E**. Say, *Soon we'll be sharing these claims in a whole-class discussion. First though, turn and talk to share your ideas with a partner. Make sure you each practice backing up your ideas with evidence in addition to sharing your claims.*

Give students 2 minutes to stand up, find a new partner, and share their claims before moving to the Scientists Circle.

Form a Scientists Circle to have a whole-group Consensus Discussion. Show **slide F** and ask students to bring their science notebook, *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, and something to write with to the Scientists Circle.

Key Ideas

Purpose of this discussion: for students to start attempting to support the idea that organisms must have changed somehow over time.

Listen for these ideas:

- It is important at this point in the unit that students agree there are lines of descent based on the "parents of parents of parents" idea at least—even if they don't agree that ancient and modern organisms connect, they do need to understand there are descendants that go back in time.
- There are variations and differences present in the populations already.
- Modern organisms we see alive now are descendants of the organisms we find fossil evidence of from millions of years ago.
- Each type of modern penguin descended from an ancient one (or something like one found in the fossil record).

Suggested prompts	Sample student responses
How are penguins of today connected to penguins of long ago?	*(Listen for students to refer to the part of the Penguin Timeline model we have been using to show that modern penguins came from parents who came from parents and so on.)*
(Ask students to think about what that must mean.) How far back does this go?	*It would go back to the first penguin(s).*
Does the line of descent need to connect to something? If not, what would that mean?	*Yes, it must connect to something. There must have been a first penguin (actually two!) to have the descendants we have today.*
Do I hear you saying that there are lines of descendants that stretch from modern penguins back to one or more of the ancient penguins?	*Yes, no, maybe?*

Take note of students who agree about the lines of descendants, then continue if needed, *OK, who does not agree that there are lines of descendants that stretch from modern penguins back to one or more of the ancient penguins?*

Share the evidence and/or justification for students' claim. Invite students to share the evidence they used to support their claim, collecting some reasons for each claim. Continue allowing students to share ideas and encourage students to agree and disagree with other students' ideas using evidence to support their claims as the discussion continues. See the Key Ideas box for specific ideas to listen for.*

Assessment Opportunity

Building towards: 6.A.2 Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support an explanation for whether the types of things that lived long ago are ancestors to the modern organisms we see today (stability and change).

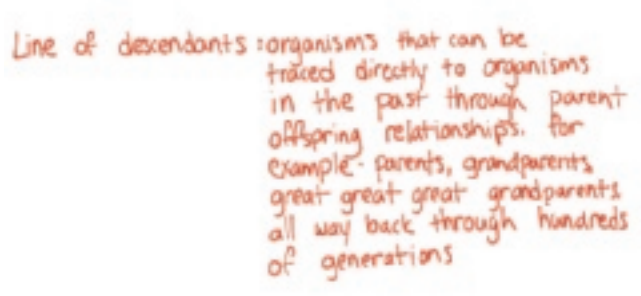
What to look and listen for

- During the Consensus Discussion for the ideas outlined in the Key Ideas box.
- See *Key: Argument for "How are penguins today connected to penguins from long ago?"* for further scoring guidance.

What to do

- If students are not using the idea that penguins had to come from somewhere, refer to the idea using different examples of animals coming from their parents. You could go back to the discussions in *Unit 8.5: Why are living things different from one another? (Muscles Unit)* about cattle and even the planaria (we couldn't have had two planaria if there wasn't one before them to split).
- If students are not bringing in the idea that the organisms must have changed over time, ask them to think about populations now and whether they are all the same with regard to every body structure and ask them to think about some of the body structures that show a lot of variation.

Add *line of descendants* to the Word Wall. A sample definition students might suggest is something like "organisms that can be traced directly to organisms in the past through parent-offspring relationships, for example, parents, grandparents, great-great-great-grandparents, all the way back through hundreds of generations".



Motivate identifying the ideas we need to figure out to help us answer some big questions. Refer to the Penguin Timeline model and say, *Let's take a moment to put ideas together from what we are talking about now and what we figured out about the fossils representing populations. There **must** have been some populations of ancient organisms that had offspring that were lines of descendants that led to modern organisms.*

As you say this, focus on one of the ancient penguin dots on the Penguin Timeline model.

Suggested prompts	Sample student responses
Did we agree that this is just a single penguin, or does this dot represent at least a few penguins that were living at the same place and time?	*The dot represents only the one or few fossils found, but there must have been more living at the same place and time because each penguin had to come from somewhere—it had to have parents. And each one likely had offspring.*
So like over here (point and refer to a dot representing a generation of modern penguins and to the dot and arrow leading to it that represent the parental generation of penguins) where we showed that this generation of penguins each descended from a set of parents … do you think we could then draw the same dot and arrow back over here for each of these ancient penguins? Where would you put those?	*Yes, those penguins must have also had parents, so you could draw a dot to the left of each dot and use an arrow to connect them like we did with the modern penguins.*
(Draw a dot to the left of the ancient penguin dot and a right-pointing arrow in between, similar to how we did with modern penguins.) OK, so those penguins had parents, but do you think it is possible that those penguins also had offspring? If so, how could we represent them?	*If the ancient penguins had offspring, we could show an arrow pointing from the fossil's dot to a dot on the right.*
(Draw an arrow leading from the ancient penguin's fossil dot to a dot to the right.) OK, so earlier we wondered how far back these dots go (point to the modern penguin dots). How far forward do you think these dots would go? (Point to the fossil penguin dots.)	*We're not sure.* *Maybe they connect to the modern penguins.* *Maybe they just keep going and then stop if they went extinct.* *Maybe they keep going but don't connect to the modern penguins.*
Even if these modern penguins don't connect to these ancient penguins, what must be true? Do they connect to something?	*Yes, they have to connect to something.* *It could be the ancient penguins.* *It could be some other organism.* *It could be something we don't have any fossil evidence for or something that looks so different we don't know they would be connected.*

Say, *So even if we aren't sure yet which lines of dots end up where, we know there are lines of dots going back to something* (point to a dot representing a modern penguin and trace the line of dots back and continue past all the dots of modern penguins toward the time of ancient penguins) *and there are lines of dots going forward to something here.* Refer to a dot representing an ancient penguin and trace the dots going forward and past existing ancient penguin dots toward present time.

Introduce and add to the New Model Ideas chart. Say, *This seems like another pretty important idea we should record. Like we've done before, let's keep a list of important ideas about our model.*

Add the following to the New Model Ideas chart:

- There must have been some populations of ancient penguins (organisms) that had offspring that were lines of descendants that led to modern penguins (organisms).
- There must also be some organisms living now or in the recent past that are descendants of the ancient organisms (penguins).

Connect these model ideas to our questions. Ask students to look back to the DQB and the chart papers from Lesson 1 of the unit subquestions to identify the big questions we asked. Say, *We were wondering "Where did all the different species of modern penguins come from?" and "Where did all the ancient penguins go?" Do you think figuring out where these lines of descendants end up connecting to would help answer these questions? Why or why not?*

Individually reflect on this discussion. Display **slide G**. Have students complete the discussion self-assessment in part 2 of *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*.

Home Learning Opportunity

If it fits your schedule better, you could have students skip part 2 of the self-assessment in class and instead complete it for home learning. If you do this, tell students they should reflect on their participation in all whole-class and partner discussions today, not only the Consensus Discussion you just finished.



End of day 1

4. Revisit arguments.

10 MIN

Materials: *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, Penguin Timeline model from Lesson 1, DQB

Individually revisit our arguments. Display **slide H**. Say, *In our last class we were working on our arguments about descendants and whether ancient penguins and modern penguins might be connected. Take a couple of minutes to work on part 3 of "How are penguins today connected to penguins from long ago?" Argument and Self-Assessment.* Give students 4 minutes to complete part 3 of *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, using a different color in part 1 to revise or add to their argument with words or pictures based on the previous class discussion.

Collaboratively revisit our arguments for why a line of descendants must exist from ancient penguins to modern penguins. If students have moved, regather in the Scientists Circle. Say, *So we are thinking that a line of dots from a population of modern penguins connects to an ancient population of penguins.* While still referring to the connecting dots on the Penguin Timeline model, pose the following questions:

Suggested prompts	Sample student responses
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?	*We know modern penguins must come from somewhere.* *We had some ideas about some possible lines, but we aren't sure and didn't agree.*
At this point we agree that a line of dots from modern penguins connects to an ancient population of penguins. So now we are debating what those lines of descent are. We are working with variations we see in the populations at two different points in time, right? Are any of the ancient fossils identical to the penguins of today?	*No.* *Some seem like they might be more similar than others, but none are exactly the same.*
Are the body structures we see in ancient penguins exactly the same as those in the modern penguins?	*No, the variations of body structures are different when we compare the modern and ancient penguins.*
Since we don't see the exact same variations of body structures in modern penguins as in the ancient ones, what can we infer is happening in a line of descendants that would connect one of the ancient populations to one of the modern ones?	*The body structures or traits must be changing somehow.* *The typical variations of body structures must be changing somehow.* *Maybe variations for body structures can appear or disappear.* *Maybe body structures can change too.*
Let's recall what we've already figured out about variations within populations. If we look at a group of individuals who are all part of the same population and we look at a certain body structure, would it be exactly the same in all of the penguins? Does every member of a population always have the same variation of a trait?	*No! Like the king penguins had a tall body structure and the Galápagos penguins had a short body structure, within each of those populations there was still a range of heights. There was variation in the trait.* *That is true for other body structures and traits as well.*

Say, *So, in Lesson 4 we looked at the height variation distributions for king penguins and Galápagos penguins and noticed that the distribution was not uniform. We had a much higher likelihood of finding penguins of certain heights, as indicated in the middle of the range, compared to other heights at the ends of the range. Let's keep this idea of variation within a population in mind as we try to explain the changes we think might be happening in an entire population over time.*

Collect *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment* so that you may provide feedback to students using *Key: Argument for "How are penguins today connected to penguins from long ago?"* before the next class.

5. Propose and share explanations. 10 MIN

Materials: science notebook, chart paper, markers, Penguin Timeline model from Lesson 1

Individually record ideas that could explain how the distribution of traits in a population could change. Ask students to open their science notebook to the next available page. Show **slide I** and give students 4 minutes to list possible causes of changes in the traits found in an entire population of descendants over time.

Share ideas as a whole class. Put up a blank sheet of chart paper next to the Penguin Timeline model and title it *Possible Causes of Changes in Traits.* Ask students to share ideas they listed about what could cause change in the traits within populations and to propose an explanation about how that could cause an entire population's trait distribution to change. As students are sharing their ideas, list them on the chart paper.

Since these are initial ideas, accept all ideas students suggest.

6. Develop new questions. 5 MIN

Materials: several 3" x 3" (or 3" x 5") sticky notes, fine-tip permanent marker

Individually record new questions on sticky notes. Move to **slide J** and ask students to record on sticky notes any questions that could help them understand what could cause traits in a population to change and *how* those changes could cause changes in the population's trait distribution over time, as well as any other new questions they may have about this phenomenon.

7. Share questions to the Driving Question Board. 15 MIN

Materials: student's completed sticky notes, several 3" x 3" (or 3" x 5") sticky notes, fine-tip permanent marker, DQB, markers, chart paper



Share questions to add to the Driving Question Board. Say, *Right now we have two subquestions next to our Driving Question Board: (1) Where did all the ancient penguins go? and (2) Where did all the different species of modern penguins come from? I'm sure some of your new questions will fit under one of these categories. However, let's also add a third category of questions to help organize the questions we have specifically about the traits changing.*

Hang blank chart paper next to the DQB and the subquestion chart papers. Title it "How did traits in populations of organisms change?" or "How the Traits Changed Over Time". Here students will post their new questions that will help us figure out the cause of the traits changing. Have sticky notes and markers available for students to use to record any new questions that arise.

Say, *Remember, it is important that we hear everybody's questions, and we might find that we have questions similar to some of our classmates' questions. Our DQB has five main areas to ask questions under, but if you have questions that fall outside of these topics, we can group those and determine another new heading as well. Remember, we are still using all these questions to help us answer that first question we had, which was* How could things living today be connected to the things that lived long ago?

Share students' questions, one by one, with the whole group. Project **slide K** and remind students how we will add questions to the DQB:

- The first student reads his or her question aloud to the class, 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 his or her 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.
- Continue until everyone has at least one question on the DQB.

Alternate Activity

If time is short, you might accelerate posting questions to the DQB like this:

- After the first student reads a question and you see that show of hands for whoever thinks they have a similar question to that one, direct the students with a hand raised to stand up and find a partner whose hand is also raised. In pairs, students can briefly compare their questions to evaluate whether they relate to the first question and how. If any pairs agree that their questions relate, everyone posts them to the board at once. Only questions where partners aren't in agreement get explained or discussed with the whole class.
- If needed, ask, *Who hasn't yet put a question on the DQB today?* to be sure that everyone has a chance to post at least one new question to the board during this lesson.

Determine if the questions should be rearranged into any new clusters. You may have been arranging new clusters as your class shared their questions, but if needed, take another moment after all students have shared their questions to examine them and determine if the questions are arranged into clusters appropriately. Then ask students to help determine a label or title for each cluster. Write these on sticky notes and place them near their related cluster.

This is a list of anticipated student questions:

- Can a whole population change at the same time?
- Why do only certain traits change and others don't?
- Do certain environments cause this change (and not other changes)?
- Do all penguins of a species live in one place?
- Do penguins of the same species living in different places look or act different?
- Does the variation or range in the population change depending on where organisms live?
- Can organisms learn to have different traits?
- Do the living organisms change individually or do only their offspring change?
- Can the genes of an entire population change at the same time?

- Is there something that causes a mutation to happen all at once for all individuals in the population?
- Can we make an entire population change by changing its environment?
- How fast does it take for the change to take effect?
- Is this type of change happening in organisms alive today due to climate change?
- Will everything keep changing in the future?
- Is there any way to observe this change ourselves?

Assessment Opportunity

Building towards: 6.B Ask questions related to what is causing changes in a whole population of organisms.

What to look and listen for: Students should express ideas that include wondering about variation in a population, where new traits come from, and in particular, mechanisms related to how things change. Such mechanisms may include the following ideas:

- environment changes or differences such as
  - climate
  - availability or distribution of food, water, shelter
  - type and number of predators
  - availability of mates
  - disease or absence of disease
- something that happens within the individual in response to the environment
- learning or experience resulting in acquiring new traits
- changes in genes passed on (e.g., mutation) or inherited (recombination of genes through sexual reproduction)
- something that time causes (e.g., long periods of time always lead to some change, change is constant)
- something that is random

What to do: Use talk moves to lift ideas about *how* populations could be changing, such as asking another student to rephrase what they heard a classmate say. If students mention variation between individuals, ask them to clarify their statement about how that alone could be causing a population to change over time. If that leads them to realize they can't explain it with variation alone, encourage them to write a question about it.

8. Navigation

5 MIN

Materials: Ideas for Investigations and Data We Need poster

Look ahead to the next lesson by thinking about how to answer some of our new questions. Show **slide L** and say, *OK, we've got a whole new set of questions to explore, motivated by trying to figure out what is causing these changes in a whole population. If we want to figure out how this happens over many generations, then we need some more data.*

Refer to your class Ideas for Investigations and Data We Need poster. Your class may have already listed ideas about data from shorter timescales or more-recent change in populations since that might be easier data to gather. If so, point to those ideas on the poster now. If not, say something like, *We have worked with data from enormous timescales—ancient to modern. Let's try looking for similar changes happening over a smaller timescale, like, over fewer generations, since that might be easier to collect more data for.*

Continue, *Turn to a partner to answer the following question: 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?*

After a moment of talk time, close today's work by saying something like, *Let's start there next time.*

ADDITIONAL LESSON 6 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.8.3: Delineate a speaker's argument and specific claims, evaluating the soundness of the reasoning and relevance and sufficiency of the evidence and identifying when irrelevant evidence is introduced.

Students write their argument on *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment* and then have a Consensus Discussion to make and defend their claims orally about whether ancient penguins (and other organisms) are the ancestors of modern penguins (and other organisms). Look and listen for students to use evidence to support their ideas and ask questions of their classmates regarding the sufficiency of evidence presented or when irrelevant evidence is introduced. A discussion self-assessment is provided in this lesson to invite students to individually reflect on how well they shared their own thinking but also how well they gave critiques to others about their arguments and evidence.

LESSON 7

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

Previous Lesson

We argued in support of claims for how modern organisms are connected to ancient organisms through a line(s) of descendants. We proposed possible explanations for those connections. We added new questions to our Driving Question Board related to possible mechanisms causing this change.

This Lesson

Investigation

3 DAYS



We explore five cases where trait distributions in the population changed over a few generations. We use a jigsaw strategy to analyze data from different studies on our group's assigned case. We develop a model to explain what was causing the shift in trait distribution over time for our individual cases.

Next Lesson

We will compare each of our case-specific system models (for finches, moths, swallows, fish, and plants) and will argue for which parts and interactions these cases have in common. We will develop a general model to explain what causes changes in the population. We will use the model to make predictions about what would happen in any population, in any environment, and over a different number of generations.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

7.A Analyze and interpret data representing mean, median, mode, or variability to examine patterns of changes over time that affect the predominance of certain traits in a population.

7.B Communicate and evaluate scientific information about a system of cause and effect relationships to explain how traits that support successful survival and reproduction become more common and those that do not become less common.

7.C Using models, construct an explanation of changes over time in the distribution of traits in a population in response to changes in environmental conditions.

What Students Will Figure Out

- Scientists collect a lot of different kinds of data to try to figure out what caused the shift in trait distribution in a population over time.
- Thinking about the relationship among structure and function, change and stability over time, and the causes and effects on both individuals and the population can provide useful lenses for developing a model to explain a complex biological system.
- We have ideas from specific cases that changes in the distribution of traits in a population is related to successful survival (and reproduction) in certain environments.

Lesson 7 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Review the reasons for looking at trait changes over a shorter time period.	A	
2	15 min	**INTRODUCE THE CASES** Become familiar with five cases of trait changes over a shorter time period and articulate an initial comparison of the cases with one another.	B-C	
3	25 min	**ANALYZE ASSIGNED CASES** Analyze a subset of data relevant to understanding the case that is being investigated.	D-G	*Finch Data Packet*, *Peppered Moth Data Packet*, *Cliff Swallow Data Packet*, *Mustard Plant Data Packet*, *Stickleback Data Packet*, *Overview: Finch Beaks*, *Overview: Peppered Moth*, *Overview: Cliff Swallow Wings*, *Overview: Mustard Plant Time to Flowering*, *Overview: Stickleback Armor* *End of day 1*
4	3 min	**NAVIGATION** Orient to goals for completing case investigations and creating a preliminary model.	H	
5	20 min	**SHARE ANALYSIS** Share their analysis of data subsets with other members of the group and answer questions about their analysis.	I	student-completed version of *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet*
6	10 min	**CREATE A PRELIMINARY MODEL** Use results of the case investigation data analyses to organize a preliminary model explaining what caused the changes observed.	J-K	student-completed version of *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet*, 5 - 5" x 8" index cards (see the "Materials preparation" section), 5 - 3" x 5" sticky notes, markers

Part	Duration	Summary	Slide	Materials
7	10 min	**REFINE YOUR THINKING USING CROSSCUTTING CONCEPTS** Use the lens of two different crosscutting concepts to examine the elements of the preliminary model in order to extend or refine thinking about the model.	L-O	*Using the CCC Lens*
				End of day 2
8	3 min	**NAVIGATE TO TODAY'S WORK BY CONSIDERING PROBABILITY** Discuss the probability of particular effects in their case studies due to particular causes.	P	completed *Using the CCC Lens*
9	7 min	**INDIVIDUAL SYSTEM MODELS** Work individually to articulate individual understanding of the system model for the case being investigated.	Q	*Develop a System Model*
10	15 min	**COME TO CONSENSUS ON THE SYSTEM MODEL** Work in small groups to come to a consensus on a chain of cause and effect for their case.	R-T	student-completed version of *Using the CCC Lens*, *Develop a System Model*, *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet*, blank sheet of paper (optional), markers, Initial Case System Model
11	15 min	**CREATE A REVISED SYSTEM MODEL POSTER** Create a poster showing a chain of cause and effect that is supported by evidence and reasoning.	U	Initial Case System Model, 1 sheet of poster paper, markers, 3" x 5" sticky notes
12	5 min	**NAVIGATION** Motivate a comparison of case system models as a way to start to put together a general model of natural selection.	V	
				End of day 3
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 7, students are ready to read Student Reader Collection 2 and then respond to the writing exercise.		Student Reader Collection 2: *Genes, Species, and Change*

Lesson 7 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Finch Data Packet* • *Peppered Moth Data Packet* • *Cliff Swallow Data Packet* • *Mustard Plant Data Packet* • *Stickleback Data Packet* • student-completed version of *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet* • *Using the CCC Lens* • completed *Using the CCC Lens* • *Develop a System Model* • student-completed version of *Using the CCC Lens* • *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet* • blank sheet of paper (optional)	• *Overview: Finch Beaks* • *Overview: Peppered Moth* • *Overview: Cliff Swallow Wings* • *Overview: Mustard Plant Time to Flowering* • *Overview: Stickleback Armor* • 5 - 5″ x 8″ index cards (see the ″Materials preparation″ section) • 5 - 3″ x 5″ sticky notes • markers • Initial Case System Model • 1 sheet of poster paper	• 3″ x 5″ sticky notes

Materials preparation (20–30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Online Resources



Determine group sizes

- There are 5 case studies used in this lesson. For larger classes, you may assign more than one group per case. If you do assign more than one group to a case, be sure to make sufficient copies of each case study that groups will be investigating.
- Each case study includes 5 data subsets that students will analyze individually, so there should be at least 5 students per case study group.
- For larger classes, you may have groups larger than 5 students and assign pairs to particular data subset(s) if needed.
- Consider assigning students to different cases based on their fluency in mathematical and computational thinking. *Finch Data Packet* is the least complex, followed by *Peppered Moth Data Packet* and *Cliff Swallow Data Packet*. *Mustard Plant Data Packet* and *Stickleback Data Packet* are the most complex.

Prepare case study materials for each group.

- Consider the high school curriculum. The swallows, moths, finches, sticklebacks, and mustard plants case studies are recommended for use in this lesson and should all be used if possible. However, some high school curricula rely heavily on one or more of these case studies, and it may be advantageous to avoid cases that students will encounter in high school courses. If possible, check with your local high school(s) biology teachers about whether avoiding the use of a certain case is necessary. For a quick guide to what students will uncover in each case study, refer to *Summary of Natural Selection Cases* in the *Teacher Guide* for Lesson 8.
- Print one copy each of *Using the CCC Lens* and *Develop a System Model* for each student.
- Print and staple sufficient copies of the case study data packets so every student in each case study group will have their own copy for that case (for example, every group of 5 students will need 5 copies of one of the following):
  - *Finch Data Packet*
  - *Peppered Moth Data Packet*
  - *Cliff Swallow Data Packet*
  - *Mustard Plant Data Packet*
  - *Stickleback Data Packet*
- Gather the preprinted color copies of each of these *Overviews* from your kit. You will reuse these color copies for all your classes. Each group will need one copy of the *Overview* for their assigned case. Note that this *Overview* is included in the data packet for each case so students can annotate a copy, but it will be printed in grayscale. This color copy allows them a clearer view of maps and other images.
  - *Overview: Finch Beaks*
  - *Overview: Peppered Moth*
  - *Overview: Cliff Swallow Wings*
  - *Overview: Mustard Plant Time to Flowering*
  - *Overview: Stickleback Armor*
- If you do not have premade color *Overviews* from the materials kit, prepare them as follows:
  - Print on cardstock one color *Overview* for each group working on that case.
  - Consider laminating these pages since you will reuse them for each class you teach and in future lessons, and you can keep them year to year.

Prepare these materials for day 2.

- 5 multicolor 5″ × 8″ index cards per group—1 blue, 1 green, 1 pink, and 2 purple
- 3″ × 5″ sticky notes, 5 per group

Prepare these materials for day 3.

- 1 piece of poster paper per group.
- 3″ × 5″ sticky notes, approximately 5 per group

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students take a deep dive into a particular set of data that shows a rapid shift in the distribution of a trait within a distinct population of an organism (finches, moths, swallows, sticklebacks, or mustard plants). These cases contain images and data from primary research studies that were done by experts on each type of organism. Each student analyzes a subset of the data that describe one of the five real-world cases. Within groups, they will analyze many types of data to generate information about their case, then communicate and synthesize the information in order to construct a system model that explains what caused the changes in the population.

Students should be familiar with and able to identify and interpret information presented in various kinds of graphs that they will encounter in their data subsets. Understanding the graph types used, as well as the statistical concepts of mean, median, mode, proportion, range, distribution, and frequency, all fall within the Common Core State Standards for middle school starting in 6th grade. Students also have had experience using the I-squared data analysis routine, identify (what I see) and interpret (what it means), across multiple units in prior grades in data analysis work.

The types of data graphs students will encounter include scatter plots, lines of best fit, histograms, and box-and-whisker plots. These are mathematical representations they will have encountered before.

- They have worked with scatter plots and lines of best fit in their prior work in *Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)* and *Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*. And, as this is designed to be the last unit of 8th grade in the sequence, many students will have done work with scatter plots and lines of best fit in their 8th grade math classes related to the following:
  - CCSS.MATH.CONTENT.8.SP.A.1 *Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.*
  - CCSS.MATH.CONTENT.8.SP.A.2 *Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.*
- They have worked with histograms in their prior work in *Unit 8.5: Why are living things different from one another? (Muscles Unit)* and *Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)*. Comparing histograms for two different populations is something some students will be doing. This builds on the prior math work in 7th grade:
  - CCSS.MATH.CONTENT.7.SP.B.3 *Informally assess the degree of visual overlap of two numerical data distributions with similar variabilities, measuring the difference between the centers by expressing it as a multiple of a measure of variability.*
- They also will have encountered box plots in their math work in 6th grade. You may want to check with your 6th grade math teachers for example data sets that students will have worked with before using box plots so you can remind students about what they have already learned:
  - CCSS.MATH.CONTENT.6.SP.B.4 *Display numerical data in plots on a number line, including dot plots, histograms, and box plots.*

Students' synthesis will include examining the data through the lenses of the "structure and function" and "cause and effect" CCCs as well as considering the CCCs of "systems and system models" and "scale, proportion, and quantity". Throughout this lesson, students will identify several of the elements that will be essential to an understanding of natural selection within their case study. However, they may not grasp them as elements that are generalizable to any other case or to an overall mechanism of population change. Their deep investigations of particular cases set them up for being able to define a general model of natural selection in the next lesson.

Where We Are NOT Going

While students will be able to explain by the end of this lesson how and why changes in trait frequencies happened in a particular population, they will not be asked to generalize any of the mechanisms they propose. The term *natural selection* is not used in this lesson since students have not arrived at a generalizable model of these mechanisms. In addition, though their explanatory system models will be based on inferences they made from the data they examined in their case studies, there will be no formalized articulation of any lines of specific evidence within their proposed explanations (system models).

In Lesson 8, students will compare their models of what caused the changes in the populations in their specific cases in order to identify common elements and mechanisms. These will lead them to an articulation of the mechanism of natural selection in that lesson.

LEARNING PLAN FOR LESSON 7

1. Navigation

5 MIN

Materials: None

Remotivate the need for analyzing cases we can inspect more closely. Display **slide A**. Say, *At the end of our last class we had a lot of questions related to what could be causing changes in the traits in a whole population over many, many generations and whether that really happened. We know we can't go back and look at what happened in the past, but we were thinking that if it happened in the past, it must be happening now, too. So we were wondering whether scientists have ever directly observed changes happening currently in a whole population. Let's think for a minute about this question: How could investigating whether such changes happen over a shorter timescale—fewer generations in any population—help us make progress on understanding what happened over a long period of time?*

Suggested prompts	Sample student responses
How could investigating whether such changes happen over a shorter timescale—fewer generations in any population—help us make progress on our questions?	*If we could see it happening over a shorter time, then it's easier to understand how it could be happening over a longer time.* *If we could understand how a change happens in a few generations, we could understand how it happens in many, many generations.* *Understanding how a change happens in a few generations would allow us to explain how it happens over millions of years.* *We could see what the specific cause is for the traits in a line of descendants changing over many, many generations.*
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?	*We need data on organisms in a population where the traits changed over a shorter time period and that scientists could actually observe in real time.*

Say, *Scientists have looked for these sorts of cases before, too. Let's dig into five different ones to see what sort of changes they measured in the populations they studied.*

2. Introduce the cases. 15 MIN

Materials: science notebook

Introduce the cases. Display **slide B**. Organize students into their groups of 5 but do not assign them to a specific organism yet. Ask them to look carefully at the information on the slide. Say, *This is just a brief summary of the changes scientists saw in the populations they studied. The scientists also collected a lot of other, related measurements about the organisms and about the surrounding environment where they lived.*

Additional Guidance

The text and images on the slide represent the five recommended case studies. If it is necessary to remove a case study (see the "Materials preparation" section), you may want to alter this slide and others containing the case summaries accordingly.

Compare the five cases in small groups. In their small groups, have students familiarize themselves with the text and pictures on **slide B** and briefly discuss what is similar and what is different among the five cases. They may want to record their ideas in their science notebook. They should be prepared to share with the class their noticings and wonderings about the similarities and differences.

Share noticings and wonderings. Refer to **slide B**. Have several students share what similarities and differences they noticed among the cases.* These are anticipated student responses:

*** Supporting Students in Developing and Using Structure and Function**

The traits that change in these populations are all obvious structural traits in the body of the organism except for the change in flowering time in mustard plants. At this point in the lesson students may think that the flower itself changes, or they may think some structural part of the plant must be changing to make the plants bloom faster or slower. In fact, the change in flowering time is brought about by a change in the structures of several intracellular proteins that are involved in signaling. This is similar to a mechanism that students explored in *Muscles Unit*, where they found out that a protein in cattle and other animals sends a message to cells that results in the formation of either typical or extra-big muscles. The information about signaling in mustard plants is available to students within the data packet. However, it is not necessary at this

- The changes happen in different parts of the organisms, like beaks, wings, coloring, bony armor, or flowers.
- The trait increases in one case, decreases in three, and is a color change in the other.
- They all have multiple years and generations, from 2 to 30 generations.
- They're all from different places, like England, the Galápagos Islands, Nebraska, Alaska, and California.
- They all happened within the last 100 years, some in the 1970s and some in the 2000s.

Assign students to groups to work on individual cases. Refer to **slide B**. Assign each group one of the 5 cases.

Additional Guidance

Within each group, there will be 5 different data subsets that students will analyze independently. Therefore, each group should have at least 5 people. For larger classes, consider assigning an additional group of 5 to one or more of the cases. Alternatively, you can assign more than 5 people to the group for each organism. In that case, more than one person will analyze a particular data subset within each group. Each student needs a copy of the full data packet for their organism.

Universal Design for Learning: At the end of 8th grade, students should be able to analyze and interpret complex graphs and other kinds of data, including scatter plots, box plots, and histograms. The data presented in this lesson rely on students' fluency with those representations. For students who might struggle with the data analysis, it may be helpful to assign them to analyze the same data subset as another member of their group. There are multiple opportunities to share their thinking about their data analysis within the group, and having two people working on the same data subset would create a natural support for students who might struggle with decoding the data by giving the opportunity to hear from another student's alternate *representations* of what the data mean. This arrangement would result in groups of more than 5 students per case.

Say, *You'll be working with the people in your group to try to figure out what caused the change in the population of organisms in your case. Your group will get a packet of data about your case, and you'll divide up the material to analyze different subsets of the data. Then you'll come back together to try to tell the whole story of what's going on in your case and explain how and why the changes happened.**

Additional Guidance

Over the last couple of lessons, the focus has shifted from thinking about individuals to thinking about populations of organisms. Within this lesson, it is important that students be able to shift their focus from populations to individuals and back again to populations. Throughout the lesson, students will be working to figure out what causes the traits in a population to change. They will have to use their analysis of the data subsets to determine how characteristics of the environment affect an individual's chances of surviving or reproducing and how that subsequently contributes to shifting the trait distribution in the whole population over time.

Discuss initial ideas in pairs before beginning to work in groups. Display **slide C**. Have students turn and talk for 2-3 minutes with a partner who is assigned to a different case than theirs. They should consider and respond to these questions:

point that students understand the distinction between flowering time as a trait and structural change in the signal proteins as a trait. Some confusion may arise later with regard to an analysis on day 2 that requires them to think more deeply about structure and function in their case study. Be prepared to assist students in the mustard plants group to connect the structure and function changes, referring back to their knowledge about the structure and function of the myostatin protein in muscle development.

*** Attending to Equity**
Universal Design for Learning: All these cases are complex. However, in order for students to figure out what caused the changes in the population, some of the cases require the use of more-advanced statistical understanding or rely on an ability to synthesize information from several different sources. Consider assigning students to different cases based on their fluency in mathematical and computational thinking. *Finch Data Packet* is the least complex, followed by *Peppered Moth Data Packet* and *Cliff Swallow Data Packet*. *Mustard Plant Data Packet* and *Stickleback Data Packet* are the most complex. This would help calibrate the challenge for different students, which is an important dimension of supporting optimal *engagement* in a task.

- Why do you think the changes may have occurred with your organism?
- What do you think might have caused those changes to happen?

After sharing initial ideas with a partner who has another case, students should get together with their designated case group.

3. Analyze assigned cases. 25 MIN

Materials: *Finch Data Packet*, *Peppered Moth Data Packet*, *Cliff Swallow Data Packet*, *Mustard Plant Data Packet*, *Stickleback Data Packet*, *Overview: Finch Beaks*, *Overview: Peppered Moth*, *Overview: Cliff Swallow Wings, Overview: Mustard Plant Time to Flowering, Overview: Stickleback Armor*

Discuss case overviews. Display **slide D**. Distribute the appropriate assemblage of one of the following handout pairs to each group. Ensure that each student receives the entire data packet and each group receives one color copy of the *Overview* section for their case:

- *Finch Data Packet* and *Overview: Finch Beaks*
- *Peppered Moth Data Packet* and *Overview: Peppered Moth*
- *Cliff Swallow Data Packet* and *Overview: Cliff Swallow Wings*
- *Mustard Plant Data Packet* and *Overview: Mustard Plant Time to Flowering*
- *Stickleback Data Packet* and *Overview: Stickleback Armor*

Students should work together with their group to read through and understand the *Overview* section of the case data packet they received, annotating in their personal copies and discussing as needed. The color copy of the *Overview* section of each data packet gives greater detail on the images and maps shown.

Give instructions for independent work with data subsets. After about 5 minutes of small-group talk, display **slide E**. Assign each student within each group to one of the 5 data subsets in the data packets.

- Subset 1: Population at the Beginning
- Subset 2: Environment
- Subset 3: Survival and Reproduction
- Subset 4: Offspring and Inheritance
- Subset 5: Population at the End

Display **slide F**. Point out to students that there is a table at the end of each "Data Subset" section that provides questions to guide their analysis. They should summarize their analysis around the two larger questions:

- Identify: What do I see in the data?
- Interpret: What does this mean?*

Tell students that after they have completed the analysis of their assigned data subset and filled in the table, they should read through the data subset section that follows the one they analyzed and annotate any noticings and wonderings. (If they analyze data subset 1, they annotate data subset 2; if they analyze data subset 2, they annotate data subset 3, and so forth. If they analyze data subset 5, they annotate data subset 1.) They will contribute their

*** Supporting Students in Engaging in Analyzing and Interpreting Data**

At this point at the end of 8th grade, students should be familiar with and able to identify and interpret information presented in the various kinds of graphs and tables that they will encounter in their data subsets. See "Where We Are Going" for examples of where they have used scatter plots, lines of best fit, histograms, and box plots in their previous work in middle school.

Understanding these graph types as well as the statistical concepts of mean, median, mode, proportion, range, distribution, and frequency falls within the Common Core State Standards for middle school starting in 6th grade. If students are unfamiliar with any of these data presentations or mathematical concepts, you may want to consider providing students with a brief review or summary of them before they engage in analyzing their assigned data subsets.

analysis of their data subset and their noticings and wonderings about the following data subset to their group discussion during the next class. For a quick guide to what students will uncover in each case study, refer to *Summary of Natural Selection Cases* in the *Teacher Guide* for Lesson 8.

Work independently to analyze and annotate the data subsets. Keep **slide F** displayed and allow students time to work independently or with a partner if you have assigned one. Students who finish early can read and annotate additional data subsets in their case data packet. Circulate among the students, assisting them as needed.

Assign home learning as needed. Display **slide G** if needed. Remind students they will be sharing their analysis with their group during the next class. They should be prepared to share what data were in their subset, what the data showed, and what they mean.

Collect completed work. Have students write their name and the date on their data packet and collect the data packets of students who have completed their analysis. Students' writing and annotations can be used as a formative assessment. Those students who have not completed the analysis of their subset should take their data packet home and complete their analysis and the annotations for home learning. The color copies of the *Overview* should also be collected at this time.*

Students also have had experience with using the I-squared data analysis routine, identify (what I see) and interpret (what it means), in data analysis work across multiple units in prior grades and should be able to use it independently.



Assessment Opportunity

Building towards: 7.A Analyze and interpret data representing mean, median, mode, or variability to examine patterns of changes over time that affect the predominance of certain traits in a population.

What to look for: In the data subsets students analyzed that include interpretations using concepts of statistics and probability, look for evidence that they can identify their data in the "Identify: What do I see in the data?" section of the table at the end of the subset and that they can interpret their data in the "Interpret: What does this mean?" section of that same table. The type of data and the interpretation of them will vary across cases and across data subsets within cases. For some students who analyzed data subsets that did not include using concepts of statistics and probability, an assessment of their work with group members' data subsets on day 2 may be necessary. Look for answers that directly and accurately address the questions asked in each table. For more-specific details of what to look for in each section of a specific case, refer to the keys in *Key for All Data Packets*.

What to do: If students are struggling to describe or interpret the data in their subset, encourage them to be guided by the specific questions in the table at the end of their data subset. Provide feedback pointing out if students have neglected to consider the specific questions in their answers. If so, ask them to revise their answers to more closely answer the specific questions in the table. If students finish their analysis as home learning, collect and assess their analyses after day 2.

Assessment Opportunity

Building towards: 7.B Communicate and evaluate scientific information about a system of cause and effect relationships to explain how traits that support successful survival and reproduction become more common and those that do not become less common.

When to check for understanding: There are multiple opportunities over the course of the lesson to assess students' understanding of this lesson-level performance expectation, including as you look over the information they've obtained and analyzed from their data packets.

The recommended time to assess this expectation is on day 2 when you collect students' completed copies of *Using the CCC Lens* and further guidance is provided in this Teacher Guide at that moment.

Other opportunities to assess students' understanding include:

- On day 2 as they evaluate others' interpretations of data while individuals share during a group discussion
- On days 2 and 3, group work provides opportunities to communicate about their growing understanding of the system they are investigating.
- On day 3 as they come to a consensus about their model and create a poster that explains the changes in their case

End of day 1

4. Navigation

3 MIN

Materials: None

Remind students of the goal of their data analysis and sharing. Display **slide H**. Ask students to recall why we are doing these investigations of changes in a population over a short time.

Suggested prompts	Sample student responses
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?	*We think that understanding what happens over a short period of time will help us understand what happens over a long period of time.*
What's the goal of your group's analysis of your case? What are you working together to try to do?	*We're working together to tell the whole story of what's going on in our case and to explain how and why the changes happened.* *We are trying to represent what is causing what in our case.*

If students do not respond with appropriate answers, remind them what the purpose is of these investigations. Say, *We're investigating these cases to help us figure out whether our idea about changes in a population over a very long time makes sense by looking at changes in a population over a shorter time. You're doing the data analysis to try to tell the story of what's going on in your case and to explain how and why the changes happened. You'll eventually share what you figure out with the rest of the class.*

Assemble in case study groups. Students should gather with their own group around a table or in a small Scientists Circle configuration.

5. Share analysis.

20 MIN

Materials: student-completed version of *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet*

Share the results of students' analyses in their groups. Display **slide I**. Return to students any data packets that you collected at the end of the last class. Review the instructions on the slide with students.

- The student who analyzed data subset 1 should begin by describing the data that are in their subset, what the data show, and what they think they mean.
- The student who annotated that subset can then share their noticings and wonderings and agree or disagree with or add to the analysis.
- Other group members can ask any clarifying questions and raise any new ideas.
- Everyone who did not analyze that data subset should then fill in the table at the end of that data subset with a brief summary of what the data show and what they mean.
- Continue until all students in the group have had a chance to share and discuss their analysis.

Give students about 20 minutes to share and discuss the data. Circulate among the groups as they share. Remind students that their goal is to figure out how and why any changes happened. The next step will be to work together to assemble the information from their data subsets in order to tell the whole story of what's going on with their organism.

6. Create a preliminary model.

10 MIN

Materials: student-completed version of *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet*, 5 - 5" x 8" index cards (see the "Materials preparation" section), 5 - 3" x 5" sticky notes, markers

Create index cards summarizing the meaning of each data subset. Display **slide J**. Distribute multicolor index cards, markers, and sticky notes to each group. Have each student create an index card using text and/or diagrams for their particular data subset.

- They will use these index cards in building their preliminary model.
- The index cards are meant to represent just a reminder of the meaning of each data subset, not a detailed summary, and should have only a sentence or so of content.
- The index card should briefly summarize what their data subset means. If appropriate, they can simply copy onto the card their summary from the "Interpret: What does this mean?" section for the data subset that they analyzed.
- Before writing on their index card, they may want to add to or revise their summary based on the conversations they had with group members regarding what their data subset means in the context of the emerging story of what happened with their organism.
- The size of the index card (5" x 8") should allow students to write big enough to be read from a few feet away.

Facilitate a brief discussion about creating a preliminary model. Display **slide K**. Tell students they will use the meaning of each data subset to help them tell the whole story of what happened with their organism.

*** Supporting Students in Engaging in Constructing Explanations and Designing Solutions**

At this point, students may perceive that they have several pieces of unconnected information and have not been shown the whole story. They are correct. In their data packets, they have in fact not been told the whole story but, rather, been provided with all the same information that scientists had with which to put an explanation together. They will need to make reasonable connections among the pieces

Suggested prompts	Sample student responses
This will be the first draft attempt at creating a system model for your case. What will making a first draft of a system model help us do?	*It helps us show what we're thinking at this point.* *It helps us communicate our thinking to others.*
How can we use these index cards and the information on them to not only tell the story of what happened with our organism but also how and why it happened?	*The cards are like pieces of a puzzle that we need to fit together.* *The cards are like parts of the story.* *We need to connect the parts of the story together.* *We have to show how they're connected to each other.*

Suggest that they organize the cards in a way that makes sense to them and connect them using sticky notes with whatever annotation or symbols they need. They should work together to try to explain what happened with their organism and how and why it happened.*

Organize index cards into a preliminary model. Refer to **slide K**. Students should discuss what they think happened in their case and try to come to some preliminary agreement in their group. They can arrange the index cards on a desktop and indicate any relationships or interactions using sticky notes.

Facilitate a brief discussion about the bigger picture. Ask students to recall why we're looking in such detail at so many different organisms.

Suggested prompts	Sample student responses
Why is it important to figure out what happens in these cases of rapid change in a population? How is that connected to our earlier work with fossils?	*We're trying to figure out what happens over many generations by looking at what happens over a few generations.* *We saw traits that were different in organisms over really long periods of time. We're trying to figure out how traits can change for a population.*
Why are we looking at five different cases? What does that get us that we might not get out of looking at only one case?	*We want to see what they have in common about how and why changes happen.* *We think this idea of a line of descent probably happens in all organisms, so we want to see what they all have in common.* *We're trying to come up with an explanation of how change happens that we can also apply to penguins and other organisms.*

of evidence they have in order to develop a model that could explain all the things that happened in their case.

Making inferences involves choosing the most likely explanation from the evidence that is available. Students should be familiar with making inferences of this type as they construct explanations based on their prior work in other units. Encourage them to consider multiple possibilities and make some educated guesses about what makes sense for the story of how and why things are changing in the system for their case. Remind them that this is a preliminary model and they'll have opportunities to reconsider and revise their model later.

7. Refine your thinking using crosscutting concepts. 10 MIN

Materials: *Using the CCC Lens*

Orient to crosscutting concepts. Display **slide L**. Say, *Since we're learning about these cases so we can apply what we learn to other organisms, we will need to think about more-general ways to understand each case. The models that you are developing represent complex natural systems of individual organisms and whole populations of organisms and their survival and reproduction, as well as their environment and what happens to them over time. In order to understand in more-general ways what changes occur in complex systems as well as what caused those changes, scientists often use the lenses of different crosscutting concepts. This can help them think more clearly about changes and their causes in a general way that could apply to other systems as well. Let's take stock of some of the different categories of crosscutting concepts we've used in the past.*

Suggested prompts	Sample student responses
Which category of thinking have we been using the most so far as we analyze our cases?	*(Accept all answers.)*
Which of these do you think might help us understand our cases more generally?	*(Accept all answers.)*

Say, *Let's use two of these categories of crosscutting concepts to look at our cases through new lenses and see if that helps us generalize our models a bit more.* Distribute *Using the CCC Lens* to each student.

Use the "structure and function" lens. Display **slide M**. Say, *The first crosscutting concept category we will use is "structure and function". Let's see how it helps you think more deeply about what changes occurred in your organism.*

Have students work with a shoulder partner in their group on their responses to the questions in the "Structure and Function" section of the handout. Allow 5 minutes or so—sufficient time for some deeper conversations to develop. Have students record their ideas on their handout. As they work, circulate among them and encourage them to push their own thinking beyond the obvious answers so they consider more or different structures, multiple functions, and multiple reasons those functions could be important.

Use the "cause and effect" lens. Display **slide N**. Say, *The second crosscutting concept category we'll use will help you think more deeply about what caused those changes in two different parts of your system—changes in individual organisms and changes in the population.* Have students work with a different shoulder partner in their group about their responses to the questions in the "Cause and Effect" sections of the handout. Allow 5 minutes or so—sufficient time for some deeper conversations to develop. Have students record their ideas on their handout.

As they work, circulate among them and encourage them to push their own thinking beyond the obvious answers so they consider how physical changes might affect behavior or interactions, what effect changes in interactions might cause, whether and how reproduction or survival could affect whole populations.

Share students' experiences with using the CCC lenses. Ask students if there was anything that surprised them about their thinking or any new insights they had while using either of the CCCs. Give as many students as possible the chance to share their experiences.

Assign home learning as needed. Display **slide O** if needed. If necessary, students can complete *Using the CCC Lens* during home learning.

Collect completed work. Collect any completed copies of *Using the CCC Lens*. Student writing on the handout can be used as a formative assessment to assess their fluency in using different crosscutting concepts to explain different relationships and interactions in their case study. Before they leave the room, have students collect their group's set of connected index cards and sticky notes from the previous activity, and store them in a way that will allow them to access and organize them next time. These will be referred to as their Initial Case System Models.



Assessment Opportunity

Building towards: 7.B Communicate and evaluate scientific information about a system of cause and effect relationships to explain how traits that support successful survival and reproduction become more common and those that do not become less common.

What to look for: *Using the CCC Lens* asks students to think more deeply about their case using two different CCCs. Look specifically for evidence of thoughtful engagement with the cause-and-effect relationships that are a part of their case. The "Cause and Effect" sections of the handout should indicate some understanding on their part that

- the trait affects an individual's survival or reproduction;
- the cause is linked to the effect probabilistically, that is, not every organism with a specific trait will always experience direct survival or reproductive benefit in every circumstance;
- the frequency of a particular trait decreases because it negatively affects survival of individuals; and
- the frequency of a particular trait increases in a population because survivors can pass on the trait to their offspring.

For specific details of what to check for in each section for each of the cases, look at *Key for Using the CCC Lens*.

What to do: If students are struggling, break the questions down for them. Encourage them to start with the simple answer to each question on the handout and then to think more deeply about why that matters in their case. Here are a couple of examples for the "Cause and Effect" sections:

- *If the trait is short wings, how does that affect an individual?* (It can maneuver better.) *What does maneuvering better cause?* (Avoiding cars and therefore surviving, and so on ...)
- *If the trait is short wings, how does that affect a population?* (Short-winged birds survive better.) *If some survive better, what happens to the population?* (Those birds reproduce and pass on their traits, so there are more of those short-winged birds in the population, and so on ...)

Provide feedback praising thoughtful answers that do not stop at the most basic answer but consider the whole system. Remind those who do not answer as thoughtfully that they should consider the whole system in their answers. If students finish their CCC thinking as home learning, collect and assess their responses on *Using the CCC Lens* after day 3.

End of day 2

8. Navigate to today's work by considering probability.

3 MIN

Materials: completed *Using the CCC Lens*

Facilitate a brief discussion to highlight the probabilistic nature of survival and reproductive advantages. Display **slide P**. Return to students any copies of *Using the CCC Lens* that you collected at the end of the last class. All students should use their copy as a reference in this discussion and the following step. Have students take a look at the "Cause and Effect on Individuals" section on *Using the CCC Lens* and direct them to individually consider 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?

Have two or three students from different groups describe for their classmates what trait variation they've been investigating and share their answers to the questions on the slide. Emphasize answers that indicate the probabilistic nature of the survival advantage or the reproductive advantage. For examples, see the suggested prompts.

Suggested prompts	Sample student responses
Would the specific trait variation you're investigating always affect an individual the same way?	*No, the longer wings make it harder for a swallow to avoid a car, but it doesn't guarantee it will get hit.* *No, the moths could still be eaten by birds, even if they're camouflaged. It's just harder for the birds to find them.*
Does the trait variation affect how likely the individual would be to produce offspring?	*Yes, if the mustard plants bloom earlier, they're more likely to be able to get pollinated than if they bloom later when there are fewer plants alive. But it's not all or none.* *Yes, if they die, they can't reproduce!*

Ask, *Does every group's trait variation work by making it more likely that organisms will survive or reproduce?* They should answer, "Yes." *Does any group have a trait variation that **always** guarantees that an individual will survive or reproduce?* They should answer, "No." Remind students to keep this in mind as they work on the next activity.

9. Individual System Models

7 MIN

Materials: *Develop a System Model*

Revisit case system model individually. Display **slide Q**. Distribute *Develop a System Model* to each student. Have them work individually to articulate their own understanding of the system model for the case they're investigating. Remind them that they are trying to tell the whole story of what's going on in their case and explain in their system model how and why the changes happened. If they finish the "CCC: Systems and System Models" section, they should go on to the "CCC: Scale, Proportion, and Quantity" section. Some students may not get to the second section. This is OK.

For details of what students are likely to include in their answers on *Develop a System Model*, see the key in *Key for Developing a System Model*.

10. Come to consensus on the system model.

15 MIN

Materials: science notebook, student-completed version of *Using the CCC Lens*, *Develop a System Model*, *Finch Data Packet* or *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* or *Mustard Plant Data Packet* or *Stickleback Data Packet*, blank sheet of paper (optional), markers, Initial Case System Model

Introduce a chain of cause and effect model. Display **slide R**. Say, *Now that you've all had a chance to think individually about the system model for your case, you need to come to a consensus within your group to explain what caused the changes that you saw happen in your population. You already know that is not a simple answer. You need to take into account all the data and information you have. One of the ways scientists do this in complex systems is to come to an agreement about a chain of cause and effect.*

Share a cause-and-effect relationship students have noted in their system. Have 3 or 4 students share an example of a cause-and-effect relationship that they've uncovered in their case.*

Suggested prompt	Sample student responses
What is an example of a part or parts of the system in your case that affect another part of your system? (Follow up each answer with What is your evidence?)	*Rain affects the food source of finches. (The evidence is that when it didn't rain, the plants died.)* *Predation affects which moths live. (The evidence is that birds eat moths, which kills the moths.)* *The length of the growing season affects which mustard plants can make seeds. (The evidence is a graph that shows that only some plants survive when there is a short growing season, and only survivors can make seeds.)* *Inheritance affects what the next generation looks like. (Evidence is that we know genes affect traits.)* *(Accept all answers as long as they represent a cause and its effect that is supported by some reasonable evidence.)*

Show examples of a chain of cause and effect. Display **slide S**. Describe the two different models shown as needed so students have a visual representation of what is meant by a chain of cause and effect. Say, *Now you'll work in your group to come to an agreement about a chain of cause and effect that explains what caused the change in your population of organisms. Remember to use all the data and what they mean to help you explain it.*

Work in groups to come to consensus about a chain of cause and effect. Display **slide T**. Have students access the resources that are listed on the slide and work together to come to a consensus on an explanation for what caused the change in their population of organisms and includes information from all the data subsets. They may want to sketch or write ideas in their science notebook or on a blank sheet of paper as they work.

* Supporting Students in Developing and Using Cause and Effect

Students often struggle with what constitutes a cause-and-effect relationship. When asked to describe something that affects another part of their system, they may describe parts or relationships that do not represent a cause and its effect, such as:

- *The passing of clean air laws and birds eating peppered moths both happened in England.* (Those things are related because they're part of the same system. However, one is not the cause of the other.)
- *The population at the beginning is related to the population at the end.* (This is a true statement, but it is not a cause-and-effect statement. The population at the beginning does not cause the population at the end.)

Check these statements by asking, *Does ___ cause ___ to happen?* If the answer is "no", it is not a cause-and-effect relationship. Lesson 6 of the *Muscles Unit* included a deep dive into defining cause-and-effect relationships; it may be helpful to remind students about that if they are familiar with that unit.

Circulate among the groups and remind them to include information from all 5 data subsets in their explanation. Encourage them to articulate the structure-function relationships clearly as well as causes and effects on the individuals and on the population.

Additional Guidance

It is important that students come up with a system model that everyone in their group can (at least mostly) agree on by discussing it and relying on evidence to support their ideas. It is also important that their system model incorporates all the elements from their data packet (perhaps by using their index cards) and that the model be in the form of a chain of cause and effect in which it is clear what elements and changes cause other changes within the system. Building a consensus based on evidence and articulating a chain of cause and effect will require them to vigorously use the SEPs and thoroughly rely on the CCCs that are built into this lesson.

However, it is not important that they come up with exactly the "correct" explanation for the changes in the population. Groups may have some different interpretations about whether the environment is triggering emergence of a new trait variation (it is not) versus simply filtering out existing trait variations (it is). The data suggest the latter rather than the former, so check that at least some groups are arguing for this role of the environment. Their ideas will be refined by interactions with other groups and by repeated application to new systems throughout the next few lessons.

Students may also propose cause-and-effect relationships that are not supported by evidence.

- *The color of the moths causes them to mate only with moths of the same color.* (This is a possible cause-and-effect relationship, but there is no evidence to support it.)
- *The plants bloomed earlier because the temperature was hotter earlier.* (There is no evidence that temperature affects when the mustard plants bloom.)

Check these statements by asking students what evidence supports their statement.

11. Create a revised System Model Poster.

15 MIN

Materials: Initial Case System Model, 1 sheet of poster paper, markers, 3" x 5" sticky notes

Facilitate a brief discussion about reasons to create a poster. Ask students why they might want to create a poster at this point. Their answers should reflect their understanding that they need to communicate their model to others.



Create posters. Display **slide U**. The goal is to have students revise their Initial Case System Model and annotate it in a way that will be useful as they talk with classmates in the next lesson about what caused the changes in their case.

Students can produce their poster in any way they would like within the time frame allowed, but they should reuse the five index cards from their Initial Case System Model. If needed, they may use other sticky notes or index cards to revise their ideas. They may choose to draw, write, use a box-and-arrow model like that depicted on the slide, present graphs, and so forth. Students should list their names on the back and leave these posters in the classroom at the end of class.* These will be referred to as their Revised Case System Models from this point forward.

To facilitate multiple classes doing this work, it may be most convenient to have students collect and turn in posters to you for storage until their class meets again. In this way, subsequent classes will not see the posters developed by previous classes. Their Revised Case System Models can be assessed before the next class. You will need to hang up their Revised Case System Models, well spaced out around the room, in preparation for the next lesson.



A sample Revised Case System Model

Assessment Opportunity

Building towards: 7.C Using models, construct an explanation of changes over time in the distribution of traits in a population in response to changes in environmental conditions.

What to look for: Each group's Revised Case System Model should show

- explicit cause-and-effect connections between elements of their system. This may take the form of a chain of cause and effect with arrows and boxes as modeled on slides S or U, or it may be less structured. But definite, explicit cause-and-effect connections should be present.
- a clear statement that the population at the end shows a difference in the *distribution* of the trait of interest. *Not all* the organisms at the end have the same trait, rather, a different trait predominates in the population at the end.

In order to address the scale of the changes over time, their model should show

- stability of the set of variations present at the beginning. That is, no new variations should be shown to occur in the population throughout the study.
- environmental changes are a primary cause that affects the population at the beginning.
    - Note: there m ay be some different interpretations among groups on whether the environment is triggering emergence of a new trait variation (it is not) versus simply filtering out existing trait variations (it is). The data suggest the latter rather than the former, so check that at least some groups are arguing for this role of the environment. You will be able to leverage these interpretations in the next lesson when you push on clarifying the role of the environment in all the systems.
- some kind of indication that time is passing (dates, number of years, number of generations, and so forth).
- an indication that the direct effect on survival and reproduction at the individual level is what results in the changes at the population level.

There are multiple additional opportunities to assess students' explanations of stability and change throughout the lesson:

- On day 2 as they construct a preliminary model after sharing and discussing all the data subsets
- On day 3 as they articulate their individual thinking on *Develop a System Model*
- On day 3 as they work together in their group to come to a consensus about their system model so that they can prepare to communicate it to other groups

What to do: If students are struggling to figure out how to assemble their poster to show their explanation, refer them to the resources they have available (listed on slide T) and the models of a chain of cause and effect that are shown on slides S and U.

Use additional sticky notes to add your comments and questions to the posters, pointing out places where the cause-and-effect connection is unclear and giving feedback on whether the poster is missing any of the other things their model should show.

12. Navigation

5 MIN

Materials: None

Facilitate a brief discussion about the reason for investigating these cases. Display **slide V**. Take a moment to celebrate with students that they have come a long way in figuring out what's going on in some very complex cases. They have used many of their skills to make a model that explains how and why changes occur in the traits of a population. Ask them to recall why they did these investigations.

Suggested prompts	Sample student responses
Why have we been looking at changes in a population of organisms over a few generations? How could this help us with making sense of patterns we saw in penguins, horses, and so forth over millions of generations?	*We think that understanding what happens over a short period of time will help us understand what happens over a long period of time.*
Why is it important to figure out what the causes are in these cases of rapid population change?	*We need to know the mechanisms at work to explain how and why changes in populations are happening. This is related to many of the questions we had.* *We're trying to come up with an explanation of how it happens that we can also apply to penguins and other organisms.*
Why did we look at five different cases? Why not just one?	*We want to see what they have in common about how and why changes happen.* *We think this idea of a line of descent probably happens in all organisms, so we want to see what they all have in common.*
So what do we need to do next if we want to take all the work from these different cases and build a general model that can explain what is causing trait variations to change in any population in any environment?	*We should see what all the cases have in common.* *We need to compare them to see what's the same for all the different organisms.* *Let's compare the cases and see what is similar about what caused the changes.*

Tell students we will use our next class to do this work of comparing what happened in each case to develop as general a model as possible for explaining change in the traits in any population.

ADDITIONAL LESSON 7 TEACHER GUIDANCE

Supporting Students in Making Connections in Math

In working with all data sets, students will use the following ideas:

CCSS.MATH.CONTENT.7.SP.B.3: Informally assess the degree of visual overlap of two numerical data distributions with similar variabilities, measuring the difference between the centers by expressing it as a multiple of a measure of variability.

CCSS.MATH.CONTENT.6.SP.A.3: Recognize that a measure of center for a numerical data set summarizes all of its values with a single number, while a measure of variation describes how its values vary with a single number.

CCSS.MATH.CONTENT.6.SP.B.4: Display numerical data in plots on a number line, including dot plots, histograms, and box plots.

Students working with *Peppered Moth Data Packet* or *Cliff Swallow Data Packet* will use the additional ideas listed below as they analyze various data subsets in their data packets.

CCSS.MATH.CONTENT.8.SP.A.1: Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.

CCSS.MATH.CONTENT.8.SP.A.2: Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts.

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

Students obtain, evaluate, and communicate scientific information throughout this lesson. The data packets students use contain quantitative and scientific information expressed in words along with information expressed visually in graphs and tables that students must integrate to make sense of each case. During their small-group discussions, students cite specific evidence from those data and texts to support their ideas about changes in these populations.

- On day 1, students work to obtain information from the *Overview* section and the data subsets of their case-specific data packets.
- On day 2, students evaluate others' interpretations of data while individuals share during a group discussion.
- On days 2 and 3, group work provides opportunities for students to communicate about their growing understanding of the system they are investigating.
- On day 3 specifically, students communicate with their group to come to a consensus about their model and create a poster that explains the changes in their case.

SCIENCE LITERACY: READING COLLECTION 2

Genes, Species, and Change

1 It's All in the Genes
2 Hunting for Mutations
3 Variation Within Species
4 Convergence
5 Evo-Devo

Literacy Objectives

- ✓ Distinguish cause(s) and effect(s) related to traits, genes, and species.
- ✓ Organize related main ideas and details about traits, genes, and species.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 5–7.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a summarizing outline in response to the reading.

Instructional Resources

Student Reader



Collection 2

Science Literacy Student Reader, Collection 2
"Genes, Species, and Change"

Exercise Page



EP 2

Science Literacy Exercise Page
EP 2

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 5: How might other living things be connected to ancient organisms?
- Lesson 6: How could organisms living today be connected to organisms that lived long ago?
- Lesson 7: How do traits found in a population change over a shorter amount of time?

Standards and Dimensions

NGSS

Disciplinary Core Ideas: LS3.A: Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits. (MS-LS3-1)

LS3.B: In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. (MS-LS3-1)

LS4.A: Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully-formed anatomy. (MS-LS4-3)

Science and Engineering Practice: Analyzing and Interpreting Data

Crosscutting Concepts: Patterns; Cause and Effect

CCSS

English Language Arts

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

convergence

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

embryo **gene therapy**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

Exercise Page



EP 2

2. Preview the assignment and set expectations.

(Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Natural Selection and Common Ancestry unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *The first reading connects the idea of variations in traits in a population to the idea that variations in the genes, due to mutation, determine those traits.*
  - *Next, you'll read how mutations that cause certain human traits are investigated and described.*
  - *Then, a photo essay will reveal the incredible variations in traits that exist within some species and why.*

- *While similar traits usually mean two species are genetically related, sometimes they don't. That's a phenomenon scientists call "convergence."*
- *Could you tell the difference between the early-developing embryos of a fish, salamander, turtle, chicken, and human? If you think "yes," think again!*

- Distribute Exercise Page 2. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a completed outline that summarizes the main ideas and details from this collection.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What parts of cells are responsible for traits?	*genes, or DNA, located on chromosomes*
What evidence is there that mutations can be inherited?	*when several people from the same family have the same mutation*
What's interesting about the embryos of fish, salamanders, turtles, chickens, and humans?	*They all look about the same, even though they will develop into species that are very different.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
Do you think having a mutation that reduces the ability to feel pain is beneficial or harmful? Explain.	*beneficial, because people who don't feel pain could rescue someone who is in danger* *harmful, because if you don't know you are burned or injured in another way, you could lose a limb*
How does the selection "Variation Within Species" support our discussions about traits in a population?	*It supports the ideas that within a population there is variation in traits and that the distribution of traits can change over time.*
What trait variations within a population are pictured in the selection "Variation Within Species"?	*color patterns and size differences*

- Refer students to the Exercise Page 2. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to complete an outline focusing on cause and effect related to traits and species that summarizes the selections in Collection 2.*
  - *Notice that the outline framework uses complete sentences, so follow the same style for your additions.*
  - *Also, look at the content of the statements that are already there to infer what kind of statement would be appropriate to go along with them.*
  - *The outline does not have spaces for all the details in every selection, so choose the ones you think are most important or interesting.*
  - *The important criteria for your work are that you summarize all five readings and use language that shows your understanding of genes, mutations, traits, and how species are related.*
- Remind students that well-organized outlines have a hierarchy with big ideas at upper levels and details or examples at lower levels.
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page



EP 2

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise. The reading begins with a summary of genetics concepts underpinning the concept of genetic mutation and concludes with evidence that humans are more similar to fish and salamanders than the reader may assume.

Pages 14–23 Suggested prompts	Sample student responses
What is the general purpose of the first selection, "It's All in the Genes"?	*It describes where genetic information is located in living things and explains that understanding genetic mutations can lead to discovering ways to help cure diseases.*
How did understanding the first part of this selection help you understand the second?	*The first part gave me a refresher in the cell structures involved in inheritance. The second part made clear that anyone trying to develop a gene therapy would have to work at a very tiny scale to alter genes.*
What was your strategy for getting the most out of the first page of this selection?	*I looked at the pictures first and tried to figure out what I was seeing; then I read the captions.* *I read a caption first and then looked at the part of the illustration that went with that caption.*
What is the general purpose of the second selection, "Hunting for Mutations"?	*It explains the steps involved in figuring out the source of a genetic mutation.*
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first article gave me the background I needed to understand where in the body mutations take place. The second article details the steps scientists took to discover the source of one particular mutation.*
How did knowing you had an outline to complete affect the way you read this selection?	*I checked the parts of the outline for this selection, saw that I needed to fill in two details, and then read the article looking for details that would work.*
What is the general purpose of the third article, "Variation Within Species"?	*It gives examples of the trait differences among members of the same species.*

Student Reader



Collection 2

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

EXTEND—Students can learn more about experimental gene therapies and how they are intended to be accomplished by replacing genes that cause a disease or disorder, adding new genes when a gene is missing, or "turning off" problem genes. Direct them to videos that are clear, engaging, and from reputable sources.

Pages 14–23 Suggested prompts	Sample student responses
In Lesson 6, we discussed how the distribution of traits in a population can change. How might the traits of the butterfly or squirrel populations discussed in this selection change?	*For the butterflies, all the females might become dark colored. Or the males might become dark, too.* *For the two squirrel populations, their traits may become more and more different over time. For example, the coloring could become more different, or one population might have larger individuals than the other.*
What did the author mean by "separating effect of the canyon" when discussing Abert's squirrel?	*that the squirrels on one side of the canyon cannot reach the squirrels on the other side to mate and produce offspring*
What is the general purpose of the fourth article, "Convergence"?	*It explains that sometimes species that are not closely related evolve to have similar structures.*
What does the environment have to do with convergence?	*If two unrelated species live in the same environment, they may end up evolving to have the same trait.*
From looking at the three examples of wings, what can you conclude about the structure and function of flight?	*that the same function can be achieved by different structures*
What is the general purpose of the fifth article, "Evo-Devo"?	*It uses illustrations to compare the appearance of embryos of different species to one another and to the adult animal.*
What pattern or patterns did you see in the graphic?	*As the embryos developed, they looked more and more like the adult animal and less and less like one another.*
Which sentence best states the main idea in this selection?	*"As you can see, distantly related animals look quite similar as early embryos."*
What do these data suggest to you about the lines of descent of these five species?	*Maybe all five species are descended from the same ancient species.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 2, students should complete the provided outline framework to summarize Collection 2. A sample completed outline is shown below, with student writing in bold, but students' outlines may vary in wording and details. Look for evidence that students thought about the crosscutting concept "Cause and Effect" as they summarized each selection and that they were consistent in using complete sentences, proper punctuation, and accurate spelling.

Genes, Species, and Change

I. Genes, which are chunks of DNA molecules, are the cause of inherited traits.
   A. Chromosomes inside the cell nucleus contain DNA.
   B. **Genes are passed from parents to offspring.**
   C. Gene therapy can change traits that cause diseases.

II. It takes effort and teamwork to find the cause of an unusual trait.
   A. First, the person's DNA is searched for mutations.
   B. **Then, proteins made by the mutated gene are compared to the "normal" gene.**
   C. **Later, mice are bred with the mutation to see if it changes their traits.**

III. **Genes are inherited in ways that cause differences in members of the same species.**
   A. Individuals of the same species of nudibranch can be different colors.
   B. The environment causes size and fur differences in a species of rabbit.
   C. **Butterflies of the same species can have different colors.**
   D. **Squirrels of the same species living apart have color and other differences.**

IV. Species that are not closely related can have similar traits.
   A. Ichthyosaurs and sharks have similar traits but are not closely related.
   B. **Many kinds of animals evolved to have wings, but they are not closely related.**

V. **The embryos of species that are not closely related can be compared.**
   A. Early embryos look almost the same.
   B. **Later embryos start to look different.**

LESSON 8

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

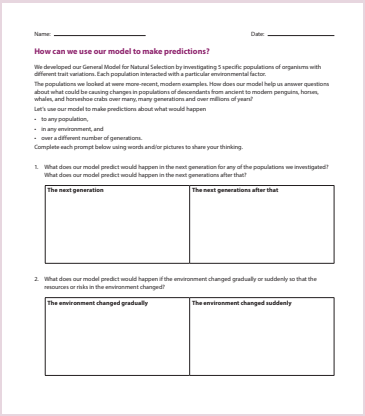
Previous Lesson

We explored five cases where trait distributions in the population changed over a few generations. We used a jigsaw strategy to analyze data from different studies on our group's assigned case. We developed a model to explain what was causing the shift in trait distribution over time for our individual cases.

This Lesson

Putting Pieces Together

2 DAYS



Name: _____ Date: _____

How can we use our model to make predictions?

We developed our General Model for Natural Selection by investigating 5 specific populations of organisms with different trait variations. Each population interacted with a particular environmental factor.

The populations we looked at were more-recent, modern examples. How does our model help us answer questions about what could be causing changes in populations of descendants from ancient to modern penguins, horses, whales, and horseshoe crabs over many, many generations and over millions of years?

Let's use our model to make predictions about what would happen

- to any population,
- in any environment, and
- over a different number of generations.

Complete each prompt below using words and/or pictures to share your thinking.

1. What does our model predict would happen in the next generation for any of the populations we investigated? What does our model predict would happen in the next generations after that?

The next generation	The next generations after that

2. What does our model predict would happen if the environment changed gradually or suddenly so that the resources or risks in the environment changed?

The environment changed gradually	The environment changed suddenly

We compare each of our case-specific system models (for finches, moths, swallows, fish, and plants) and argue for which parts and interactions these cases have in common. We develop a general model to explain what causes changes in the population. We use the model to make predictions about what would happen in any population, in any environment, and over a different number of generations.

Next Lesson

We will carry out two investigations using a computer simulation. We will argue for why we get different outcomes when we simulate different types of white blood cells in the environment with the same starting population of bacteria.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

8.A Respectfully provide and receive critiques about one's explanations and model ideas related to what in the system is remaining stable (e.g., traits within individuals and patterns of inheritance) and what is changing (e.g., distribution of traits) and what causal mechanisms (e.g., competitive advantages, selection events) are at work on different populations in different (eco)systems.

8.B Use a model that includes unobservable mechanisms describing more than one cause and effect relationship between different parts and components in a system to make predictions about how natural selection leads to a change in the distribution of traits in a population over time, while heritable traits of each individual remain stable.

What Students Will Figure Out

- There was variation in specific traits between individuals in a population in the past.
- Individuals with certain trait variations are sometimes able to more easily access available resources needed for survival, causing them to survive better and reproduce more than other individuals.
- The traits that grant an advantage for surviving or reproducing can be passed on to their offspring.
- Distribution shows more individuals with the trait variation that allows them to survive or reproduce better.

Lesson 8 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	2 min	**NAVIGATION** Briefly discuss next steps.	A	
2	10 min	**POSTER WALK AND TALK** Carry out a poster walk and talk with a partner to compare two different cases.	B	Revised Case System Model posters, timer
3	18 min	**CO-CONSTRUCT SOME GENERALIZED STATEMENTS** Start building together as a class the parts of a general model for explaining all these cases.	C	1 green and 2 purple 3" x 3" sticky notes, Revised Case System Model posters, General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape
4	11 min	**DEVELOP OTHER GENERAL MODEL IDEAS** Work with a partner to develop additional general model ideas to explain multiple cases.	D	1 pink and 1 blue 3" x 3" sticky notes, Revised Case System Model posters, General Model poster, prepared colored papers and index cards (see Materials Preparation section), markers, transparent tape
5	4 min	**REFLECT ON OUR DISCOURSE CONTRIBUTIONS** Complete self-assessment questions on discourse contributions.	E	*Argumentation Self-Assessment*
				End of day 1
6	10 min	**EVALUATE OUR GENERALIZED STATEMENTS** Compare the previously created model ideas with a new partner to determine if and how they need to be modified to work for the partner's case.	F	Revised Case System Model posters

Part	Duration	Summary	Slide	Materials
7	12 min	**CO-CONSTRUCT GENERALIZED DESCRIPTIONS AND CLARIFY THE REMAINING PARTS OF THE MODEL** Create general statements describing and clarifying main elements of the General Model for Natural Selection.	G	General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape
8	12 min	**CONNECT THE PARTS OF THE MODEL** Articulate the cause-and-effect relationships between the different parts of the general model.	H-I	General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape
9	5 min	**ADD WORDS WE EARNED TO THE GENERAL MODEL** Discuss the terminology associated with these components and interactions.		General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape
10	6 min	**USE THE MODEL TO MAKE PREDICTIONS** Use the model to make predictions about changes in populations over different amounts of time (number of generations) and in different environments.	J	*How can we use our model to make predictions?*, General Model poster

End of day 2

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• science notebook • 1 green and 2 purple 3" x 3" sticky notes • 1 pink and 1 blue 3" x 3" sticky notes • *Argumentation Self-Assessment* • *How can we use our model to make predictions?*		• Revised Case System Model posters • timer • General Model poster • prepared colored papers and index cards (see Materials Preparation section) • 10 yellow sticky notes (5" x 8") • markers • transparent tape

Materials preparation (30 minutes)

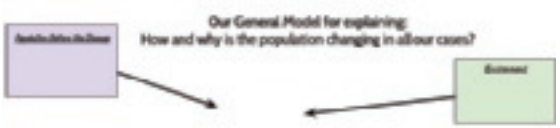
Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

The Revised Case System Model posters from Lesson 7 should be hung up for students to visit in this lesson. Ensure that all posters from each class period are well spaced out around the room as 1-5 pairs of students may be visiting a poster at any one time and will need to refer to it in their discussions.

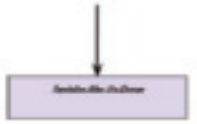
Prepare for each class a General Model poster that is approximately 3′ x 4.5′. Title the poster "Our General Model for explaining: How and why is the population changing in all our cases?" Add titles to landscape-oriented sheets of letter-size paper, as detailed in the bullets below, and attach them to the poster, positioned as shown in the image.



- purple paper: "Population before the Change"
- purple paper: "Population after the Change"
- green paper: "Environment"

Add arrows in marker to the poster as shown in the image. Hang the poster to be used in your Scientists Circle.

Prepare for each class the following materials and have them ready to attach to the poster during class discussion.



- Add titles to landscape-oriented, letter-size paper, as detailed in the bullets below.
  - pink paper: "Survival and Reproduction"
  - blue paper: "Offspring and Inheritance"
- Cut pieces of blank white copy paper in half lengthwise. On 3 of these long half-sheets, landscape-oriented, write the sentence stem "Because of this ...".
- Use 5" x 8" white index cards (or paper) to make the following labels for the poster. Put one term per card and write in large capitals to fill the card.
  - " = ENVIRONMENTAL INTERACTIONS"
  - " = COMPETITIVE ADVANTAGE"
  - " = SELECTION"
  - " = LARGELY HERITABLE TRAITS"
  - "NATURAL SELECTION"

You will find incremental images of the General Model as it is developed throughout this *Teacher Guide*, but larger versions of these sample images are also provided for your reference in *Lesson 8 Sample Images for General Model*. You will need 1 green, 1 pink, 1 blue, and 2 purple 3" x 3" sticky notes per student. You will need 10 5" x 8" yellow sticky notes to construct the General Model with the class.

Print out sufficient copies of *Argumentation Self-Assessment* and *How can we use our model to make predictions?* for every student to have one of each.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to help students develop and refine a general model for what is causing population-level changes in traits in populations. The bulk of the lesson engages students in identifying parts, interactions, and mechanisms for the model. And it generalizes the model by having students articulate it for a single case, then for two cases, and eventually for all five cases. By the end of the lesson, students will have developed a general model for natural selection that they will have derived from evidence and argumentation.

In many ways, this is one of the most complex models that students will have developed in so far, due to the fact that students are inductively building and revising the models many times and are doing this in relatively short amounts of time between each revision. In addition, each round of revision relies heavily on productive discourse norms and experience with triangulating the model against a larger and larger set of evidence, also in a relatively short amount of class time.

The use of the crosscutting concept "stability and change" is critical in the development of this model. Students historically struggle with confusing and combining what is changing and what is not in natural selection, particularly at the population level as opposed to the individual level. In this lesson students will identify that there are changes happening at an aggregate level (population-level changes and environmental changes), but no changes are occurring at the gene- or trait-heritability level. Students will identify that the kinds of differences happening on the individual level are only based on (a) how well particular trait variations function and (b) how this functioning influences the chances of dying versus surviving long enough to reproduce. The repeated rounds of discussion toward building the classroom consensus model are designed to push on this distinction.

Students don't yet have direct evidence for whether their model (for natural selection) accurately predicts and explains what would happen to other populations, in other environmental conditions, or over different lengths of time. Testing their predictions using their current model against a new suite of phenomena is the focus of the next two lessons.

Where We Are NOT Going

This lesson does not introduce the words "natural selection" as part of the model's name at the beginning. Instead, the term is reserved until the class has derived the entire model together at the end of day 2. While parts of this model were given the labels "competitive advantage" and "selection", the term *survival of the fittest* was intentionally avoided as it might tend to convey the idea that some traits are the best rather than being "relatively better on average in a probabilistic sense" for a given environment. The term *selective pressure* was avoided as students' current understanding of *pressure* is a particle-level mechanism, developed in their prior work in *Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*, rather than a population-level mechanism.

We do not yet identify the importance of *changes* in the environment as the trigger for shifts in selection; we will do that in the next lesson. Different c*hanges* to the environment can lead to different selective pressure (that term not used in the unit) and different competitive advantages from certain trait variations, which can lead to different shifts in the distribution of traits over time.

The probabilistic nature of competitive advantages as well as the resulting effects on the variability in the outcomes of natural selection will be uncovered in the next two lessons but is not addressed in this lesson.

The historical background for who first derived this model for natural selection (Charles Darwin) is not introduced in this lesson. Avoid introducing the idea that someone well known already developed this model as it would take away the sense of accomplishment in the student sensemaking and would also undermine the motivation for testing the model in the next two lessons.

LEARNING PLAN FOR LESSON 8

1. Navigation

2 MIN

Materials: None

Facilitate a brief discussion about our next steps. Display **slide A**.

Suggested prompt	Sample student response
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?	*Understanding what happens over a few generations for any of these populations will help us understand and explain what might have happened over a long period of time from the distant past to today.*

Tell students this will be our mission then for the next two class periods. We will try to develop as general a model as possible for explaining the changes in traits in any population over time.

2. Poster Walk and Talk

10 MIN

Materials: science notebook, Revised Case System Model posters, timer

Orient students to the challenges in identifying similar causes, mechanisms, or relationships across case studies. Display **slide B**. Say, *Let's get ready to share our case with someone who has a different case. Our goal is to share our case and hear another case so that we can find any causes, mechanisms, or relationships that the two different cases seem to have in common. Since many parts of the system models you put together are likely to be different and because you looked at different organisms, different places, and different times, while hearing a summary of a different case you will need to be listening for similarities in the relationships between those parts and similarities in what caused something to happen.*

Prepare for a poster talk with a partner from a different case. Introduce the discussion protocol on the slide:

- 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 that is similar to one in their own system model.
- The person listening signals these similarities across the two cases by snapping fingers a few times. This will allow the person presenting to continue on with their explanation without pausing yet for questions.

Emphasize that students should talk to just their partner as they do this, but that both people should feel free to walk around to visit each other's poster for each talk. Explain that they will need to stand far enough away from their poster, though, to make sure other pairs visiting the poster can see and reference it too as they talk. Ask students to bring with them their notebook and something to write with for the next activity after this but to refrain from writing anything down for this initial poster walk and talk.

Assign partners to work across cases. Pair students to ensure the following case comparisons:

- finches and moths
- finches and swallows
- finches and plants
- finches and fish
- moths and swallows
- moths and plants
- moths and fish
- swallows and plants
- swallows and fish
- plants and fish

Carry out the poster talks. Have students meet with their partner and start sharing their first system model. Set a timer for 4 minutes. Remind students when the time is up to switch to having the other person share the second system model, and you will again set the timer for 4 minutes. When that time is up, cue students to start the next activity.



Additional Guidance

Summary of Natural Selection Cases is provided for your reference as you circulate among partners while they talk.

3. Co-construct some generalized statements.

18 MIN

Materials: science notebook, 1 green and 2 purple 3" x 3" sticky notes, Revised Case System Model posters, General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape

Regroup as a whole class in a Scientists Circle around the General Model poster spot. Display **slide C**. Distribute two purple and one green 3" x 3" sticky notes to each student. Students will use these sticky notes to build the general model in their notebook as you build the General Model poster.

Develop a generalized statement together as a class. Say, *I heard some snapping at many different points in your discussions. This is a sign that there are many places where you identified a cause, relationship, or mechanism that might be similar across your two cases. Let's get ready to capture those in the form of some general statements about what is happening in both cases that is not case specific. Let's do some examples together first so we can figure out how we might phrase these general model ideas we are trying to develop.*

You will find incremental images of the General Model as it is developed throughout this *Teacher Guide*, but larger versions of these sample images are also provided for your reference in *Lesson 8 Sample Images for General Model*. Please note that in Lesson 9 you will be adding a few more ideas to the model. You may want to look ahead so that you can plan accordingly if you are trying to fit the final model in a certain amount of space.

Have students open up to the next blank page in their science notebook and title it as follows:

- Our General Model for explaining: How and why is the population changing in all our cases?

*** Supporting Students in Developing and Using Structure and Function**

The connection of particular structures of organisms with their particular functions is an element of structure-function thinking that students should be familiar with from standards in the K-2 and 3-5 grade bands. Making the connection explicit here is a way to leverage their familiarity with this concept in order to scaffold the progression of the use of this idea into the middle school grade band, needed now from this point forward in the unit.

Throughout this lesson, students are substantiating their understanding that complex systems and processes can be

Key Ideas

The purpose of this first part of the Consensus Discussion is to

1. co-construct examples of generalized model ideas and
2. build together the start and the end of the General Model for Natural Selection poster for 3 parts of the model (Population before the Change, Population after the Change, and Environment).

Note: The populations are labeled "before the Change" and "after the Change" in this model since the "Beginning" and "End" of the individual cases were all at different times. "Before the Change" and "after the Change" are more-generalizable terms, but they represent the Beginning and End populations described in Lesson 7.

The following guidance outlines one way to manage construction of this part of the General Model. The outline might feel overly prescriptive and lead to a discussion where you feel a tendency to "look for the right answer" for each part of the model. That could, in turn, devolve into a "what goes here" guessing game.

To avoid this potential pitfall, it's important to realize that you are simply creating a structure to capture and organize all the students' ideas. Help students realize that their role is to identify, articulate, and revise the common ideas that they all agree on until they best represent all five cases. Use student language where possible (where it approximates what is shown in the examples).

Co-construct language to describe general statement(s) for the purple Population before the Change paper. Say, *If we are going to create a general model to explain how and why the population is changing in all our cases, let's start by trying to capture what it is about the phenomenon we are trying to explain. What is the kind of population change we are trying to explain? Since you used purple index cards in your cases to describe this change in the population, let's start with what is on your purple index cards.*



Prompt students for how they could phrase a general statement for not only what is true for their specific case but what could be true across all the cases. The following discussion prompts give one example of how to do this.

After this part of the discussion, co-construct a general statement for these ideas and put it on the purple Population before the Change paper. Here are two different examples of statements your class might use:

- The starting population of organisms had variation in a specific trait.
- There was a distribution of variations for a particular trait in the initial population.

Have students write the same statement(s) on one of their purple sticky notes and put it in their science notebook on the top-left of their General Model page.

modeled and that those models can be used to describe how the system's function depends on the relationships among its parts. In this case, the functioning of the system is an emergent property of the system—population-level changes in the traits of the population over time. Explaining this process depends on understanding the relationships among its parts (which are represented on the colored papers in the model being constructed):

- trait distributions in the population before the change
- environmental variables
- effects on survival and reproduction (on individuals)
- heritability of traits (via genes)
- change in trait distributions in the end (on the population)

Hence, the focus in these sections of the lesson is on the **function** of the relationships among the parts: genes, traits, individuals, populations, and the environment.

Suggested prompts	Sample student responses
So in every case we have a population, but were all the populations the same? What organisms were in the populations we studied? How would you generalize your population?	*Birds.* *Flying things.* *No, wait, that isn't true for plants.*
OK, so if we said in every case we have a population of animals, would that be general enough to summarize what is true in every case?	*No.*
We need a more-general way of referring to these parts of the system. A population of what?	*Living things.* *Organisms.* *Individuals.*
This is great, we have a lot of different ways we could say what it's a population of that isn't case specific. But let's go a step further—what can we say about how the individuals in that population compare in terms of the trait of interest. Are they all identical?	*No.*
So what was different about the individual organisms in these different populations?	*They had different wing lengths.* *They had different colors or patterns.* *They had different beak lengths.* *They had different flowering times.* *They had different numbers of bony plates.*
How would we describe that sort of difference between individuals without referring to a case-specific trait?	*The individuals had different traits.* *There were trait variations in the population.* *There was variation in traits between individuals across the population.*

Co-construct language to describe general statements for the other purple paper—Population after the Change. Say, *OK great, so then if this is the population before the change* (refer to that purple paper), *let's now describe the population after the change. Remember, we want a general statement that can work for any case.*



Prompt students for how they could phrase a general statement for not only what is true for their specific cas e but what could be true across all the cases. The following discussion prompt gives one example of how to do this.

After this part of the discussion, co-construct a general statement and put it on the purple Population after the Change paper. Here is an example:



- The distribution of variations in a particular trait changed in the population.

Have students write this on their second purple sticky note and put it in their science notebook at the bottom of their General Model page.

Suggested prompts	Sample student responses
What in general is changing in the population?	*The traits. How many organisms in the population had each trait variation.* *The amount of variation in traits or body structures.* *The average size of the body structure changed.*
Was it always the size of something that changed?	*No, sometimes it was the color like in the moth example, or sometimes it was the timing of the trait like in the plants. Or the number of bony plates like in the fish.*
So, we can say trait variations changed. Did all the individuals in the population get the different traits in the generations after the change?	*No, only some of the individuals in the population ended up with different trait variations.* *But more of the individuals in the population after several generations had a certain kind of trait at the end of the study than at the beginning.*
So regardless of size or color or timing or how many actually had the different traits, the distribution of the traits changed. Would that statement work for all our cases?	*Yes, that works.*

Co-construct language to describe general statement(s) for the green Environment paper. Say, *Each of you organized your case system model to start at the top with a description of what was important about the environment for your case. Let's describe how these environments compare across every case.*



Prompt students for how they could phrase a general statement for not only what is true for their specific case but what could be true across all the cases. The following discussion prompts give one example of how to do this.

After this part of the discussion, co-construct a general statement and put it on the green Environment paper. Here are is one example:

- Different environments have different living (biotic) and nonliving (abiotic) things in them.

Have students write this on their green sticky note and put it in their science notebook on the top-right of their General Model page.

Suggested prompts	Sample student responses
What were some of the things that were different about what was in each environment?	*Environments could have roads or overpasses, different kinds of plants or trees, different amounts of rain, different predators, different food sources ....*
OK, so different environments have different living and nonliving things in them. What were some of the science terms we learned in seventh grade in Maple Syrup Unit for categorizing living and nonliving things in the environment?	*Biotic means living, and abiotic means nonliving things.*
Were the living, or biotic, parts of the environment the same in every case?	*No.*
Were the nonliving, or abiotic, parts of the environment the same in every case?	*No.*

Additional Guidance

If students readily recall the terms *abiotic* and *biotic* from prior instruction, include references to them in the subsequent discussion and in the summaries you write. While it could be helpful to continue to use these terms for some classes, it may be a barrier for others. So don't dwell on these terms if they seem to slow down the model construction process. In such cases, stick with using *living* and *nonliving* instead of *biotic* and *abiotic* in the remainder of the work. Now is not the time to add these sorts of peripheral words to a Word Wall.

Discuss what to write in between the arrows. Say, *We have arrows coming together from the population of organisms before the change and from the environment. Let's try to describe the relationship between these two components.*

In each part of this Consensus Discussion, important elements of the model are identified and described. In each case, the exact language of the element is less important than the concept. Use students' words as much as possible. Keep

in mind, however, that these elements will be referred to in future lessons, so it is important that student language that is used accurately captures the basic concept.

Key Ideas

The purpose of the Consensus Discussion is to surface these two ideas:

- There are some things in the environment that are needed for survival and reproduction, and there are some things in the environment that are harmful.
- The variation in structure results in a variation in function.

Suggested prompts	Sample student responses
How would you, in general, describe the relationship between these two components—environment and population before the change?	*The population of organisms is inside the environment.* *They interact somehow.*
Can we all agree that in all cases the environment and the population of organisms interact in some way?	*Yes.*
OK, can we represent that idea by saying there are environmental interactions in every case?	*Yes.*

Add the = ENVIRONMENTAL INTERACTIONS white index card or paper to the General Model poster, centered between the top two arrows. Have students write this in the same position in their science notebook on their General Model page.



Clarify the role of the first two elements in the model. Say, *These interactions are the results of what we described on the purple papers and the green paper, namely, that the population of organisms interacts with different things in the environment. But we are trying to identify what all our cases have in common. Can we clarify what it is about the environment that is important in that interaction in all our cases? Can we clarify what it is about the beginning population that is important in that interaction in all our cases? Let's try to describe those kinds of similarities related to the interactions across all the case studies. Let's start with the arrow coming from the Environment paper.*

Prompt students for how they could phrase a general statement for not only what is true for their specific case but also what could be true across all the cases. The following discussion prompts give one example of how to do this.

After this part of the discussion, co-construct on 1 or 2 yellow sticky notes a general statement clarifying the role of the environment. Here is an example:

- There are some things in the environment that are needed for survival and reproduction, and there are some things in the environment that are harmful.

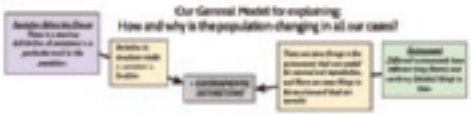


Add this piece over the arrow between the green Environment paper and the = ENVIRONMENTAL INTERACTIONS card.

Have students write this clarifying statement directly in their notebook next to the related arrow on their General Model page.



Suggested prompts	Sample student responses
Let's start with the arrow coming from the Environment. We said our different environments have different living, or biotic, and nonliving, or abiotic, things in them. What were some examples of those that our different populations interacted with?	*Cars and overpasses, different tree surfaces, different predators, different food sources, different amounts of rain ...*
Why are these important things for these organisms? What do they need these for?	*They need these to live.* *They need these to reproduce.*
OK, so in each of these cases, the environment provides living and nonliving, or biotic and abiotic, things that are needed for survival and reproduction. Is everything in the environment helpful for organisms?	*No, sometimes there are things that are dangerous too.* *No, there are predators or bad weather events or pollution.*
So can we say that the environment can also have living and nonliving (or biotic and abiotic) things in it that are potentially harmful to the organisms living there?	*Yes.*



Prompt students to clarify the role of the population before the change. Say, *Now let's look at the arrow coming from the Population before the Change.*

Prompt students for how they could phrase a general statement for not only what is true for their specific case but also what could be true across all the cases. The following discussion prompts give one example of how to do this.

After this part of the discussion, co-construct on 1 or 2 yellow sticky notes a general statement clarifying the role of the variations in the population before the change. Here are two examples:



- Different structures have different functions.
- Variation in structure results in variation in function (e.g., shorter wing size -> maneuverability vs. longer wings -> flying longer distances).

Add this piece over the arrow between the purple Population before the Change paper and the = ENVIRONMENTAL INTERACTIONS card.

Have students write this clarifying statement directly in their notebook next to the related arrow on their General Model page.

Suggested prompts	Sample student responses
Now, let's clarify the importance of there being different trait variations in the population. Why does that matter? How are these differences in structures between individuals related to what they can do?	*The variations in structures lead to some kind of different functions.** *They allow the organism to do something different.*
Let's think through one specific example. The swallows group—what were the different trait variations your organism could have?	*The birds could have shorter wings or longer wings.*
What was the function of having a shorter wing length?	*Shorter wings were better for quick maneuvers.*
So do the other cases have a similar structure-and-function relationship where certain trait variations provide at least slightly different functions for the individuals that have them?	*Yes.*

4. Develop other general model ideas.

11 MIN

Materials: science notebook, 1 pink and 1 blue 3" x 3" sticky notes, Revised Case System Model posters, General Model poster, prepared colored papers and index cards (see Materials Preparation section), markers, transparent tape

Prepare the whole class for partner work. Display **slide D**. Say, *This is a great start. You and your partner will continue creating statements that reflect what we think is true across every case. You'll focus on the parts of your two cases that are described on the pink Survival and Reproduction cards and blue Offspring and Inheritance cards. Also, we know that useful scientific models explain not only the model parts and components but also the relationships among those parts and components.*

Continue, *Let's add arrows that show the cause-and-effect relationships between the other parts of the model. And then we should describe the cause-and-effect relationships between the parts we linked with an arrow similarly to*



*** Attending to Equity**
Universal Design for Learning: Using sentence starters and graphical scaffolding are powerful ways to support *action and expression* for diverse learners.

what we did for our individual case system models. But now we want general statements that describe what's similar in all the cases. These general cause-and-effect statements can start with the phrase "Because of this . . . ", like the example I'm showing you here.

Draw an arrow pointing down from the = ENVIRONMENTAL INTERACTIONS card. Put a white "Because of this . . . " paper across that arrow.

Prepare partners from each case to work together. Ask students to rejoin their partner from their poster talk. Recap the mission students have with their partners: they will need to do the following on their own model in their 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 …."*

Remind students that when they are talking with their partner, they should be citing relevant evidence and posing and responding to questions when more detail is needed.

Distribute 1 pink and 1 blue sticky note to each student. Encourage them to take their notebook with them and revisit with their partner the Revised Case System Model posters explaining their cases, if they wish, as they write up the ideas that would be part of a general model for explaining both of their cases. They should make detailed notes in their science notebooks on their General Model page to record their descriptions of the cards and their cause-and-effect statements.

Tell students not to worry about any clarifying statements (on yellow sticky notes) now. We will do those together as a class later, as needed.

Assessment Opportunity

Building towards: 8.A.1: Respectfully provide and receive critiques about one's explanations and model ideas related to what in the system is remaining stable (e.g., traits within individuals and patterns of inheritance) and what is changing (e.g., distribution of traits) and what causal mechanisms (e.g., competitive advantages, selection events) are at work on different populations in different (eco)systems.

What to look and listen for: Students should propose statements that could work across both cases, asking questions to clarify the meaning of those statements and critiquing the statements in order to make them better fit the evidence from both cases. When students are doing this you are likely to hear them saying things like this:

- Does this work for your case too?
- How should we rephrase this so it takes into account X?
- I have an idea of how we modify that idea slightly so that it also captures what is happening in my case.
- Though I can see how X is happening in your case, something different was happening in mine.
- This (X) seems really similar to something that was going on in my environment. In my case, Y was happening. So how can we best describe what it is that is similar in both X and Y?

What to do: If students are struggling to come up with general statements, encourage them to focus on articulating the similarities between their cases and then describing them in non-case-specific terms. The bulleted examples above may be helpful to encourage richer discourse.

If students are stuck on articulating any causal relationships, you could provide additional sentence stems to assist them in coming up with cause-and-effect statements linking their general statements. For example, "In both cases, it seems like because of X, Y happens."

If needed, a second opportunity to assess this lesson-level performance expectation in a similar way happens at the start of day 2 when students follow the discussion protocol on slide F.

5. Reflect on our discourse contributions.

4 MIN

Materials: *Argumentation Self-Assessment*

Introduce the self-assessment. Show **slide E**.



Say, *You've done some amazing work across the last lesson and today. I am excited for us to pool together in our next class all these generalized model ideas you have worked on today. Before you share those next time, I want you to reflect on the discourse you participated in today and the role you had in shaping each other's thinking.*

Provide each student with a copy of *Argumentation Self-Assessment* and ask students to complete this and turn it in as they leave class.

Assessment Opportunity

Building towards: 8.A.2: Respectfully provide and receive critiques about one's explanations and model ideas related to what in the system is remaining stable (e.g., traits within individuals and patterns of inheritance) and what is changing (e.g., distribution of traits) and what causal mechanisms (e.g., competitive advantages, selection events) are at work on different populations in different (eco)systems.

What to look and listen for:

- Look for students to reflect on their contributions and discourse practices, specifically around giving respectful critiques. If a student selects NO on the statement about respectful critiques, look for the student to reflect on how they could improve next time.
- The fifth statement addresses whether students were able to apply their particular thinking to the broader concept of explaining changes over time. Look for students who select NO to reflect on why that might be and be prepared to provide additional supports.

What to do: Students' responses can be used in planning additional support or interventions that may be needed by classes or by specific individuals.

- Much of the rest of this lesson and the balance of this unit rely on students thoughtfully considering multiple interpretations and various potential claims as models and explanations are developed. So if student responses indicate that students are struggling with contributing to discourse and arguing respectfully, review with students the classroom norms for providing respectful critiques.

- If students do not connect their model with changes over time, take the opportunity when those topics arise during class activities on day 2 to emphasize the connections with numbers of generations and the time that passes with each generation.

End of day 1

6. Evaluate our generalized statements. 10 MIN

Materials: science notebook, Revised Case System Model posters

Evaluate general statements for a new partner's model. Show **slide F**. Say, *If the statements you wrote in your notebook with your previous partner are general enough to explain what is happening in two cases, they may be general enough to describe what is happening in the other cases as well. Let's test them out to see if that is true and revise them if needed so that they are general enough.*

Introduce the new discussion protocol. Assign everyone to a new partner who has a different case than their previous partner. Introduce the new discussion protocol for this task as shown on the slide and listed here:

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.

Encourage students to relocate as necessary to reference their Revised Case System Model posters as they discuss with their new partner and to modify the statements in their notebook as needed.

Give students 8-10 minutes to discuss their model ideas, alternating who is sharing first as they go through their ideas.

Additional Guidance

While you circulate to listen in on these conversations, consider reassessing students for 8.A Respectfully provide and receive critiques about one's explanations and model ideas related to what in the system is remaining stable (e.g., traits within individuals and patterns of inheritance) and what is changing (e.g., distribution of traits) and what causal mechanisms (e.g., competitive advantages, selection events) are at work on different populations in different (eco)systems.

7. Co-construct generalized descriptions and clarify the remaining parts of the model. 12 MIN

Materials: science notebook, General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape



Facilitate a Consensus Discussion. Display **slide G**. Have students move to the Scientists Circle. Review the purpose of the partner work students have done and say, *What were the components and interactions that were causing changes in the populations across all our cases? Let's work together to get some of those generalized statements you came up with onto our class model. We have the blue and pink papers that we will add to our general model now to describe the parts of our case models that we think they have in common*.

Cue students to refer to their notebook where they have recorded on the pink and blue sticky notes their generalized model ideas they wrote with their partners. Ask them to look for the most important ideas they had in common regarding the changes that were seen in the populations they studied. While students are reviewing their statements, place the pink Survival and Reproduction paper and the blue Offspring and Inheritance paper on the General Model poster anywhere along the sides. They will be relocated later.

*** Attending to Equity**

Universal Design for Learning: Students vary in the amount of scaffolding they need for memory and transfer of information in order to improve their ability to access their prior learning. All learners can benefit from assistance in how to transfer the information they have to other situations. The use of these hand signals helps anchor instruction by linking to and activating relevant prior knowledge in a memorable and transferable way. Furthermore, by using these hand signals as an additional *representation* of these ideas, we are providing visual, nonlinguistic supports for vocabulary clarification, which helps promote understanding across multiple languages.

Additional Guidance

It doesn't matter which of these two sets of ideas—(1) Survival and Reproduction or (2) Offspring and Inheritance—is addressed first. As students surface an idea, continue building on that idea together and recording it on the corresponding colored paper (pink or blue) before prompting for the next idea.

Say, *Before we work on connecting these blue and pink sheets to the other parts of the model or figure out what order they go in, let's first agree on how to describe these two parts of the model.*

Prompt students for how they could phrase a general statement for what is true not only for their specific case but what could be true across all the cases.



Co-construct a general statement for the concept on the blue Offspring and Inheritance paper. Here are two examples:

- These traits are heritable. Parents pass these trait variations to offspring.
- Offspring inherit these trait variations from their parents.

Co-construct a general statement for the concept on the pink Survival and Reproduction paper. Here are two examples:

- Some individuals have better trait variations for surviving or reproducing than others.
- Individuals with certain trait variations survive and/or reproduce.

Don't have students make any further text additions or annotations to their notebook from this point onward. Rather, have them put a check mark near any of their own model ideas as they are captured on the class model.

Clarify the role of the Offspring and Inheritance element in the model not articulated so far. Push on how traits are passed on to offspring. Help students review and articulate what exactly is passed on and how it is physically passed on when we use a shorthand phrase like "heritable traits are passed on to their offspring".

Key Ideas

With prompting, students should be able to recall a mechanism for how traits are inherited that articulates the connections among sex cells, chromosomes, genes, proteins, and traits from their prior work in *Muscles Unit*. These connections include these ideas:

- Traits themselves aren't actually passed on.
- Rather, each parent passes on genetic information in the form of specific alleles they contribute to their offspring via a sex cell.
- Genes contain the instructions that result in the formation of molecules called proteins, which are structural components that cells build.
- Proteins are used in the formation of physical traits.

The discussion prompts that follow this box give one example of how to facilitate this conversation.

If a version of this was already added to the Ideas for Investigations and Data We Need poster from Lesson 4 or the New Model Ideas chart from Lesson 6, you can refer to it now. If not, ask students to recap what they figured out in the *Muscles Unit* unit about how a trait like heavy musculature got passed on to the offspring cattle. An example discussion below demonstrates one possible way this could be facilitated.

Suggested prompts	Sample student responses
I heard you say that in the cases you looked at the trait variations were passed on to their offspring. So you're saying the traits are heritable, right? What is some of the evidence that these traits were heritable?	*Offspring had the trait variations the parents had, or something in between.*
How does this actually happen? What is physically getting passed from parents to offspring?	*Genes.* *Genetic material.* *Alleles.*
Great, so let's do a quick review of what this means. Where can we find an allele?	*Alleles are found on the chromosomes.*
And how would these chromosomes happen to get to the offspring?	*The chromosomes are in the egg and sperm.*

Suggested prompt	Sample student responses
OK, so the sperm fertilizes the egg, and now the offspring has these alleles from the parents. When that fertilized egg grows and splits many times to make an organism, it results in all the cells having those alleles. So how does that lead to whatever trait we are talking about?	*The allele is responsible for making a specific protein.* *Having different proteins in cells can lead to having different trait variations. Like when the cattle had a protein that wasn't able to send a message inside cells, that resulted in extra-big muscles.*

After articulating these connections, capture a summary statement of the connections. Co-construct on 1 or 2 yellow sticky notes a general statement clarifying the mechanisms of inheritance. Here are two examples:

- Sex cells with genetic material → certain alleles → certain proteins → specific trait variations
- Sex cells with chromosomes are passed on. → These have genes that affect which proteins to produce. →
  The proteins are used to form specific traits/variations.

Place this piece on the General Model next to the blue Offspring and Inheritance paper.



Clarify the role of the Survival and Reproduction element in the model not articulated so far. Say, *We have described the component of Survival and Reproduction; now let's clarify in our general model why this component is important.*

Key Ideas

It is anticipated that at this point the class will have landed on an idea for the Survival and Reproduction element like "some individuals have better traits for this than others" or "individuals with certain traits survive and/or reproduce". Now is the time to clarify the two important ideas listed here:

- **Connecting traits to survival:** Individuals with certain trait variations can survive better in this environment (or individuals with certain trait variations tend to die off more often in this environment).
- **Connecting survival to reproduction:** To produce offspring an individual needs to survive long enough, and individuals that survive longer can have more offspring.

The discussion prompts that follow this box give one example of how to facilitate this conversation.

Suggested prompts	Sample student responses
I heard you say that some individuals had trait variations that were better than other individuals had. What do you mean by "better"? Better at what? Do you have examples from the case studies that could help us define this more effectively? How do different trait variations affect the individual?	*The darker moths were better at not getting eaten by predators in polluted areas.* *Shorter wings made it so birds could make tighter turns and could maneuver better so they didn't get hit by cars.* *Different beak sizes helped birds eat different food.* *Mustard plants that bloomed earlier could be sure they could be done growing before the water was a limiting factor.* *Sticklebacks with fewer bony plates could swim more quickly and hide in small spaces to avoid predators.*
OK, so how does this relate to how long they would tend to survive in that environment?	*Some individuals with certain trait variations were better at getting what they need to survive, like food or water. This would allow them to survive longer than individuals that don't have that trait variation.* *Some of them were better at avoiding things that will kill them, like predators or cars. This would give them a better chance at surviving longer in that environment than individuals that don't have that trait variation.*

Connect survival to reproduction. Say, *So it sounds like these examples show that certain trait variations make it so individuals that have them are better at surviving, but the title of the card says "Survival **and Reproduction**".*

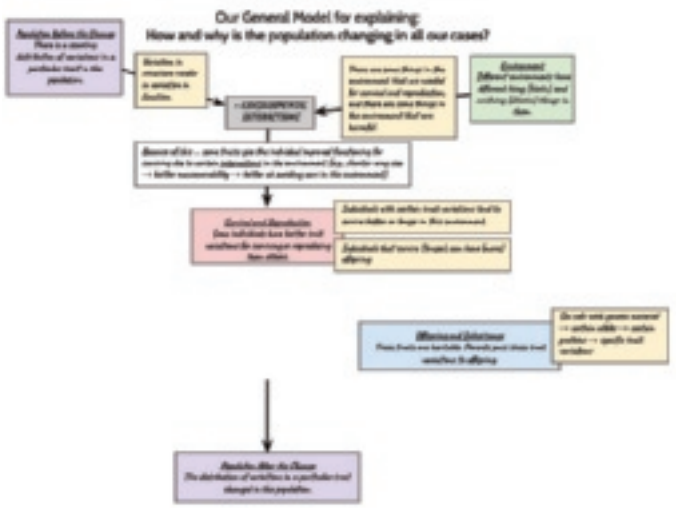
Suggested prompts	Sample student responses
How does reproduction factor in here?	*For the mustard plants, they had to stay alive and make flowers to reproduce before the lack of water would kill them.* *Many organisms cannot reproduce right away when they are born. They have to stay alive long enough to reproduce.*
So what if an organism dies? How does this affect whether it can have any more offspring?	*Well, dead things can't reproduce anymore.*
How does when an individual dies affect how many offspring it is able to have?	*The longer an individual lives, the more offspring it could have.* *Also the sooner an individual dies the less offspring it could have.*
In general, which individuals in the population tend to reproduce more often?	*The ones that survive long enough can reproduce.* *The ones that have the right trait variations for surviving in the environment are able to reproduce.*

After students have articulated the connection between traits and survival and the connection between traits and reproduction, co-construct on yellow sticky notes general statements clarifying the roles of these connections. Since there are two critical ideas here, you may want to put them on two separate sticky notes to accentuate that both are important.

- Individuals with certain trait variations tend to survive better or longer in this environment (or individuals with certain trait variations tend to die off more often in this environment).
- Individuals that survive (longer) can have (more) offspring.

Add the sticky notes next to the pink Survival and Reproduction paper.

Prompt students to clarify the role of Population after the Change in the model. Say, *We have one part of our model left here with a general description that we haven't clarified yet. We have written "the distribution of trait variations changed in the population" to describe the population after the change. Can we clarify what we mean by "the distribution of trait variations changed in the population"?*



Key Ideas

There are two critical ideas that you are helping students articulate for the statement on the purple Population after the Change paper. Both are related to what it means that the traits in the population are changing:

- There is a shift in the percent or proportion of individuals that have certain variations; this may result in a new mean, median, or mode (affecting what is typical).
- No new trait variations are in the population that were not there before.

Prompt students for how they could phrase a general statement for not only what is true for their specific case but also what could be true across all the cases. The following discussion prompts give one example of how to do this.

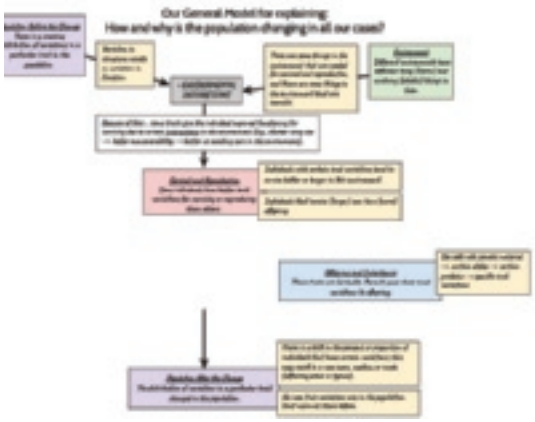
Suggested prompts	Sample student responses
Let's think about what we mean by a change in the distribution of trait variations by talking about one of our cases—the moth case. How many trait variations were present in the population?	*There were two variations.* *Some were dark and others were light.*
Which one was more prevalent before the change that was studied, and which was more prevalent after?	*The dark moths were more prevalent to start, and then at the end the light were more common.*
How would you describe those relationships mathematically? What happened to the percentage or proportion of each?	*At the start the proportion or percentage of dark moths was higher than light, but at the end the proportion or percentage of light moths was higher than dark.*

Suggested prompts	Sample student responses
If you were trying to help someone understand this idea, what kind of visual cues could you use? Could you use your hands to enact a visual representation of what you mean by a shift in the proportion of the two different variations in their population over time?	*(Students are likely to show one hand going up and the other hand going down.)*
What about other groups? How many variations did you have in your population?	*There were many different variations.* *Many different beak sizes.* *Many different wing lengths.* *A lot of different amounts of days to flowering.*
So how were you able to determine that the population changed?	*There was a different proportion of trait variations relative to each other.*
What happened to the distribution of those populations? Did you see a change in the mean, median, or mode?	*There was a new mean, median, or mode.* *The distribution of traits shifted.*
*If you were trying to help someone understand this idea, what kind of visual cues could you use? Could you use your hands to enact a visual representation of what you mean by a shift in the proportion of the different variations in their population over time?**	*(Students will likely show the shape of a graph plot by "air drawing" a curve.* *They may indicate the variation was less spread out.* *They may indicate the curve moved to the left or right.)*
Are there new trait variations in the population at the end of the studies that weren't there at the beginning?	*No, there aren't any new traits.* *There are just more or less individuals in the population that have those certain variations of the trait.*

After this conversation, co-construct on yellow sticky notes a general statement clarifying what is meant by a change in distribution of the traits. Since there are two critical ideas here, you may want to put them on two separate sticky notes to accentuate that both are important.

- There is a shift in the percent or proportion of individuals that have certain variations; this may result in a new mean, median, or mode (affecting what is typical).
- No new trait variations are in the population that were not there before.

Add these to the right of the purple Population after the Change paper.



8. Connect the parts of the model. 12 MIN

Materials: science notebook, General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape

Decide how the pink and blue papers should be arranged on the General Model poster and articulate the cause-and-effect ideas that connect them. Display **slide H**.

Say, *Great, it looks like we have some solid general descriptions here for these ideas. How do they connect to the rest of our model ideas? Which of these big ideas do you think best connects to the Environmental Interactions arrow we see on our model? And what "Because of this . . ." statement connects them? Turn and talk with a shoulder partner about what part you think is caused by the environmental interactions and how it is connected.*

Students should talk with a partner for a minute or two about whether the blue or the pink paper comes next and to agree on how to articulate the "Because of this . . ." statement to connect them.

Alternate Activity

If you think your students could benefit from a movement break, direct them to "stand and talk" with a partner across the circle rather than turning to a neighbor while still seated.

Additional Guidance

As they put these parts in order and connect them, students may have ideas that don't directly relate to the environment and will instead connect the ideas on the blue and pink papers to each other, such as, "Well, survival and reproduction must come first on the model because you can't really pass on alleles if you don't survive to do so." That is OK. Our next step will make connections to the interactions described above, so if they do not do that here, there will be a place a bit later where we focus on those ideas. The critical moves here are:

1. to arrange the components in the order described below and
2. to make this order logical to students.

Connect the Environmental Interactions element with the pink Survival and Reproduction paper. After students have had a chance to discuss their ideas and come to an agreement on what part comes next, say, *OK. Which comes next, the pink or the blue, and how does the environmental interaction cause that next step in the model?* Allow students to share. There are likely to be two different proposals.

- Some students will have concluded that because of the environmental interactions, the survival and reproduction of individuals are affected.
- Some students will have concluded that because of the environmental interactions, the inherited traits have been affected (the environment changed the genes).

Before establishing the connection to the pink Survival and Reproduction paper on the model, both proposals should be acknowledged and considered. But it is critical that students realize that the environment did not change the genes, rather, because of trait variations they already had, certain individuals were able to better survive and reproduce in that environment. Use the following prompts to guide students to realize that there is no evidence that supports the environment causing a change in the genetic information.

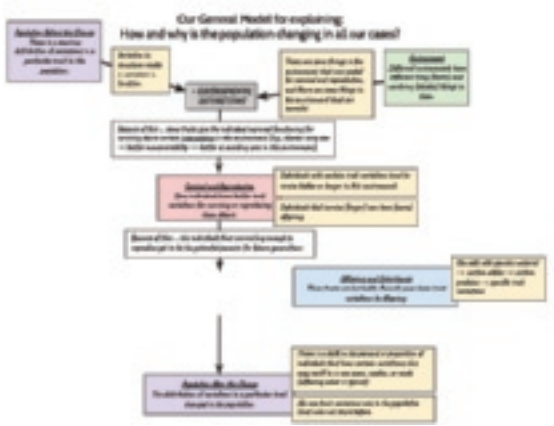
Suggested prompts	Sample student responses
What evidence is there that the survival of individuals was affected by the environment interacting with their trait variations?	*Longer-beaked finches could eat the bigger seeds that were the only food in the environment.* *Shorter-winged swallows could avoid cars in their environment.* *Lighter-colored moths could hide better from birds when there was less pollution.* *Shorter-flowering-time plants could survive and produce seeds sooner in a drier environment.* *Sticklebacks with fewer bony plates could hide better from predators.*
What evidence is there that the genetic information that makes the proteins that make the traits of certain individuals was affected by the environment?	*There were more individuals in the population at the end who had better trait variations.* *The distribution of the trait variations in the population changed.*
What was different about the trait variations in each population at the end? Were there brand new traits in the population at the end?	*No, there were no **new** traits. There were just **more** individuals with one kind of variation that had been there all along.*
So if there were not any brand-new traits in the population at the end, is there any evidence that there were changes in the genetic information?	*No.* *We don't know for sure that the genes didn't change, but we don't have any evidence that they did change.*
So which connection do we have stronger evidence for?	*We have stronger evidence supporting the idea that the environmental interactions affected the survival and reproduction of individuals depending on their trait variations.*

When the class has agreed that because of the environmental interactions, the survival and reproduction was affected, move the pink paper and its attached yellow sticky notes into the position below the arrow from the Environmental Interactions element.

Then use student suggestions to fill in the "Because of this . . ." statement on white paper that is positioned over the arrow that connects Environmental Interactions with Survival and Reproduction. Here is an example.

- Because of this ... some traits give the individual improved functioning for surviving due to certain interactions in the environment (e.g., shorter wing size -> better maneuverability -> better at avoiding cars in the environment).

Draw an arrow descending from the pink Survival and Reproduction paper.



Additional Guidance

This is an important discussion, and students must be convinced before moving on. Do not ignore disagreements. They must be resolved. Students have adequate evidence to draw on from across all their cases that the environment is not changing these traits in any individual and therefore has no direct causal effect on the traits that are in an individual. This should be justification enough to leave the blue Offspring and Inheritance paper to the side and deal with the direct effects on the pink Survival and Reproduction paper first.

Connect the pink Survival and Reproduction paper with the blue Offspring and Inheritance paper. Display **slide I**, say, *Great! 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?* As students talk for a minute or two, prepare to use the two additional white "Because of this . . . " papers to record the cause-and-effect statements linking the remaining parts of the model.

After students have had a chance to discuss their ideas and come to an agreement on what part comes next, say, *OK, what comes next, the blue or the purple, and how does survival and reproduction cause that next part?* Allow students to share. Most, if not all, will connect survival and reproduction with offspring and inheritance.

Move the blue paper and its attached yellow sticky notes into the position below the arrow from the Survival and Reproduction element (and above the arrow you already had leading to the purple Population after the Change paper).



Then, use student suggestions to fill in the "Because of this . . ." statement on white paper and position it over the arrow that connects Survival and Reproduction with Offspring and Inheritance. Here are two examples.

- Because of this ... the individuals that survive long enough to reproduce get to be the potential parents for future generations.
- Because of this ... the survivors get to have offspring.

Connect the blue Offspring and Inheritance paper with the purple Population after the Change paper.

Say, *One left! Turn and talk with a different partner about what "Because of this . . . " statement connects them?* After students have had a chance to discuss their ideas for a minute or two, allow them to share their "Because of this . . . " statements.

Use student suggestions to fill in the "Because of this . . ." statement on white paper and position it over the arrow that connects Offspring and Inheritance with the Population after the Change. Here are two examples.

- Because of this ... the offspring will likely have the trait variations of their parents. More offspring with certain variations grow up to be adults in the population.
- Because of this ... offspring will resemble their parents and more individuals with those variations are added to the population.



9. Add words we earned to the General Model.

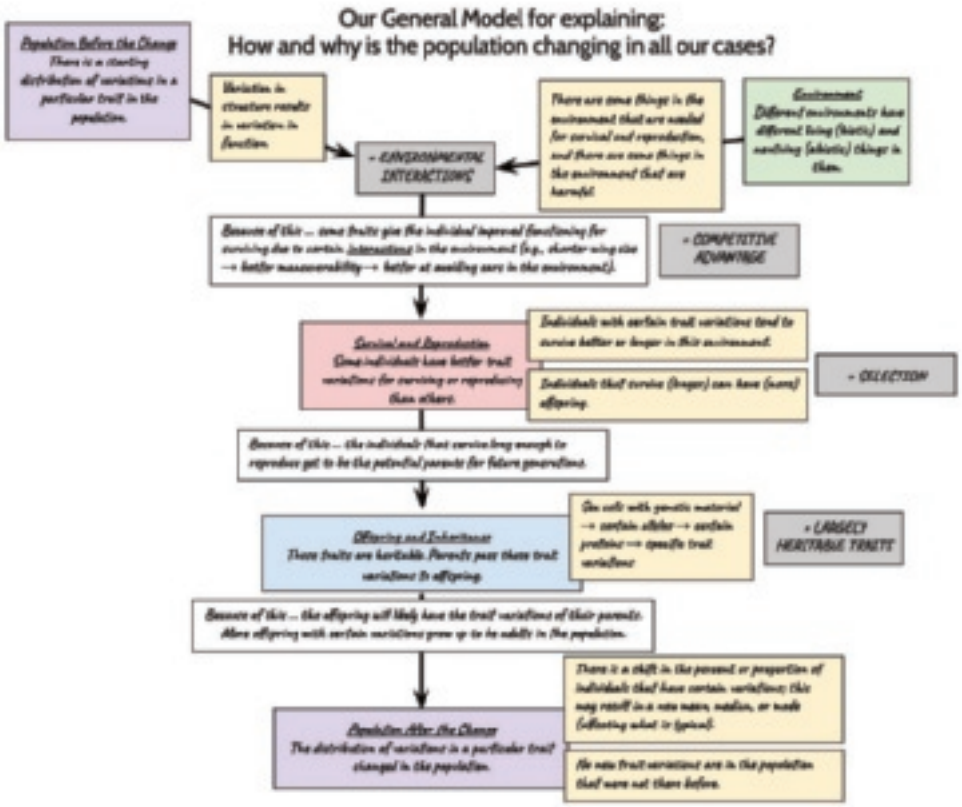
5 MIN

Materials: science notebook, General Model poster, prepared colored papers and index cards (see Materials Preparation section), 10 yellow sticky notes (5" x 8"), markers, transparent tape

Celebrate the model and simplify terminology in service of making this model useful. Give students a moment to look over the class General Model and ask them to consult their notebook for any other ideas that may not be represented fully in our model. Have students put a checkmark near any model ideas in their notebook that we have on the General Model as they recognize them.

At this point students may offer more ideas, which will likely already be represented somewhere on the class General Model. You may add clarification statements based on the contributions. For each idea offered, ask the class if this is a new idea or if it is already reflected in an existing model idea.

Say, *This model really feels like we can explain all the cases we looked at. Do you think it might be able to explain what happens to other organisms as well? If we want to use this model, we might want to include some terminology that will make these different components and interactions more efficient to talk about. We have several new words that we have earned that we can add to this general model, and moving forward we will be able to use these words to describe these ideas quickly.*



Add the index cards with the following words we earn to the General Model:

- = COMPETITIVE ADVANTAGE
- = SELECTION
- = LARGELY HERITABLE TRAITS

Additional Guidance

This protocol for adding words we earn to the Word Wall is a little different than the typical Word Wall protocol since the definitions for these terms will already be on the model to the left of where we are posting the terms. If your students are used to using the Word Wall as a go-to resource, it is OK to add these words to that Word Wall, too.

Synthesize the ideas to coherently describe how the population has changed. Say, *We can use the new terminology to help talk through what happened to cause the changes in populations that were observed in our case studies.*

Use the General Model and refer to each section as we "walk through" the general events that led to the change. Invite different students to contribute at each step along the way. The general synthesis would be something like this:

- A population of organisms has variety in a trait, and those variations function differently when interacting with certain resources or risks for that organism in that environment.
- Some individuals have trait variation(s) that give(s) them a competitive advantage over others for getting those resources or avoiding those risks in that environment.
- Individuals with the variation(s) that give(s) them a competitive advantage survive more often and/or longer and have more offspring than other individuals in the population.
- The survivors are the individuals with the variation(s) of the trait(s) that helped them survive and reproduce better; these are the potential parents of more offspring in the next generation.
- As long as those traits are heritable, they are passed to their offspring,
- Their offspring are added to the population. This shifts the distribution of traits.

10. Use the model to make predictions.

6 MIN

Materials: *How can we use our model to make predictions?*, science notebook, General Model poster

Propose a test of the model. Remind students that a scientific model is more powerful the more types of phenomena it can explain and that, so far, our model has been developed using only 5 cases for something that we've already seen occur in the past. Propose that in order to test the generalizability of the model it should also be able to predict outcomes in new cases as well.*



Name the mechanism we have modeled. Emphasize that this model describes an outcome occurring in populations in a lot of places in the "wild" or in settings where people aren't intentionally trying to change the population and in some cases are nothing more than observers of a relatively isolated ecosystem. Contrast this with examples where people are trying to change a population of offspring over many generations, citing examples from students' prior work in *Muscles Unit*, such as breeding for heavy musculature in cattle or colors of goldfish. Recall that this human-controlled process is called *selective breeding* or *artificial selection*. Explain that the process we have developed a model for is often referred to as *natural selection* as a way to distinguish that, though it too generates changes in the distribution of traits in the population of descendants due to selection, that selection is being produced by natural systems rather than an artificial or human-designed one as was the case in the examples from *Muscles Unit*.

Add the = NATURAL SELECTION card next to the title of the class General Model.

Additional Guidance

Note that in Lesson 9 you will use printouts of photos of each class's General Model, so you may choose to take that photo at the end of the class. Once you have a readable version, add a title to it indicating what class period it is for.

*** Supporting Students in Engaging in Developing and Using Models**

Here is an opportunity to further emphasize that one major goal of developing scientific models is to develop ones that are very generalizable and hold over long periods of time and for as large a class of phenomena as possible. You could make an explicit connection here to eventually needing to see if the model can be used to explain the changes we observed in penguin populations happening over millions of years. Applying the model to that class of phenomena will require working with the assumption that theories and laws that describe the natural world operate today as they did in the distant past. This is an important element of the modeling practice and one that students used in their prior

Connect to penguins, horses, whales, and horseshoe crabs. Remind students that though we developed this natural selection model to account for the population changes occurring in these cases over a few generations, we originally sought out these kinds of short-term-changes-in-population cases because we had questions about what could be causing changes in populations of descendants from ancient to modern penguins, horses, whales, and horseshoe crabs over many many generations.

work to explain what is happening over really long periods of time in Earth's past.

Complete an exit ticket to use the General Model for Natural Selection to make predictions. Show **slide J**. Distribute *How can we use our model to make predictions?*. Ask students to work individually using the General Model for Natural Selection to make predictions for what the model predicts would happen in any population, in any environment, and over a different number of generations.



Students will refer to their completed *How can we use our model to make predictions?* in Lesson 9, so if you collect it for assessment, be ready to return it to students at the beginning of your next class.

Assessment Opportunity

Building towards: 8.B Use a model that includes unobservable mechanisms describing more than one cause and effect relationship between different parts and components in a system to make predictions about how natural selection leads to a change in the distribution of traits in a population over time, while heritable traits of each individual remain stable.

What to look for: Use *How can we use our model to make predictions?* for sample student responses for each prediction prompt.

What to do: Students' responses can be used in planning additional support or interventions that may be needed by classes or by specific individuals. If students are missing key components or interactions in the model when making predictions or not making cause and effect statements, plan on revisiting these aspects of the model before moving on to the simulation in Lesson 9.

In particular, students may struggle with what constitutes a cause-and-effect relationship. Cause-and-effect relationships explain why the effect happened. They do not simply describe that something happened next.

Provide individual written feedback to students regarding any missing or inaccurate characteristics using comments like these:

- How are these connected?
- What causes what here?
- Please explain why this happens.

Additional Guidance

We do not yet identify the importance of *changes* in the environment as the trigger for shifts in selection; we will do that in the next lesson. Different *changes* to the environment can lead to different selective pressure (that term not used in the unit) and different competitive advantages from certain trait variations, which can lead to different shifts in the distribution of traits over time.

ADDITIONAL LE SSON 8 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.8.3: Delineate a speaker's argument and specific claims, evaluating the soundness of the reasoning and relevance and sufficiency of the evidence and identifying when irrelevant evidence is introduced.

Students work in partnerships to create a general model that explains both of their cases, then share those model ideas with another partner to see if they can also explain a third case. Each time they discuss these model ideas, students make claims about cause-and-effect relationships between some parts of their system and cite broad patterns in the evidence from their cases to support those ideas. Each student provides and responds to feedback to and from their partner as to whether those mechanisms apply across both systems. A discussion self-assessment is provided in this lesson to invite students to individually reflect on how well they shared their own thinking but also how well they gave critiques to others about their arguments and evidence.

LESSON 9

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

Previous Lesson

We compared each of our case-specific system models (for finches, moths, swallows, fish, and plants) and argued for which parts and interactions these cases have in common. We developed a general model to explain what causes changes in the population. We used the model to make predictions about what would happen in any population, in any environment, and over a different number of generations.

This Lesson

Investigation

2 DAYS



We carry out two investigations using a computer simulation. We argue for why we get different outcomes when we simulate different types of white blood cells in the environment with the same starting population of bacteria.

Next Lesson

We will plan and carry out an investigation using a new bacteria simulation to test what will happen when we change the environment by a different factor other than predation. We will run our experiment, collect data, and use our model (natural selection) to explain our results.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

9.A Construct an argument that changes in environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population, using evidence derived from analysis of graphical data representations generated from an investigation using a computer simulation.

What Students Will Figure Out

- Changes in the environment can lead to different changes in the traits of the population.
- Trait variations that provide an individual a competitive advantage in one environment may give it a disadvantage in another environment.
- Competitive advantage affects the chances (or probability) of certain individual outcomes.
- The longer this process (natural selection) continues (over more generations), the more variations tend to be removed from the descendant population.

Lesson 9 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	3 min	**NAVIGATION** Add our General Model for Natural Selection to our Progress Trackers.	A	Progress Tracker Copy of Our General Model, tape, scissors, General Model for Natural Selection poster
2	7 min	**PLAN TO TEST OUR MODEL** Discuss what we need in a simulation to test our model and predictions.	B-C	*How can we use our model to make predictions?* (completed)
3	5 min	**INTRODUCE SOME MODEL ORGANISMS** Introduce the types of organisms often used in population studies and review the way in which bacteria reproduce.	D-E	
4	6 min	**ANALYZE STRUCTURES IN SALMONELLA AND BRAINSTORM TYPES OF ENVIRONMENTAL INTERACTIONS** Discuss the structural variation seen in photos of *salmonella* and brainstorm environmental interactions the bacteria might experience.	F-G	*Flagella Image for Word Wall*
5	2 min	**ORIENT TO STRUCTURES THAT FIGHT OFF INFECTION** Learn about two types of white blood cells that fight bacteria infections in the human body.	H	White Blood Cell Consuming a Bacterium (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
6	8 min	**ORIENT TO THE SIMULATION** Orient to what is in the computer simulation.	I	Salmonella Hunt Orientation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
7	9 min	**INVESTIGATE CHANGES IN TRAIT VARIATIONS IN A POPULATION: INVESTIGATION 1** Use a simulation to investigate how trait variations in a population of bacteria change when white blood cells chase them down.	J	computer, Salmonilla Hunt simulation, *Investigation 1*

Part	Duration	Summary	Slide	Materials
8	5 min	**MAKE SENSE OF RESULTS** Explain how the population changed and make an argument for why the population changed in this way.	K	*Investigation 1* *End of day 1*
9	8 min	**DISCUSS RESULTS** Summarize key findings from the simulation and identify new things to keep in mind and look for in the next investigation.	L	*Investigation 1* (completed)
10	5 min	**MAKE PREDICTIONS** Make predictions about what will happen to the population if we change the simulation environment.	M	
11	12 min	**INVESTIGATE CHANGES IN TRAIT VARIATIONS IN A POPULATION: INVESTIGATION 2** Use a simulation to investigate how trait variations in a population of bacteria change when white blood cells hunt for bacteria by staying in one place and letting bacteria come to them.	N-P	computer, salmonella hunt (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), scratch paper (optional)
12	8 min	**DISCUSS RESULTS** Discuss what we found happened to the bacteria population when the environment changed.	Q	
13	10 min	**REVISE OUR GENERAL MODEL FOR NATURAL SELECTION** Use what we figured out from the simulation to revise our General Model for Natural Selection and what we have in our Progress Tracker.	R	Progress Tracker Copy of Our General Model, General Model for Natural Selection poster, yellow sticky notes (5" x 8"), markers
14	2 min	**INTRODUCE THE HOME LEARNING** Summarize how our model was refined by testing it and introduce the home learning.	S	*Refining and Applying Our General Model for Natural Selection* *End of day 2*

Lesson 9 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • Progress Tracker Copy of Our General Model • tape • scissors • *How can we use our model to make predictions?* (completed) • computer • Salmonella Hunt simulation • *Investigation 1* • *Investigation 1* (completed) • scratch paper (optional) • *Refining and Applying Our General Model for Natural Selection*		• General Model for Natural Selection poster • *Flagella Image for Word Wall* • Salmonella Hunt Orientation • 8.6 Lesson 9 Salmonella Hunt Simulation (See the **Online Resources Guide** for links to the orientation and simulation. **www.coreknowledge.org/cksci-online-resources**) • yellow sticky notes (5″ x 8″) • markers

Materials preparation (40 minutes)

Online Resources 

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Take photos of the General Model for Natural Selection that you built with each class in the last lesson. Test print a copy of each one. Make sure the text is sharp enough to read. If it's not, either reshoot the photo or recreate the model as a digital version. Once you have a readable version, add a title to it indicating what class period it is for. This document will now be referred to as the *Progress Tracker Copy of Our General Model*.

Print a copy of the corresponding *Progress Tracker Copy of Our General Model* for each student in each class period.

Print 1 copy each of *Investigation 1* and *Refining and Applying Our General Model for Natural Selection* for every student.

Print 1 color copy of *Flagella Image for Word Wall* to add as a reference to your Word Wall during the appropriate point indicated in the lesson.

Test the video and simulation links. (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

- Lesson 9 Salmonella Hunt Orientation
- Salmonella Hunt simulation

- Animation of a white blood cell consuming a bacterium
- Bacterial growth under the microscope

Watch the Lesson 9 Simulation Orientation video, which introduces the Salmonella Hunt simulation. Spend some time familiarizing yourself with the simulation interface and output. Run each investigation outlined in the lesson on your own prior to running the investigations with the class.

Obtain enough computers or devices for each student to work on their own computer. Make sure that student computers and devices can access the simulation.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

This lesson draws on ideas about probability that students will have developed in grade 7 according to the Common Core State Standards for Math. Students will have had experiences with probability in that prior grade related to inferences they can make based on drawing samples from a population as well as calculating probability of chance processes.

The simulation students use includes two elements of chance processes as part of the code for the model. One is the initial placement of the bacteria when "setup" is pressed. The other is how much each bacterium turns right or left in each tick of the simulation when no predator is near it. That random turning helps simulate a random wiggle movement across the simulated world.

When considering how to test their General Model for Natural Selection, students will recall the simulation they used in *Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit)*. If your students did not experience the Unit, that's OK—they can recall other similar simulations they have used, or they can make inferences and predictions about the benefits and drawbacks of using a simulation during that discussion.

Students will be drawing on ideas from their work in *Unit 6.6: How do living things heal? (Healing Unit)* when considering bacteria populations and white blood cells. Additionally, students will be drawing on ideas from their prior work in *Unit 8.5: Why are living things different from one another? (Muscles Unit)* that bacteria are single-cell organisms, they asexually reproduce, and any heritable traits in two new bacteria produced this way would be the same as in the original parent bacterium, since they both would inherit all the same genes as were in the parent cell. The Simulation Orientation video provides evidence of these mechanisms being integrated into simulation code. Two short videos are provided in this unit to reintroduce students to how bacteria reproduce (8.6 Lesson 9 Bacterial Growth under the Microscope) and how certain white blood cells fight off a bacterial infection (8.6 Lesson 9 White Blood Cell Consuming a Bacterium). Note that this lesson talks about "types" of bacteria, even when referring to a specific genus such as *salmonella*, since it is not necessary for this unit that we classify various species of bacteria.

Where We Are NOT Going

Flagella number may have a positive association with speed of forward movement in only some types of bacteria and in only certain types of fluids. No attempt is made to explore other relationships between structure and function of flagella, such as the ability to move in different directions or the ability to anchor onto solid surfaces (e.g., intestinal tissue).

While no attempt is made to explore the underlying code of the simulation during the class period, some students may find it interesting to inspect and modify it on their own. It is recommended, however, that you not show students how to do this until after the next lesson. If students discover this feature themselves by clicking on the purple "NetLogo Code" bar, encourage them to reserve tinkering with the underlying modeling assumptions in the simulation (computer) code until after this lesson or the next lesson.

Though it can be highly motivational for some students to recode the underlying assumptions, rules, and representations in a computer model, it can also be a distraction for those students to be doing this during class time focused on other learning goals. Students may be able to generate some really interesting, additional scientific investigations by tinkering with the code. More information on how to change and recompile the code for this simulation can be found at https://ccl.northwestern.edu/netlogo/.

LEARNING PLAN FOR LESSON 9

1. Navigation

3 MIN

Materials: science notebook, Progress Tracker Copy of Our General Model, tape, scissors, General Model for Natural Selection poster

Add our General Model for Natural Selection to our Progress Trackers. Display **slide A**. Say, *Last time, we made some great progress developing our General Model together. Let's add that model to your Progress Tracker. But instead of copying the entire model by hand, I took a photo of the class model we made together and printed you a copy to add to a page in your Progress Tracker.*

Refer to the General Model for Natural Selection poster from the last class in the discussion below. Say, *Before we add it, let's recall what this is a model for.*

Suggested prompts	Sample student responses
Can someone remind us, what kind of phenomenon in the world did this model help us explain?	*Changes in the distribution of trait variations in a population over many generations.*
What question, therefore, does this model help answer?	*How and why do the trait variations in a population change over time?*

Distribute copies of the *Progress Tracker Copy of Our General Model*. Have students use scissors and tape to add this page to their Progress Tracker and circle the related question on the top of the model: How and why is the population changing in all our cases?

Additional Guidance

You may notice we call this model our General Model **for** Natural Selection from this point forward (specifically **not** our model **of** natural selection). It is important to remind ourselves what it is a model **for** (explaining all the cases we have investigated) rather than only what it is a model **of**. That emphasis on "model for" helps ground it as a tool that we are developing and refining in service of explaining something about a particular class of phenomena. A good article for educators that explains the importance of this framing in more detail can be found online. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

2. Plan to test our model.

7 MIN

Materials: science notebook, *How can we use our model to make predictions?* (completed)

Discuss what types of experiments we can conduct to test our model and predictions. Show **slide B**. Say, *We developed our General Model for Natural Selection by investigating five specific populations of organisms with different trait variations. Each population interacted with a particular environmental factor. We used our model to make predictions about what would happen to any population, in any environment, and over a different number of generations. You can reference the predictions you made in the handout* How can we use our model to make predictions?.

Continue, *To test these predictions, we would need an experimental system we could manipulate. There are two different types of systems that scientists typically use to plan and carry out such experiments. One of these systems involves working with a population of live organisms, similar to the population of planaria you investigated in the Muscles Unit. Another system that can be manipulated in order to test a model is a simulation of a system that has a population in it, similar to what you did with orangutans in Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit). There are advantages and disadvantages to using one approach over another.*

Suggested prompts	Sample student responses
What are potential advantages of using live organisms rather than a simulation to test our model?	*(Accept all responses.)*
What are potential advantages of using a simulation rather than live organisms to test our model?	*(Accept all responses.)*
How could using a simulation to test our model under different conditions help us determine whether our model can be used to explain what might have happened to populations of penguins, horses, whales, and horseshoe crabs over millions of years?	*(Accept all responses.)*

Say, *We will use the simulation approach to test our model.*

Determine what we need in our simulation. Display **slide C**. Say, *Let's brainstorm what we need in a simulation in order to test our model. Make a T-chart in your science notebook and list what needs to be a part of the system in the simulation and the things we need to be able to change or control in the simulation in order to test our model and predictions about what would happen to any population, in any environment, and over a different number of generations.*

After students have had a couple minutes to brainstorm independently, give students a couple of minutes to share the ideas with a partner. Then use the questions below to have students share as a class.

Suggested prompts	Sample student responses
What are some of the things you listed as needing to be a part of the system in the simulation in order to test our model?	*We need trait variation in a population.* *The trait needs to be heritable.* *The variations should have differences in function.* *There should be living and nonliving things in the environment to interact with.* *Those interactions should affect individual survival.*
What are some of the things you listed that we need to be able to change or control in the simulation?	*The amount of trait variation.* *What the trait variations are.* *The size of the population.* *The living and nonliving things in the environment, like, the amount of water or food or predators or pollution.* *The amount of time or the number of generations that the simulation runs.*

3. Introduce some model organisms. 5 MIN

Materials: None

Introduce examples of the types of organisms scientists use when working with living organisms. Say, *We made predictions about whether our model was general enough to explain changes in the trait variations in any population. We will need a population with trait variations to test the predictions we made, and because we made the predictions using our model, testing our predictions means we will also be testing our model. Let's take a look at the types of organisms that are commonly used by scientists to study what the trait variations are in offspring over many generations.*

Show **slide D**. Say, *This is a list of some common organisms that scientists choose to work with when they design an experiment that uses living organisms.*

Suggested prompts	Sample student responses
Why do you think these sorts of organisms are commonly used for studying trait variations in offspring over many generations?	*(Accept all responses.)*
Which one of these would allow you to see in the shortest amount of time what happens in a line of descendants over a very large number of generations?	*The one that reproduces the fastest.* *Bacteria.*

Say, *Being able to see change over generations quickly is one of the main reasons scientists use these sorts of organisms for investigations. Another thing you identified that we'll need in our simulation is that the trait needs to be heritable. So let's look at how we know trait variations are heritable in these kinds of organisms.*

Discuss the advantages in using an asexually reproducing organism. Show **slide E**. Review what it means to reproduce asexually and why it might be easier to determine if a trait variation is heritable by using an organism that reproduces asexually instead of sexually.

Suggested prompts	Sample student responses
Some organisms can reproduce asexually. How is this different from sexual reproduction?	*The offspring have only one parent in asexual reproduction rather than two.* *In asexual reproduction, the offspring's genetic information will be exactly the same as the parent's, unlike in sexual reproduction where offspring get half of their genetic information from each parent.*
What happens to a bacterium cell when it reproduces asexually?	*The bacterium cell splits into two new cells.*
Why might it be easier to determine if a trait variation is heritable using an organism that reproduces asexually instead of sexually?	*The offspring should have the exact same genetic information as the parent. So if the trait variation is heritable, then it would be the same in the offspring as it is in the parent.*

Additional Guidance

If students have completed the *Healing Unit* and they analyzed the planaria investigations as part of their work in *Muscles Unit*, these connections should be quite accessible. If they haven't completed at least one of these units or if this connection is difficult for them to make, remind them that bacteria are single-celled organisms and that you want to look again at how they reproduce.

Show the Bacteria Reproduction video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)**.** Ask, *What do you notice?* Students should say, "Bacteria reproduce by dividing in half."

* Supporting Students in Engaging in Constructing Explanations and Designing Solutions

Some students may question why we (or scientists) would want to use an organism that reproduces asexually for a test of a model for natural selection rather than one that reproduces sexually since penguins, horses, whales, and horseshoe crabs all reproduce sexually. If so, here is an opportunity to discuss how to best test the generalizability and applicability of our model to all living things. Help students recall that we already have seen some evidence of how it works on plants and animals, so seeing how it works on another type of living thing (bacteria) which is neither a plant nor an animal would also help us better test its generalizability.

Point out that before an individual bacterium splits into two when it reproduces, it first produces a duplicate set of many of the structures that make it up, including all its genes, which in bacteria are on only a single chromosome. This ensures that each new cell that splits off from the parent cell gets the same genetic information as what is in the original parent cell. This is a simpler process than what happens in sexually reproducing organisms, where each parent produces sex cells with only half their chromosomes in them, a male sex cell and a female sex cell merge during fertilization, and the resulting offspring now has a copy of only half of the chromosomes that each parent originally had.

Say, *So, asexual reproduction is another reason that scientists often use bacteria when studying heritable trait variations over many generations.* Additionally, scientists find bacteria particularly useful to study because they have a relatively large impact on human health. A lot of simulations have already been built to study bacteria in different environments. We will use one of those simulations to test our General Model for Natural Selection.*

Remind students that there are different types of bacteria. Explain that some types of bacteria have a positive impact on human health, like the kind that is in yogurt (*lactobacillus*), which live in our digestive system. Explain that there are also other types of bacteria that have a negative impact on human health, like the ones that make us sick if they get into parts of our body, like a staph infection from a cut, an ear infection (swimmer's ear), or food poisoning from a *salmonella* bacteria infection.

Additional Guidance

Students will have been introduced to different types of bacteria before in *Healing Unit*.

Introduce some health impacts of *salmonella* infections and explain that *salmonella* will be the population we will be using in the simulation. Say, *The simulation we will be using to test our model includes a population of* salmonella *bacteria. In the United States alone, this is a type of bacteria that causes 1,350,000 intestinal infections per year and 420 deaths per year. Let's learn a bit more about this type of bacteria and think about what it interacts with in the environments it lives in. This will help us figure out how we can replicate some of those environmental interactions when we plan and carry out investigations with the simulation.*

4. Analyze structures in *salmonella* and brainstorm types of environmental interactions. 6 MIN

Materials: *Flagella Image for Word Wall*

Introduce photos of individual *salmonella*. Show **slide F**. Say, *You identified that in a useful simulation the organism's population would need to have trait variations. Even though there are different types of bacteria, a population of any single type of bacteria will have individuals that have trait variations. For many characteristics, such variations are hard to see even when we observe them through a microscope since they are single-celled organisms. But let's take a moment to see if we can notice any trait variations in individual* salmonella *bacteria from this photograph of them taken under a microscope.*

Discuss the prompts on the slide as a whole class. Add *Flagella Image for Word Wall* to the Word Wall during this discussion to provide a visual reference to what flagella are.

Suggested prompts	Sample student responses
The structures seen sticking out of some of these individual salmonella bacteria are called flagella. They use these structures to move around. What variation do you notice among them?	*They have a different number of flagella.*
Do you think any of these variations would give some individuals an advantage for surviving in certain environments? Why?	*It seems like more flagella would help a bacteria move faster, so it seems like more flagella would be better.* *Or maybe more flagella help them turn quicker.* *Unless maybe more flagella are harder to control.* *It probably depends on what is in the environment.*

Brainstorm environmental conditions and elements for the simulation. Show **slide G**. Say, *We've identified a type of trait variation that could be included in our simulation for our* salmonella *population. But we also determined that our model requires more than trait variation alone. Earlier, we identified things that would need to be able to be changed in the environment. Now let's get more specific about what those things would be for these bacteria. Let's brainstorm some of the things that* salmonella *bacteria might interact with in their environment that would affect the survival or reproduction of individual bacteria.* Give students a minute to brainstorm on their own and then ask them to share their ideas with the whole class.

Suggested prompts	Sample student responses
What are some things in the environment outside of our bodies that can kill bacteria?	*Hand sanitizer.* *Disinfectants.* *Certain types of light, like UV, or radiation.* *Extreme heat or cold.*
What are some things in the environment inside of our bodies that can kill bacteria? *(If the immune system isn't mentioned, then ask the following.) How does our body naturally fight an infection?*	*Antibiotics.* *The immune system.* *Fever.* *Rest.* *Immune system.* *White blood cells.*
What are some of the resources in these environments that bacteria need to live, grow, and reproduce?	*Space.* *Water.* *Food.* *A certain temperature range.*

Validate all these as interesting variables to potentially explore in a simulation. Say, *These are all great ideas. Any one of these would be a specific factor in the environment that we could change and experiment with.*

5. Orient to structures that fight off infection.

2 MIN

Materials: 8.6 Lesson 9 White Blood Cell Consuming a Bacterium (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Transition to thinking about immune responses to bacteria. Say, *Let's look a bit more at how our bodies fight off an infection and the structures the body produces to help it do that. We can consider how we might use the simulation to recreate those interactions.*

Introduce the first type of white blood cell. Show **slide H**. Tell students that this short video shows how one type of white blood cell (a type of phagocyte called a neutrophil) fights off a bacterial infection. Show the neutrophil phagocytosis video 8.6 Lesson 9 White Blood Cell Consuming a Bacterium (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

Introduce a second type of white blood cell. Say, *One type of white blood cells in your body, called neutrophils, chase down bacteria, engulf them, and destroy them. Another type of white blood cell in your body is called a monocyte. Monocytes also engulf bacteria, but they don't move around very much. Instead, they stay in an infected tissue and wait for bacteria to come to them, which allows them to engulf and destroy those bacteria that happen to get close enough.*

6. Orient to the simulation.

8 MIN

Materials: 8.6 Lesson 9 Salmonella Hunt Orientation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Orient to the computer simulation. Display **slide I**. Tell students that this video shows how to use the simulation. Play the Simulation Orientation video.

Discuss what is in the simulation. Say, *The video oriented us to some of the objects and interactions in the computer simulation. Let's think about the parts of the simulation that would represent the heritable trait variation and environmental factors that you said we needed.*

Suggested prompts	Sample student responses
What trait variation is in this population?	*There is trait variation in the number of flagella.*
When bacteria reproduced, the two new cells that were produced each had the same number of flagella as the parent cell they came from. What does this tell us about whether flagella number is a heritable trait variation in this simulation?	*Flagella number must be a heritable trait variation since it is the same for offspring as it is for parents.*

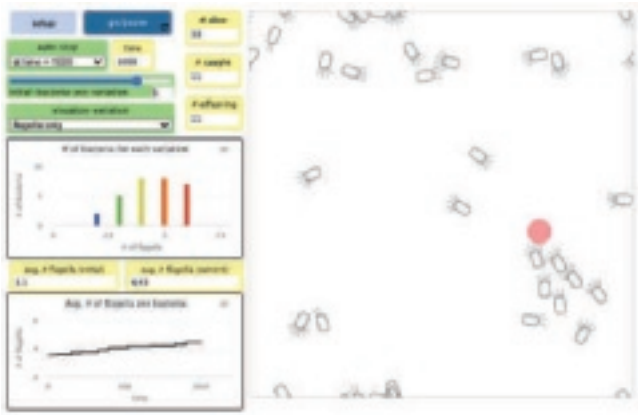
Suggested prompts	Sample student responses
How can we use this simulation to mimic an environment that has only neutrophils in it, which is the type of white blood cell that chases down bacteria?	*We could chase bacteria around with our mouse and click on them.*
What would we do differently in the simulation if we wanted to mimic an environment that has only monocytes in it, which is the stationary type of white blood cell?	*We could wait for bacteria to come to our mouse cursor.*

Identify that we have two investigations to pursue. Say, *It sounds like we have two different environmental conditions we could simulate. Let's try each of those as their own separate investigation—one where we interact with the bacteria like a neutrophil would, and then later we can try another investigation where we interact with the bacteria like a monocyte would. That will let us see what happens under different environmental conditions, which was one of the things we said we wanted to experiment with in the simulation.*

7. Investigate changes in trait variations in a population: Investigation 1.

9 MIN

Materials: computer, Salmonella Hunt simulation (See the **Online Resources Guide** for links to theis resource. **www.coreknowledge.org/cksci-online-resources**), *Investigation 1*



Orient to the first part of bacteria investigation. Show **slide J** and distribute copies of *Investigation 1*. Students should each work on their own computer but should be paired up so that they can compare their results with a partner. Tell students that they are going to use the directions on this slide—which can also be found on their handout—to carry out the first investigation. Point out that the settings shown for the simulation will ensure that it automatically stops after running for about 1 minute, which will ensure the comparison they make with their partner is for an equal amount of time. Explain that this will leave them at least 5 minutes for the discussion questions shown on the slide and the handout. Most students will end up with a result similar to but not exactly like the image shown here.

Carry out investigation 1. Have students carry out this part of the investigation as shown on **slide J**. After 3 minutes, cue students to start responding to the questions at the bottom of the slide. They should write their responses on the handout in step 6 of part A.

8. Make sense of results.

5 MIN

Materials: *Investigation 1*

Make sense of the investigation. Show **slide K**. Students should use the remaining time to individually answer the two questions in part B of *Investigation 1*. Collect student handouts before the end of the period to review students' entries.



Assessment Opportunity

Building towards: 9.A.1 Construct an argument that changes in environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population, using evidence derived from analysis of graphical data representations generated from an investigation using a computer simulation.

What to look for: Look in students' *Investigation 1* handout for at least one of these two sets of related lines of evidence and new model ideas being proposed to explain these results.

- Evidence: There was a shift in the distribution of the proportion of bacteria that have a particular trait variation; over time it shifts toward a larger proportion of individuals with more flagella.
- Reasoning: This is because more flagella allow bacteria to move faster, which gives them a competitive advantage for surviving (and reproducing).
- Evidence: There is some variability in results between simulation results.
- Reasoning: This is due to some elements of chance or randomness in the environment.

What to do: Identify students who have neither a line of evidence nor a related new model idea in their handout. Leave these students a note letting them know you will ask them to describe

1. what the evidence is or ideas are that another student shared and
2. whether they had similar or different findings or ideas.

Make an effort to recruit those students into the two discussions on day 2 of the lesson.

End of day 1

9. Discuss results.

8 MIN

Materials: *Investigation 1* (completed)

Discuss findings as a class. Show **slide L**. Redistribute the *Investigation 1* handout you collected last time. Cue students to look back at their work on that handout for a minute before sharing with the whole class. Use the questions on the slide (also shown as prompts below) to start the discussion.

Key Ideas

Purpose of this discussion: To summarize key findings from the simulation and to identify new things to keep in mind and look for in the next investigation

Listen for these ideas:

- There was a shift in the distribution of the proportion of bacteria that have a particular trait variation; over time it shifts toward a larger proportion of individuals with more flagella.
- This is because more flagella allow bacteria to move faster, which gives them a competitive advantage for surviving (and reproducing).

- There is some variability in results between simulation results.
- This is due to some elements of chance or randomness in the environment.

Suggested prompts	Sample student responses
How did the bacteria population change in the simulated environment?	*Over time there were more bacteria with more flagella and fewer bacteria with fewer flagella.* *There was a larger proportion of bacteria with five or six flagella and less (or none) with one or two.*
How can we explain this outcome in terms of competitive advantage?	*It is advantageous to be able to move faster in this environment because it helps you get away from the predator (or white blood cell or cursor).* *Those with more flagella survive longer because they are harder to catch.*
Why might you and your partner have gotten similar shifts in the distribution of trait variations but not exactly the same results?	*It might be due to slight differences in how we hunt (or how quickly our computers respond). I might be a faster hunter than my partner, causing differences in the results.* *It might be due to random chance of where the bacteria were at the start of the simulation.*
Did anyone end up with a population that had one or more variations eliminated from it completely?	*(Accept all responses.)*

Summarize this discussion by saying, *OK, that was one test of our model using a new population in one kind of environment. But we also had different predictions about what would happen if we changed the environment. So we can do that by simulating the population as if it were in an environment with the other kind of white blood cell we discussed last time—a monocyte.*

Also, some of us were wondering about what would happen if we ran the simulation for longer, if there were more generations of bacteria. So let's first test the new environment and see what we find, and then we can let the simulation run for longer and see if that has any effect on the result. Let's make some predictions about what we think we would see happen in both of these cases.

10. Make predictions.

5 MIN

Materials: None

Make predictions. Show **slide M**. Give students a couple of minutes to discuss their predictions with a partner, then have them share with the class.

Suggested prompts	Sample student responses
What do you think will happen to the population if we change the simulation environment so that it has only nonmoving white blood cells—the monocytes—in it? Why do you think that?	*The distribution of trait variations will shift again.* *We will get the same sort of shift. There will be a larger proportion of bacteria with more flagella by the end of the simulation than at the start. This is because being fast will still be advantageous to avoiding the white blood cell.* *We will get an opposite shift. There will be a larger proportion of bacteria with less flagella by the end of the simulation than at the start. This is because the faster bacteria move more, increasing their chance of getting caught by the nonmoving white blood cell.* *There will not be a change in distribution because slow and fast bacteria have the same chance of being caught by a nonmoving white blood cell.*
Would anything change if you ran the simulation under those conditions for a longer period of time?	*Yes, it would keep shifting.* *No, it wouldn't shift anymore.* *It depends on how long you run it. It would keep shifting up to a point and then stop shifting after that.*

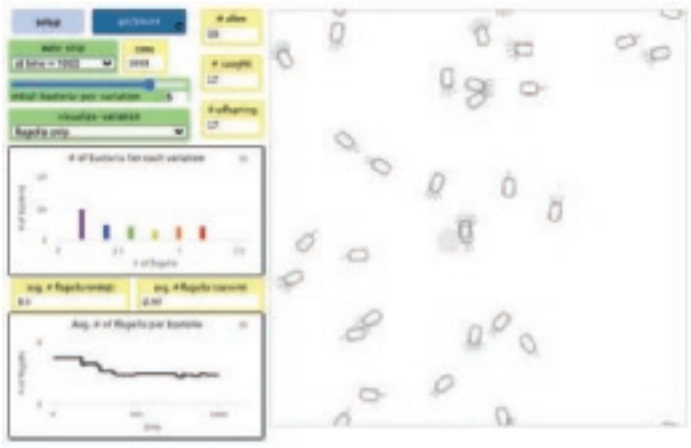
11. Investigate changes in trait variations in a population: Investigation 2.

12 MIN

Materials: science notebook, computer, Salmonella Hunt simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), scratch paper (optional)

Set up the second investigation. Students should again each work on their own computer but should be paired up so that they can compare their results with a partner.

Carry out investigation 2. Show **slide N**. Have students click on "setup" to start the second investigation. Before they press "go/pause", remind students that they are going to hunt the bacteria by keeping their cursor in one place and letting the bacteria run into it. Most students will end up with a result similar to but not exactly like the image shown here.



Have students record the results that will help them determine if there was any change in the distribution of the trait variations in their populations. Students can record these results in their notebook or on a separate piece of scratch paper so that they can compare them to the results they get in the next step when they run the simulation longer. It will take about 2 minutes to produce these initial results and an additional 5 minutes to discuss with a partner their answers to the questions at the bottom of **slide N**.

Show **slide O**. Give students another 2 minutes to compare with their partner how many different trait variations (flagella) there are in each of their populations from the simulation so far.

After students have done this, tell them that they will prepare to carry out a continuation of this investigation for a longer length of time. They should *not* click on "setup" to reset their environment, but follow directions to continue it from where they left off.

Show **slide P**. As directed on the slide, tell students to simply adjust the "auto-stop" setting to "at time = 4000", and the simulation will continue running once they click on "go/pause". It will take about 2 minutes to produce the results and additional 3 minutes to discuss them with a partner.

12. Discuss results.

8 MIN

Materials: None

Discuss findings as a class. Show **slide Q**. If there is time, move into Scientists Circle for this and the following conversations. Use the questions on the slide (also shown as the sample prompts below) to facilitate the discussion.



Assessment Opportunity

Building towards: 9.A.2 Construct an argument that changes in environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population, using evidence derived from analysis of graphical data representations generated from an investigation using a computer simulation.

What to look and listen for

- There was a shift in the distribution of the proportion of bacteria that have a particular trait variation; over time it shifts toward a larger proportion of individuals with fewer flagella.
- This was a shift in a different direction than in the previous investigation.
- Loss of trait variation occurs over time.
- Outcomes are not exactly the same every time due to chance (since this is based on probability)—there are elements of chance or randomness in the environment.

What to do: If some students seem unready to volunteer their findings, tell all the class to prepare to weigh in on every finding they hear shared by other students and that this will require them all to be ready to

- restate what the finding was and
- say whether they had similar results.

Use this strategy to help reinforce the aspects of arguing from evidence that require ongoing efforts from everyone to actively listen to and work with one another's ideas.

Suggested prompts	Sample student responses
How did the bacteria population change in this different environment?	*It produced an opposite result compared to the previous investigation.* *Over time there were more bacteria with fewer flagella and fewer bacteria with more flagella.* *There was a larger proportion of bacteria with one or two flagella and less (or none) with five or six.*
How can we explain this outcome in terms of competitive advantage?	*It is advantageous to be able to move slowly in this environment because you will run into the stationary predator (or white blood cell or cursor) less often.* *Those with fewer flagella survive longer because it takes longer for them to run into something that kills them.*
How did running for a longer length of time affect the results?	*The population lost variations.* *It kept shifting up to a point and then stopped shifting after that.*
Why might you and your partner have gotten similar shifts in the distribution of trait variations but not exactly the same results?	*It might be due to random chance of which bacteria multiply.* *I might have my cursor in a different position than my partner, causing differences in the results.*
How did the shifts you saw compare to your predictions?	*(Accept all responses.)*

13. Revise our General Model for natural selection.

10 MIN

Materials: science notebook, Progress Tracker Copy of Our General Model, General Model for Natural Selection poster, yellow sticky notes (5" x 8"), markers

Facilitate a Consensus Discussion. Suggest that we return to 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. Display **slide R** and cue students to turn to their *Progress Tracker Copy of Our General Model*.

Key Ideas

Purpose of this discussion: To discuss whether additional clarification needs to be added to the model

These are four key ideas that the class may decide are needed:

1. Changes in the environment can lead to different changes in the trait variations of the population.
2. Trait variations that provide an individual a competitive advantage in one environment may give it a disadvantage in another environment.
3. Competitive advantage affects the chances (or probability) of certain individual outcomes.
4. The longer this process continues (over more generations) the more variations tend to be removed from the descendant population.

The prompts below give one suggested way to elicit student ideas so that a version of these ideas comes up naturally as well as suggested places to update the model to reflect the addition of the four ideas listed above. Use student language where possible (where it approximates what is shown in the examples).

Check in on whether we need to add to our model about the effect(s) of changes in the environment (key idea #1). Ask students whether our model explains the type of changes we saw in the bacteria population for either investigation—a shift in the distribution of the trait variations in a particular environment. Students should say, "Yes."

Ask students whether the model explains that changes in the environment can lead to what we saw in the simulation results after both investigations—different types of changes in the trait variations in the population.

If students say it does, and everyone is in agreement on this, ask whether they want to add an annotation to the model to this effect. If they say, "No", then move on. If they say, "Yes", add the following to a yellow sticky note and place it at the top-right side of the model and connect it with a line to the green paper labeled "Environment":

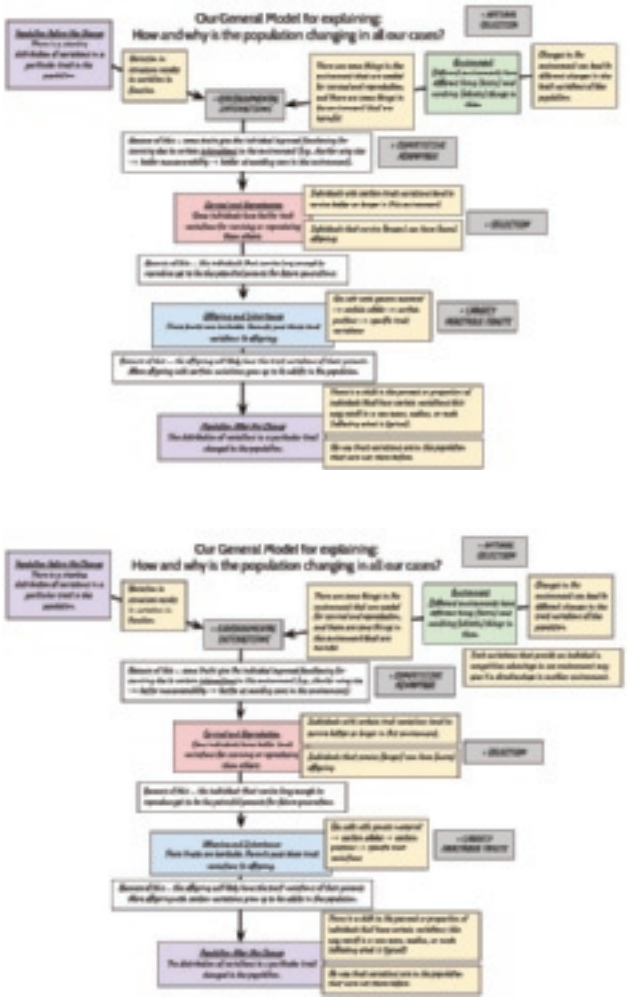
- **Changes in the environment can lead to different changes in the trait variations of the population.**

If you add this annotation to the model, have students add a corresponding annotation to their *Progress Tracker Copy of Our General Model*.

Add to our model about variations that provide a competitive advantage or not (key idea #2). Ask students whether more flagella or fewer flagella gave bacteria a competitive advantage for survival. Students will say that it depends on the environment they are in.

Ask students in which environment did more flagella and faster movement give bacteria a competitive *dis*advantage. Students will say it was in the second one (monocytes waiting for bacteria to come to them).

Point out that though our model says some trait variations provide an individual a competitive advantage, it says nothing about those being a disadvantage in another environment.



Add the following idea to a yellow sticky note and place it to the right of the = COMPETITIVE ADVANTAGE card:

- **Trait variations that provide an individual a competitive advantage in one environment may give it a disadvantage in another environment.**

Have students add a corresponding annotation to their *Progress Tracker Copy of Our General Model.*

Add to our model about competitive advantage affecting the chances of certain individual outcomes (key idea #3). Ask students whether a bacterium that has 6 flagella in the first environment we simulated is guaranteed to not get caught. Students will say, "No." Ask about a bacterium with 1 flagellum in the second environment. Students will again say, "No."

Ask students how we would describe what it means to have a competitive advantage if it is not guaranteed to help you survive or reproduce more often. Students will likely suggest ideas like these:

- It improves the individual's chances (in that particular environment).
- It gives the individuals a higher probability of surviving or reproducing.

Remind students of earlier claims they made of why they and their partner generated slightly different outcomes when they ran the simulation and how there was an element of chance or probability in that as well.

Point out that though our model says some trait variations provide a competitive advantage, it says nothing about competitive advantage having an element of chance or probability to it. Add the following idea on a yellow sticky note and place it right below the key idea #2 sticky note:

- **Competitive advantage affects the chances (or probability) of certain individual outcomes.**

Have students add a corresponding annotation to their *Progress Tracker Copy of Our General Model.*

Add to our model about how the more generations this process continues through, the more variations tend to be removed from the descendant population (key idea #4).

Ask students whether all the trait variations that we started with in the population remained in the population as we continued to run the simulation over a longer length of time. Students will say, "No."

Point out that though our model says that the distribution of trait variations will shift, it doesn't say anything about the possibility of trait variations being removed completely from the population.

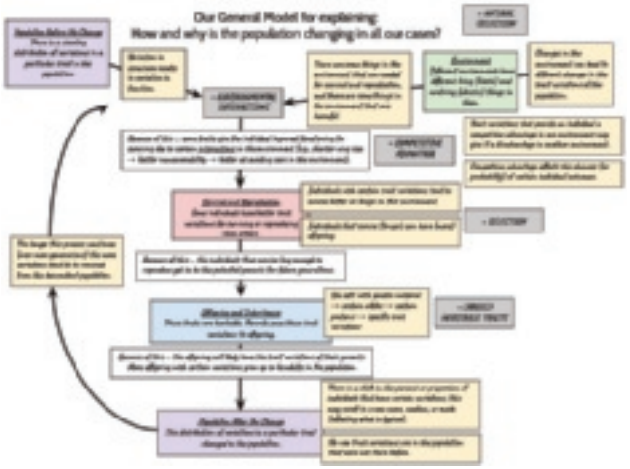
Ask students what tended to happen to the number of trait variations remaining in the population as they ran the model for a longer period of time. Students will say that they tended to decrease.

Add an arrow looping from the left side or bottom of the purple Population after the Change paper up to the yellow sticky note about structure and function. Add the following idea to a yellow sticky note and place it on top of that looping arrow:

- **The longer this process continues (over more generations) the more variations tend to be removed from the descendant population.**

Have students add a corresponding annotation to their *Progress Tracker Copy of Our General Model.*





14. Introduce the home learning.

2 MIN

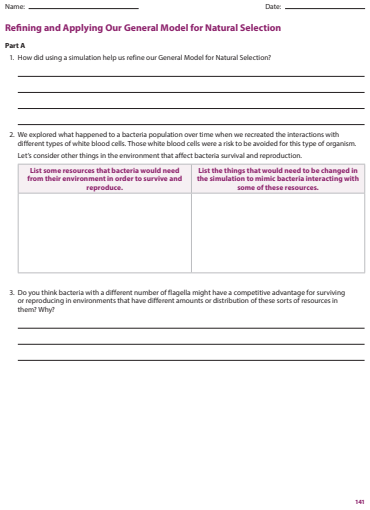
Materials: *Refining and Applying Our General Model for Natural Selection*

Summarize how our model was refined by testing it. Say, *While we were able to explain some of the results in the simulation using our prior version of the General Model for Natural Selection, the results from those tests of the model revealed some nuances that helped us refine our model further. And that came just from testing the model against environmental changes that involved something like a predator.*

Preview the context for the next lesson and introduce the home learning. Show **slide S**. Say, *We still have not tested our General Model against other environmental changes, such as those related to the resources that this bacteria population would need for survival and reproduction. Let's plan to do that in our next lesson using a modified version of this simulation. In the next lesson, you will work independently to plan and carry out how you want to modify the resources in the environment for these simulated bacteria. You will carry out your investigation using the simulation, you will analyze your results, and you will explain the outcomes. To prepare for those next steps, start considering some of these related questions in your home learning.*

If students are interested in connecting their learning back to the penguins at this point, part B of the home learning provides an opportunity for this connection. The whole class will have the opportunity in upcoming lessons to explain changes in the penguins, so this is an optional part of the home learning for students with a high level of interest.

Distribute *Refining and Applying Our General Model for Natural Selection*.



Name: _____ Date: _____

Refining and Applying Our General Model for Natural Selection

Part A

1. How did using a simulation help us refine our General Model for Natural Selection?

2. We explored what happened to a bacteria population over time when we recreated the interactions with different types of white blood cells. Those white blood cells were a risk to be avoided for this type of organism.

   Let's consider other things in the environment that affect bacteria survival and reproduction.

List some resources that bacteria would need from their environment in order to survive and reproduce.	List the things that would need to be changed in the simulation to mimic bacteria interacting with some of these resources.

3. Do you think bacteria with a different number of flagella might have a competitive advantage for surviving or reproducing in environments that have different amounts or distribution of these sorts of resources in them? Why?

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LESSON 10

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

Previous Lesson

We carried out two investigations using a computer simulation. We argued for why we got different outcomes when we simulated different types of white blood cells in the environment with the same starting population of bacteria.

This Lesson

Investigation, Putting Pieces Together

2 DAYS



We plan and carry out an investigation using a new bacteria simulation to test what will happen when we change the environment by a different factor other than predation. We run our investigation, collect data, and use our General Model for Natural Selection to explain our results.

Next Lesson

We will demonstrate on a transfer task assessment what we have learned. We will give and receive peer feedback on our explanations. We will revise our explanation based on peer feedback.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

10.A Plan and carry out an investigation in a simulated environment to collect data about how environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population, using evidence derived from analysis of graphical data representations generated from a computer simulation in two different investigations.

10.B Construct explanations based on evidence collected from running a simulation and using science ideas included in our General Model for Natural Selection for how and why small changes in an environment may cause large changes in trait variations in a population over long periods of time.

What Students Will Figure Out

- Our model (General Model for Natural Selection) tends to produce different outcomes in different environmental conditions.
- Any change in the environment that affects the resources needed for survival and reproduction can lead to shifts in the distribution of trait variations in a population.
- Natural selection tends to remove certain variations from a population over time; this outcome becomes more pronounced as time goes on.

Lesson 10 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Navigate from the previous lesson by considering resources bacteria would need from their environment in order to survive and reproduce.	A-B	completed *Refining and Applying Our General Model for Natural Selection*
2	8 min	**ORIENT TO THE SIMULATION** Orient students to what is in the computer simulation.	C	completed *Refining and Applying Our General Model for Natural Selection*, 8.6 Lesson 10 Comparing Bacteria in Different Environments (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
3	5 min	**MAKE PREDICTIONS** Make predictions about what will happen to the number of bacteria in the population over time.	D	
4	10 min	**EXPLORE THE SIMULATION** Frame the investigation and individually explore the simulation.	E-F	computer, Comparing Bacteria in Different Environments simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), General Model for Natural Selection
5	17 min	**INVESTIGATE** Distribute and orient to the data collection sheet. Carry out investigations and record data.	G-H	*Different Environmental Conditions and Results*, computer, Comparing Bacteria in Different Environments simulation transparent tape

End of day 1

Part	Duration	Summary	Slide	Materials
6	5 min	**NAVIGATION** Navigate from exploring the simulation to developing an explanation for each outcome.	I	completed *Different Environmental Conditions and Results*
7	30 min	**EXPLAIN THE DIFFERENCES IN THE TWO ENVIRONMENTS** Write explanations for Environment 1 and Environment 2 and cross-reference with the General Model for Natural Selection.	J-K	science notebook with Progress Tracker Copy of Our General Model (from Lesson 9), *My Model for Changes in Bacteria Populations*, completed *Different Environmental Conditions and Results*, General Model for Natural Selection, transparent tape
8	5 min	**MAKE PREDICTIONS ABOUT LONG PERIODS OF TIME** Predict outcomes of running the simulation for really long periods of time.	L	science notebook with Progress Tracker Copy of Our General Model (from Lesson 9), General Model for Natural Selection
				End of day 2
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 10, students are ready to read Student Reader Collection 3 and then respond to the writing exercise.		Student Reader Collection 3: *Selection and Survival*

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• completed *Refining and Applying Our General Model for Natural Selection* • computer • Comparing Bacteria in Different Environments simulation • *Different Environmental Conditions and Results* • transparent tape • completed *Different Environmental Conditions and Results* • science notebook with Progress Tracker Copy of Our General Model (from Lesson 9) • *My Model for Changes in Bacteria Populations*		• 8.6 Lesson 10 Comparing Bacteria in Different Environments (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • General Model for Natural Selection • transparent tape

Materials preparation (40 minutes)

Online Resources



Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Review the video 8.6 Lesson 10 Comparing Bacteria in Different Environments (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) which introduces the Comparing Bacteria in Different Environments simulation. Test the simulation link. Spend some time familiarizing yourself with the simulation interface and output. Run each investigation outlined in the lesson on your own prior to running the investigations with the class.

Print a copy of both *Different Environmental Conditions and Results* and *My Model for Changes in Bacteria Populations* for each student prior to the lesson. These will need to be trimmed to fit into the student notebook. Be sure to do this ahead if you do not plan on having the students take the time to trim.

Obtain enough computers or devices for each student to work on their own device. Make sure that student devices can access the simulation URL, too.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

The purpose of this activity is to give students a way to quickly test several variables in the environment and determine the cause and effect between change in environment and change in the number of individuals in a population that have a certain trait variation. Recall that we use the term *trait* when referring to a population of the same species. Many of these traits are body structures, and it would not be wrong to call them that, but we have been using the term *body structure* when comparing different species because they don't all have the same characteristics.

With the simulation in this lesson, students will also see that when an environment selects for certain trait variations over longer periods of time, some variation will disappear from the population. Once that variation is gone, it will not return—regardless of how the environment is changed.

By the end of the simulation students should be able to use "cause and effect" and "structure and function" to justify predictions they made regarding how trait variations change when populations are exposed to specific environments.

Where We Are NOT Going

Students will make predictions regarding only the trait variation that is already present in the population. We are not introducing new trait variations, and we are not yet exploring the idea of the role of mutations in the appearance of new trait variation.

LEARNING PLAN FOR LESSON 10

1. Navigation

5 MIN

Materials: completed *Refining and Applying Our General Model for Natural Selection*

Navigate into the lesson by referencing the previous investigation and next steps. Ask students to remind you what they figured out in the previous lesson.

Listen for students to say something like they figured out that, depending on the hunting strategy of the white blood cell in the environment, bacteria with different trait variations had a competitive advantage or disadvantage, meaning that some were better able to survive and reproduce and others were less able to survive and reproduce.

Ask students to remind the class what we were wondering about at the end of the last lesson.

Summarize this conversation by saying something like, *We figured out that our model could explain the changes in the trait variation distribution in a population of simulated bacteria due to one type of environmental change, which was predators, and we wondered if it would predict and explain outcomes from other changes to the environment. Let's think some more about what those other environmental changes could be, such as resources this bacteria population would need for survival and reproduction.*

Turn and talk about resources bacteria would need from their environment in order to survive and reproduce. Present **slide A** and instruct students to look at their home learning, *Refining and Applying Our General Model for Natural Selection*. Remind students that they individually brainstormed resources bacteria would need from their environment in order to survive and reproduce.

Have students share the ideas they brainstormed using the prompts below and on the slide. Give time for students to turn and talk with a partner before sharing with the whole class.

Suggested prompt	Sample student responses
What are some of the resources that bacteria would need from their environment in order to survive and reproduce?	*(Accept all responses. Responses may include the following.)* *Food source and water.* *Space.* *Protection from harsh environmental conditions.* *A certain temperature range.*

Suggested prompt	Sample student responses
What are the things that would need to be changed in the simulation to mimic bacteria interacting with some of these resources?	*(Accept all responses. Responses may include the following.)* *We could add a water source or a food source. Bacteria could get energy from the food or water source or lose energy when they move.* *We could build in spaces that might be good for bacteria to live in and other spaces that are difficult for bacteria to live in.* *We could build in a way to change the temperature.*

After students have shared, summarize by saying, *It sounds like there are a lot of things in the environment that can either help or hurt an individual bacterium's ability to survive and reproduce—food, water, space, and protection from harsh conditions. Let's pick one of these to focus on today—let's think specifically about food.*

Engage students, using the prompts below, in thinking about trait variations that may provide a competitive advantage or disadvantage for bacteria with relation to food.

Suggested prompt	Sample student responses
Would some of the bacteria we looked at before have a competitive advantage in environments with limited food?	*(Accept all responses. Responses may include the following:)* *Bacteria that can move quickly might be better able to reach the food more quickly, giving them a competitive advantage.* *But, if a bacterium moves faster, it might also use more energy, so it might be at a competitive disadvantage because it is burning energy faster.*

Orient to the bacteria in the simulation. Present **slide B** and introduce the following ideas:

- There are many different types of bacteria in the world, beyond *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.

Say, *Let's work with a simulation that has the same trait variation in the population (the number of flagella), but we'll switch to an environment where the bacteria need to get some type of food to survive and reproduce.*

2. Orient to the simulation.

8 MIN

Materials: completed *Refining and Applying Our General Model for Natural Selection*, 8.6 Lesson 10 Comparing Bacteria in Different Environments (See the**Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Orient to the computer simulation. Display **slide C**. Show the video introducing the simulation 8.6 Lesson 10 Comparing Bacteria in Different Enviroments (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

Discuss what is in the simulation. Say, *The video oriented us to some of the objects and interactions in the computer simulation. Are there parts of the simulation that would represent the heritable trait variation and environmental factors that you said we needed?* Listen for students to say, "Yes," and then list a part of the simulation or environmental factor that they listed on *Refining and Applying Our General Model for Natural Selection*.

Suggested prompts	Sample student responses
What changes have been made to the bacteria in this simulation?	*Bacteria can gain and lose energy.*
How do bacteria gain and lose energy?	*Bacteria gain energy by eating algae.* *Bacteria lose energy by moving. Bacteria lose more energy when they move faster.*
How do environmental conditions vary?	*We can add more or less water, which grows algae. Bacteria eat the algae for energy.* *We can also change the location and amount of the water in the environment.*

3. Make predictions.

5 MIN

Materials: None

Make predictions about what will happen to the number of bacteria in the population over time. Present **slide D** and have students turn and talk with a partner about the prompts on the slide:

- Predict what will happen to the number of bacteria in each of these populations over time. Explain your reasoning.

As students share in their Turn and Talk, circulate the room to listen for ideas that you can leverage in the whole-class discussion.*

After they have had an opportunity to talk with a partner, invite several students to share with the rest of the class.

Suggested prompt	Sample student response
What do you predict will happen over time to each of the bacteria populations shown on the slide?	*The bacteria will die out in the right environment, but not the left one, because there is no food in the right environment.*

*** Attending to Equity**

Universal Design for Learning: This is an important opportunity to emphasize that each individual has contributions to make to their community of learners. Throughout this unit, students have been encouraged and expected to be open to sharing knowledge products that represent their current thinking and learning from their classmates, which can support their *engagement* if the classroom culture is one that values diverse thinking and ideas. It is through differences in thinking that the class will grow their knowledge together.

Consider following up with the prompts below.

Suggested prompts	Sample student responses
What do bacteria need food for?	*They need food to survive. They will die if they run out of food.* *They need food to reproduce. They can only reproduce if they have enough energy.*
If there is enough food for some to survive, then what do you predict will happen to the distribution of flagella variations in the surviving population?	*(Accept all responses.)*
What if you change the distribution or amount of resources in the environment?	*(Accept all responses.)*

4. Explore the simulation.

10 MIN

Materials: computer, Comparing Bacteria in Different Environments simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), General Model for Natural Selection

Frame the investigation. Present **slide E** and say, *Last time we tested our model, we uncovered some new ideas to add to it.*

Pause and refer to any new ideas that the class added to their General Model for Natural Selection in the last lesson.

Say, *We wanted to test it for other types of environmental changes besides predators. Let's use this new simulation to continue testing our model.*

Introduce the assessment component of this investigation. Say, *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. Before we get to explaining our ideas, we need to explore the simulation, running multiple trials, until we find*

- *one kind of environment that repeatedly selects for certain trait variations in bacteria and*
- *at least one more kind of environment that repeatedly selects for different trait variations in bacteria.*

Individually explore the simulation. Show **slide F** and give directions for accessing the Comparing Bacteria in Different Environments simulation. Explain that students will take some time to individually explore the simulation. Focus student explorations using the prompts on the slide:

- Try to find two environmental conditions that result in very different results of trait variation distribution.
- Run multiple trials to confirm the general trend holds for these environmental conditions.

Give students about 8 minutes to run various trials. As students explore the simulation, circulate to observe the trials, notice interesting outcomes, and connect individual students' trials to others in the room.

*** Attending to Equity**

Universal Design for Learning: Allowing students to *express* their ideas using multiple modalities supports student ownership of their learning by giving students choice, access, and control in navigating their own understanding around the science ideas.

Additional Guidance

Students may wish to talk casually with one another while they run trials. This chatter can be a productive way for students to learn from one another and get ideas about how to set up their own trials.*

5. Investigate.

17 MIN

Materials: *Different Environmental Conditions and Results*, computer, Comparing Bacteria in Different Environments simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), transparent tape

Plan for data collection. Present **slide G** and pass out *Different Environmental Conditions and Results*. Orient students to the rows in the tables. It may help to show students where in the simulation they can find the data. For instance, you can point to the part of the simulation interface that shows "# deaths" for each environment.

Individually carry out the investigation and record data. Present **slide H** and instruct students to use their individual exploration of the simulation to guide their investigation. All student responses and data should be recorded on *Different Environmental Conditions and Results*, which you can collect as a formative assessment at the end of class today. Students will need to use *Different Environmental Conditions and Results* at the start of day 2, so have them ready to hand back then.



* Supporting Students in Developing and Using Stability and Change

This activity provides an opportunity for student choice in how they set up the environments, and not all students will test the same conditions. However, each student will bring their results to their explanations where they can explain how the small changes in one part of a system might cause large changes in another part for each environment.

Assessment Opportunity

Building towards: 10.A Plan and carry out an investigation in a simulated environment to collect data about how environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population, using evidence derived from analysis of graphical data representations generated from a computer simulation in two different investigations.

What to look and listen for: Look for investigation setups with two different environmental conditions that yield two different results in the distribution of trait variations. Look for students running the investigation multiple times and tracking their findings for each run. An example student response is available in *Key for Different Environmental Conditions and Results*.

What to do: Identify students who are struggling to produce different results in trait variations. Press those students to consider the differences in environmental conditions and how they might be able to more greatly alter the environmental conditions to yield different results.

Prompt students to continue testing their setup for multiple trials and note the outcomes.

End of day 1

6. Navigation

5 MIN

Materials: completed *Different Environmental Conditions and Results*

Share investigation results with a partner. Return students' *Different Environmental Conditions and Results*. Show **slide I** and have students turn and talk with a partner to share their investigation setup and findings and then discuss the following questions:

- Did the population change over many generations?
- Did different environments cause this change?

Once students have shared their investigations, use these prompts below to summarize the findings in a whole-class discussion.

Suggested prompts	Sample student responses
Did the population change over many generations?	*Yes, in all environments, it did.*
Did differences in the environment cause the changes in each population?	*Yes, differences in the environment seemed to be one of the main causes of the changes.*

Remind students that when we originally set out on this investigation, we realized that it could be a great opportunity to assess ourselves to see how far we have come in using our General Model of Natural Selection to explain how and why different environments can cause different types of population changes. Say, *Let's see how far we have come. Let's see if we can explain the differences between the two environments using every piece of our generalized model.*

7. Explain the differences in the two environments.

30 MIN

Materials: science notebook with Progress Tracker Copy of Our General Model (from Lesson 9), *My Model for Changes in Bacteria Populations*, completed *Different Environmental Conditions and Results*, General Model for Natural Selection, transparent tape

Orient to the General Model and the handout. Present **slide J** and distribute *My Model for Changes in Bacteria Populations* to each student. Since they will refer to the *Progress Tracker Copy of Our General Model* (from Lesson 9) in their notebook during this work, they should wait to tape *My Model for Changes in Bacteria Populations* into their notebook until they are finished with the next activity (and possibly after you collect it for assessment and return it).

Explain that the handout is a scaffold for the model that includes only the main headings. It is the same scaffold for each environment. To help orient the students to the handout, have them work individually to locate the major headings depicted on *My Model for Changes in Bacteria Populations* in their *Progress Tracker Copy of Our General Model* or the class poster of the General Model. Say, *Since we are going to try to use our General Model to explain the two different environments that you investigated, I thought it might be helpful to use this structure to organize our ideas. We will need to combine our General Model ideas with the evidence that we collected in order to explain both environments.*

Remind students that Environment 1 is the left side of the simulation and Environment 2 is the right side of the simulation.

Explain that our goal is to develop coherent explanations for *how* and *why* different environments caused the changes we observed. We have evidence of the changes (the data on *Different Environmental Conditions and Results*), and our goal now is to apply the specific mechanisms from our General Model to these two specific contexts.



Write an explanation for Environment 1 and for Environment 2, cross-referencing with the General Model. Present **slide K** and review the instructions. Students should start by writing their explanation for Environment 1 (the left side). They can use *My Model for Changes in Bacteria Populations* to organize their thinking and should write directly on that handout. As students generate their explanations, they should cross-reference them with the General Model. Students can place a check mark next to each model idea on their *Progress Tracker Copy of Our General Model* that they can point to in their own explanations. Once students are satisfied with their explanation for Environment 1, prompt them to move on to Environment 2.

Assessment Opportunity

Building towards: 10.B: Construct explanations based on evidence collected from running a simulation and using science ideas included in our General Model for Natural Selection for how and why small changes in an environment may cause large changes in trait variations in a population over long periods of time.

What to look and listen for: Look for students using all the model ideas from the General Model for Natural Selection and evidence from their investigation in their explanations for both environments. Look specifically to see how students are explaining that small changes in the environment can have large changes in the system for trait variation within that population of bacteria. An example student response is available in *My Model for Changes in Bacteria Populations*.

What to do: Identify students who have missing model ideas or who have not connected model ideas to evidence from their investigation. Leave these students a sticky note on their work letting them know you will ask them to

1. check to make sure all the model ideas are included and

2. connect model ideas to evidence from the investigation.

Follow up with those students after returning their model explanations to them.

8. Make predictions about long periods of time.

5 MIN

Materials: science notebook with Progress Tracker Copy of Our General Model (from Lesson 9), General Model for Natural Selection

Turn and talk with a partner about running the simulation for a really long time. Using the prompt on **slide L**, have students make predictions about what might happen to trait variations in a population if they ran the model for a really long time. Have students share their ideas with the whole class after they have had a chance to share with a partner.

Suggested prompts	Sample student responses	Follow-up questions
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?	*It is possible that certain trait variations might be totally lost from the population.*	*Does that mean some trait variations would disappear completely from the population?*
Why do some trait variations tend to disappear from the population?	*Some trait variations give an individual a competitive disadvantage, which means they are less likely to survive and reproduce, so the trait variation will likely not be passed on to offspring. Eventually, there may be no more bacteria with that trait variation left in the population to pass it along.*	*How could we represent this in our General Model?*
Losing entire variations from a population seems like a big change. What could cause that, again?	*A change in the environment, like how much water or algae is available or where.*	*So even a small change to the environment can have a big impact?*

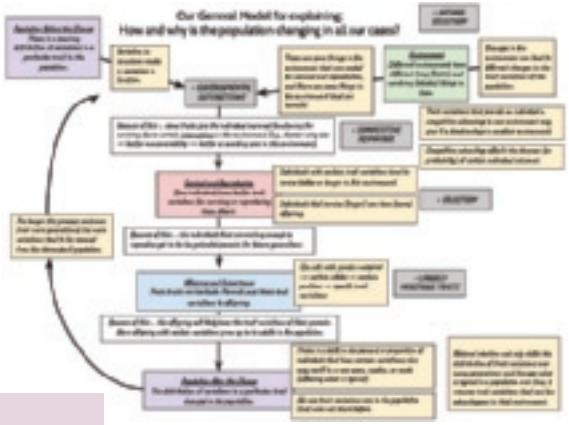
Summarize by saying, *It sounds like we can add this idea to our General Model. Let's add it now.*

On the General Model for Natural Selection, add the following model idea near the purple Populations after Change paper:

- Natural selection not only shifts the distribution of trait variations over many generations and changes what is typical in a population over time, it removes trait variations that are less advantageous in that environment.

Have students add this idea to their *Progress Tracker Copy of Our General Model* in their science notebooks (from Lesson 9).

Say, *Next time let's try out our General Model for a new phenomenon.*



Additional Guidance

In Lesson 12, students will use a photo printout of the class General Model for Natural Selection, so you may choose to take a photo of it now to prepare for that lesson.

Selection and Survival

1 The Most Famous Writer Seldom Read
2 Darwinian Dictionary
3 Artificial Selection
4 Young Scientists Podcast
5 Pigotie Survival: A Classroom Game

Literacy Objectives

- ✓ Distinguish cause(s) and effect(s) related to evolution.
- ✓ Organize related details about natural and artificial selection.
- ✓ Translate text to visual/graphic representation of ideas.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 8–10.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a Venn diagram in response to the reading.

Instructional Resources

Student Reader



Collection 3

Science Literacy Student Reader, Collection 3
"Selection and Survival"

Exercise Page



EP 3

Science Literacy Exercise Page
EP 3

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 8: How can we model what is causing the changes in the populations happening across all our case studies?
- Lesson 9: How well does our General Model predict and explain the changes happening over time in a different population?
- Lesson 10: Why does our General Model tend to produce different outcomes in different environmental conditions?

Standards and Dimensions

NGSS

Disciplinary Core Ideas: LS4.B: Natural selection leads to the predominance of certain traits in a population, and the suppression of others. (MS-LS4-4)

LS4.B: In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring.

LS4.C: Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. (MS-LS4-6)

Science and Engineering Practices: Constructing Explanations and Designing Solutions; Using Mathematics and Computational Thinking

Crosscutting Concept: Cause and Effect

CCSS

English Language Arts

RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

adaptation **evolution** **natural selection**

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

artificial selection **probability**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

Exercise Page



EP 3

2. Preview the assignment and set expectations.

(Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Natural Selection and Common Ancestry unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *First, you will read two brief excerpts from, possibly, the most famous book written about living things. There is a side-by-side interpretation that neatly interprets what Charles Darwin was saying.*
  - *Then, you'll read definitions and discussions of three science terms essential to understanding how species change over time.*
  - *Once you've got "natural" selection down, you'll read an article about how humans influence change in species.*

- *A transcript from a fictitious podcast follows. It's an interview with a dog show judge who has deep knowledge of dog breeds and dog breeding.*
- *Finally, you'll read instructions for a game that simulates changes in a population caused by natural selection.*

- Distribute Exercise Page 3. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a Venn diagram comparing and contrasting natural selection and artificial selection.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What did Charles Darwin mean by the phrase "the struggle for life"?	*that not all offspring live long enough to have their own offspring*
How do scientists make glow-in-the-dark fish?	*They insert a gene from a glow-in-the-dark jellyfish into the eggs of fish that don't glow.*
How is it that dog breeds that are so different in their traits can mate and have offspring?	*All dogs are the same species, and members of a species can mate and produce offspring.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
According to Darwin, how do the condors and ostriches differ in reproductive traits?	*The condors lay only one or two eggs at a time, and the ostriches lay 20 or so.*
What is the advantage to a bird laying many eggs at once?	*There is a better chance that some of the offspring will survive long enough to reproduce.*
In the pigotie survival game, what trait of the chicks increases the probability that they will be eaten by the Chukkers hawks?	*Their color—if they are green or blue, they are more likely to be seen than if they are yellow.*

- Refer students to the Exercise Page 3. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to draw and fill in a Venn diagram comparing and contrasting natural selection with artificial selection.*
  - *"Comparing" means identifying ideas that are common to both types of selection. "Contrasting" means identifying ideas that are only true of one or the other.*
  - *This is a chance for you to show your understanding of evolution, adaptation, traits, and survival. So try to include terms such as these in your diagram.*
  - *The important criteria for your work is that you draw clear distinctions between the types of selection in a way that is easy for the reader of your diagram to interpret.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page



EP 3

4. Facilitate discussion.

(Friday)

Facilitate class discussion about the reading collection and writing exercise. The collection begins with two excerpts from Charles Darwin's scientifically monumental 1859 book, *On the Origin of Species*. Interestingly, although the idea of change over time is central to it, the word *evolution* did not appear in the book until a revised edition published in 1872.

Student Reader



Collection 3

Pages 24–35 Suggested prompt	Sample student response
What is the general purpose of the first selection, "The Most Famous Writer Seldom Read"?	*It pairs a historical 1859 scientific book with comments that interpret the writing for today's reader.*

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Pages 24–35 Suggested prompts	Sample student responses
What did you find challenging about reading from a science book that is more than 150 years old?	*I wasn't sure of the usage of some words that I know, such as* score, stock, *and* organic.
	Some of the words are spelled differently than I usually see them, such as favourable, organisation, *and* characterised.
	The sentences are long!
How helpful did you find the text in the right column? Why?	*pretty helpful because it reads more like the language we use in class discussions*
	helpful because it explains the important points Darwin made
What is the general purpose of the second selection, "Darwinian Dictionary"?	*It explains what certain terms in this unit mean and how to interpret them.*
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first article uses two of the three terms. The second article gives more details and interpretation about what they mean.*
While there is almost no controversy among scientists about how evolution generally works, some nonscientists find it conflicts with their beliefs and promote alternative interpretations online and elsewhere. What are some reliable sources to use if you want to learn more about the science of evolution?	*A reference librarian could provide scientific books, periodicals, encyclopedias, websites, and so on.*
	websites and online articles hosted by scientific institutions
	online science encyclopedias
	ask-a-scientist websites
What is the general purpose of the third article, "Artificial Selection"?	*It explains what artificial selection is and gives two examples of how it happens.*
How did your work in Unit 5 Genetics prepare you for reading this article?	*In Unit 5, we investigated artificial selection in plants and selective breeding of cattle. So, that was good background for reading about two other ways that artificial selection occurs.*

SUPPORT—Many students may be unfamiliar with the somewhat antiquated word *score*. Explain that it means the quantity 20. Point out that Abraham Lincoln's 1863 Gettysburg Address begins with "Four score and seven years ago. . .," and have students calculate the total years the phrase means.

EXTEND—Have students follow the directions and play the simulation game in groups of two or three. Provide one die and green, blue, and yellow markers or highlighters per group. Instruct each group to draw the results of each round as shown in the reading. Connect to math by having students calculate the percentage of each color bird remaining at the end of each round. Then, students can argue what effect, if any, color had on survival.

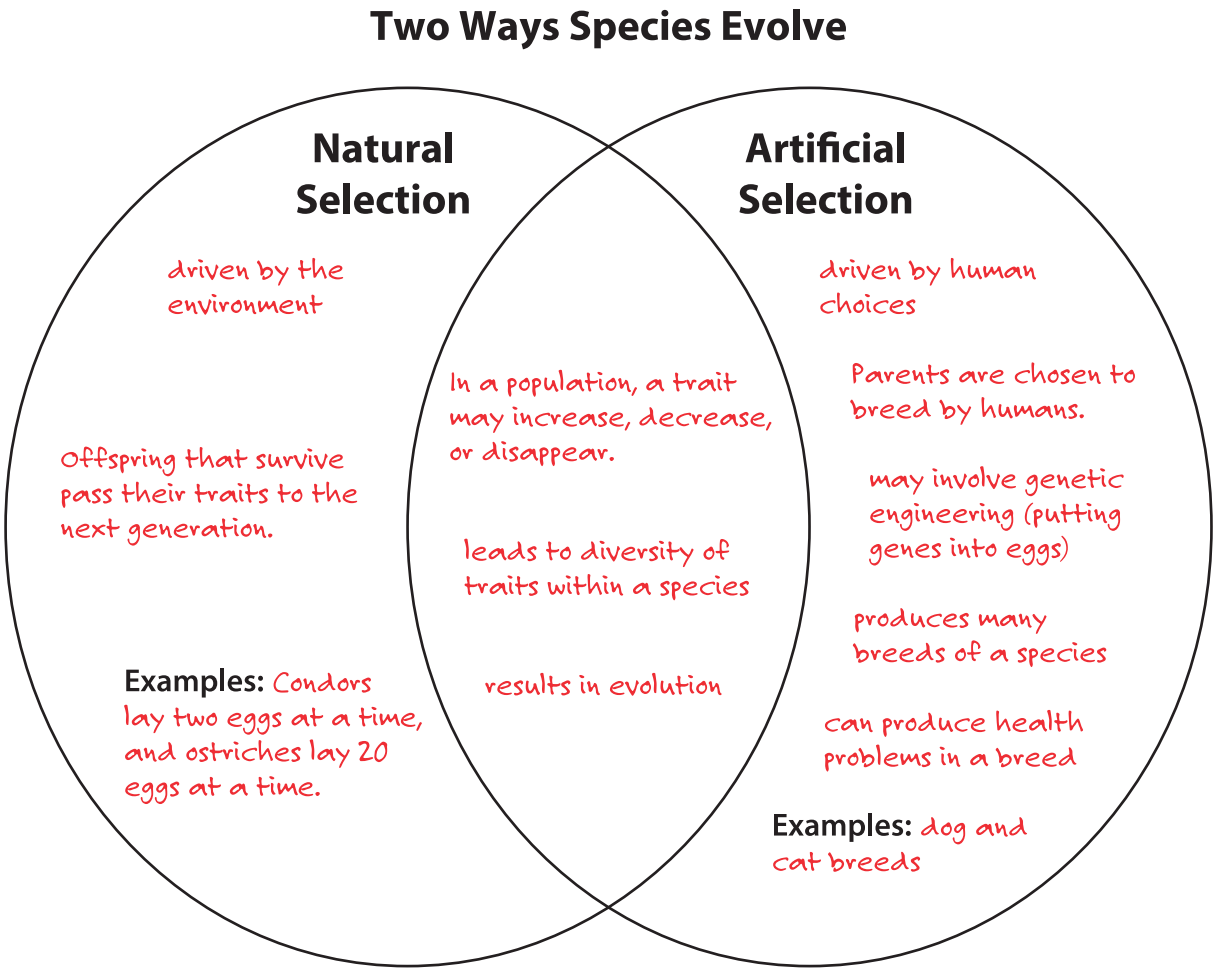
Pages 24–35 Suggested prompts	Sample student responses
How was this reading useful when you developed your Venn diagram?	*I got most of the ideas for the diagram from this article.* *It was very clear how natural and artificial selection contrast. That was useful for filling in where the two circles overlap.*
What is the general purpose of the fourth article, "Young Scientists Podcast"?	*It describes some interesting facts about dog breeds and dog breeding in an entertaining format.*
What part(s) of the text assured you that this is a reliable source for information about artificial selection?	*The host said the guest is a dog show judge, and the guest said he has been a judge for over 20 years.*
What is a problem caused by selective breeding of dogs that natural selection might not cause? How could you show this in your Venn diagram?	*Breeding dogs to bring out certain traits can cause the dogs to have health problems. This might not happen in natural selection as much, so I could show this as a difference in the parts of the circles that do not overlap.*
What is the general purpose of the fifth article, "Pigotie Survival: A Classroom Game"?	*The purpose is to list the rules of a game to simulate natural selection and show how the game could turn out if you played all the rounds.*
What detail(s) in the introduction might help you make your prediction of how the game would turn out?	*The introduction says that the chicks look for food when they are on the sand. If you look at the picture and see that the sand is yellow, you might predict that yellow chicks are less likely to be seen by the hawk that eats them.*
Is this game simulating natural or artificial selection? Explain your reasoning.	*natural selection, because wild hawks are preying on the chicks and people don't seem to have a role*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 3, students should draw a Venn diagram and add details to compare and contrast natural and artificial selection. Look for evidence that students' statements are scientifically correct, that statements of commonalities are written where the two circles intersect, and that statements that differentiate are written where the circles do not intersect.

Use the rubric provided on the Exercise Page to supply feedback to each student.



LESSON 11

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

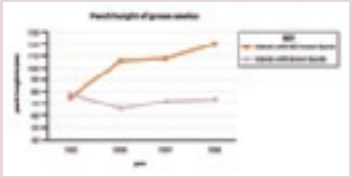
Previous Lesson *We planned and carried out an investigation using a new bacteria simulation to test what happened when we changed the environment by a different factor other than predation. We ran our experiment, collected data, and used our model (natural selection) to explain our results.*

This Lesson

Putting Pieces Together

1 DAY





Data source: Stuart, Y. E., et al (2014). Rapid evolution of a native species following invasion. . . Science, 346(6208).

We demonstrate on a transfer task assessment what we figured out in Lessons 1-10, using science ideas to develop a full explanation for the green lizard perch height phenomenon. We give and receive peer feedback on our explanations. We revise our explanation based on peer feedback.

Next Lesson *We will update our General Model for Natural Selection to add mutation and then use it to explain differences in body structures in horses and horseshoe crabs over very long periods of time.*

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6



What Students Will Do

11.A Construct and revise an explanation using a model to explain why a change to the environment (cause) leads to a predominance of certain genetic variations of traits in a green lizard population that increase some individuals' probability of surviving and reproducing (effect).

What Students Will Figure Out

- Green lizards live higher in the trees after the brown lizards are introduced to their habitat because of trait variation in the initial population of green lizards.
- Green lizards with larger toe pads and more sticky scales have a competitive advantage to climb higher for food and habitat that allows them to survive long enough to reproduce and pass down those trait variations to their offspring.
- This results in a shift in trait variation distribution in the green lizard population after the change (the introduction of brown lizards), with an increase in toe-pad size and amount of sticky scales.

Lesson 11 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Raise the question of whether the General Model for Natural Selection could help us explain differences seen in other organisms.	A	General Model for Natural Selection
2	20 min	**DEMONSTRATE UNDERSTANDING ON AN ASSESSMENT** Individually demonstrate understanding on an assessment.	B	*Green Anole Lizard Explanation*, Progress Tracker Copy of Our General Model (updated in Lesson 10)
3	8 min	**PROVIDE AND RECEIVE FEEDBACK** Provide and receive feedback with a partner about *Green Anole Lizard Explanation*.	C	completed *Green Anole Lizard Explanation*, *Peer Feedback Guidelines* (optional)
4	7 min	**RESPOND TO FEEDBACK** Use feedback to make any revisions to students' *Green Anole Lizard Explanation*.	D	completed *Green Anole Lizard Explanation*, *Peer Feedback Self-Assessment*
5	5 min	**NAVIGATION** Consider the power of the General Model for Natural Selection in explaining the penguin phenomenon we have been working to figure out.	E	

End of day 1

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Green Anole Lizard Explanation* • science notebook • Progress Tracker Copy of Our General Model (updated in Lesson 10) • completed *Green Anole Lizard Explanation* • *Peer Feedback Guidelines* (optional) • *Peer Feedback Self-Assessment*		• General Model for Natural Selection

Materials preparation (20 minutes)

Online Resources



Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Print 1 copy each of

- *Green Anole Lizard Explanation* and *Peer Feedback Self-Assessment* for each student.
- You may choose to print a copy of *Peer Feedback Guidelines* per student to help them provide and receive feedback, or have them refer to it in their student editions. Alternatively, you can project a digital version of *Peer Feedback Guidelines* for students to reference while they work. If students were already able to give feedback in Lesson 5, consider forgoing using *Peer Feedback Guidelines* in order to support their developing independence in giving feedback.
- Also, consider printing *Model Scaffold for Green Lizard Explanation* for students who need additional support in their explanation. This can be done in color or grayscale.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students develop an explanation for a new, related phenomenon. They draw on their knowledge building throughout the unit, including our General Model for Natural Selection.

This lesson focuses explicitly on constructing an explanation. The practices of "Constructing Explanations and Designing Solutions" and "Developing and Using Models" are inextricably linked, and, while students will not iterate on the model in this lesson, they will use the General Model they developed over the course of the unit to articulate their explanation. Students will engage in the practice of "Engaging in Argument from Evidence" by critiquing each other's explanations through peer feedback.

The crosscutting concept of "cause and effect" is used to help students articulate the different mechanisms involved in natural selection. In this case, students use cause-and-effect relationships to explain a phenomenon that occurs in a natural system.

Where We Are NOT Going

While some other curricula include changes in DNA of the anole lizards, this lesson does not include specific genetic information because it is beyond the scope of this unit.

LEARNING PLAN FOR LESSON 11

1. Navigation

5 MIN

Materials: General Model for Natural Selection

Facilitate a brief discussion about the General Model for Natural Selection. Display **slide A**. Point out the class poster of the General Model for Natural Selection**.** Ask students the two questions on the slide:

- *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?*

As students respond, push them to provide a hypothetical example or one from earlier in the unit. Listen for students to note a change in the environment, differences in the distribution of trait variations before and after the change, offspring, inheritance, and competitive advantages to survival and reproduction.

2. Demonstrate understanding on an assessment.

20 MIN

Materials: *Green Anole Lizard Explanation*, science notebook, Progress Tracker Copy of Our General Model (updated in Lesson 10)

Introduce the assessment. Say, *In this unit, we've developed a general model for natural selection that we have applied to several cases in different environments. Today we will explore a new phenomenon happening with a different type of organism. We can see if our General Model holds up and we can still use it to explain what is happening even though we have never investigated this ecosystem together before.*

Ask students to take out their notebook and find their *Progress Tracker Copy of Our General Model* and examples they have of organisms changing over time.*

Administer assessment individually to students. Display **slide B** and hand out one copy of *Green Anole Lizard Explanation* to each student. Note to students that they have a choice in modality for sharing their answers, which include oral or written or pictorial or a combination of the latter two.*



Alternate Activity

If some of your students need additional scaffolding for their green lizard explanation, you may provide *Model Scaffold for Green Lizard Explanation*, which displays the General Model scaffold used in Lesson 10.

Universal Design for Learning: For the assessment, students are asked to write an explanation. Some students may find more success *expressing* their ideas by explaining this orally through recording themselves and then turning in the recording or presenting to you during an appropriate time in the classroom.

*** Supporting Students in Engaging in Constructing Explanations and Designing Solutions**

Students use the class General Model developed in Lessons 8-10 to help them explain the green lizard phenomenon. If students get stuck, encourage them to review the model since it is a helpful sensemaking tool for explaining the phenomenon.

*** Attending to Equity**

Supporting Emerging Multilingual Learners:

Consider providing sentence starters for students who need additional support. Post a list of sentence starters on chart paper for everyone to use, or if only some students need support, write

Assessment Opportunity

Building towards: 11.A Construct and revise an explanation using a model to explain why a change to the environment (cause) leads to a predominance of certain genetic variations of traits in a green lizard population that increase some individuals' probability of surviving and reproducing (effect).

What to look for: This is a transfer task to give students an opportunity to use the three dimensions to make sense of their General Model for Natural Selection using a new phenomenon. Allow students to choose how to share their understanding through oral response, written response, pictorial response, or a combination of both. For specific scoring guidance, use *Key: Green Anole Lizard Explanation*.

What to do: This is meant to be a summative assessment task for this lesson set, and it gives you a grading opportunity. The task includes a scoring guide located in *Key: Green Anole Lizard Explanation*. Scoring guides are meant to highlight important ideas students should include in their responses. If students share these ideas If students share these ideas at other points in the assessment, it is up to you to decide if that understanding is sufficiently demonstrated. Students will continue to use these ideas in the next two lesson sets.

sentence starters on strips of paper and put them in an envelope for individuals or groups of students who would benefit from the additional support. Example sentence starters:

- My evidence for this is . . .
- I know this because . . .
- Changes in trait variations happen when . . .
- The environment played a role because . . .
- The _____ was an advantage because . . .

3. Provide and receive feedback.

8 MIN

Materials: completed *Green Anole Lizard Explanation*, *Peer Feedback Guidelines* (optional)

Pair up and share with a partner their *Green Anole Lizard Explanation*. Show **slide C**. Distribute *Peer Feedback Guidelines* for students to tape into notebooks if desired or have students find it in their student edition. Explain how students will give each other feedback in a conversation. Point out that students may want to take notes during this partner-feedback talk.

If students were already able to give feedback in Lesson 5, consider forgoing using *Peer Feedback Guidelines* in order to support their developing independence in giving feedback.

Have students get up and find a partner to share with.

Alternate Activity

Have students give and get feedback using sticky notes instead of verbal feedback. Prompts for what to write include the following:

- I wonder about _____. I noticed you _____.
- I appreciate how you _____.
- It would be clearer if you added _____.
- I see you're thinking about _____.
- Do you think you should add _____?

4. Respond to feedback.

7 MIN

Materials: completed *Green Anole Lizard Explanation*, *Peer Feedback Self-Assessment*

Reflect on peer feedback. Display **slide D** for reminders about receiving feedback, also listed below. Explain, *We use peer feedback to improve our work, making it clearer, more accurate, and better supported by evidence. When you receive feedback, you should 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.*

Give students 4 minutes to make any additions or revisions to their explanation using the feedback provided.

Distribute *Peer Feedback Self-Assessment*. Giving students this opportunity to reflect on their progress in giving and receiving feedback will help build their skills in this important area.

Collect *Green Anole Lizard Explanation* and provide teacher feedback so that students may use these ideas in the following lessons.

Home Learning Opportunity



If students do not have time to complete *Peer Feedback Self-Assessment* during class, have them finish it for home learning.

5. Navigation

5 MIN

Materials: None

Consider how our General Model can be used to explain the patterns we have observed in penguins and other organisms. Present **slide E** and say, *We have seen the power of our General Model in explaining multiple phenomena that we have observed. Do you think that our General Model can be equally powerful in explaining the patterns we have observed in penguins or other organisms?*

Tell students that in the next lesson, we are going to dive deeply into thinking about how the General Model can be used to explain these patterns in other organisms. For now, have students begin to think with a partner about how it can be applied.

Instruct students to work with a partner to select one of the questions on the slide to discuss. Students should share their thinking about the question in preparation for diving deeply into all three of the questions in the next lesson.

- 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?

ADDITIONAL LESSON 11 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

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

Like the data packets in Lesson 7, the *Green Anole Lizard Explanation* contains qualitative and quantitative and scientific information expressed in words along with information expressed visually in photos, a table, and a graph that students must integrate to make sense of the case. When they explain the change in the green anole population using the General Model for Natural Selection, students cite specific evidence from those data and text to support their explanation.

LESSON 12

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

Previous Lesson

We demonstrated on a transfer task assessment what we have learned. We gave and received peer feedback on our explanations. We revised our explanation based on peer feedback.

This Lesson

Putting Pieces Together, Problematizing

2 DAYS



We update our General Model for Natural Selection to add mutation and then use it to explain differences in body structures in horses and horseshoe crabs over very long periods of time.

Next Lesson

We will use what we know about natural selection and mutation to develop a model to show how modern penguins could be connected to one another and to ancient penguins through common ancestors. We will construct possible explanations for how the penguins are connected and compare our explanations with others' and decide that limited evidence means there are many possible explanations.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

12.A Construct a scientific explanation for how natural selection acting over generations has caused organisms' body structures to change over time in response to changes in environmental conditions.

What Students Will Figure Out

- Mutation is the source of new variation and can explain body structures in modern organisms that are not seen in ancient organisms.
- Natural selection could be the mechanism that is causing the greater changes we see over longer periods of time.

- Mutations and natural selection could link modern organisms with their ancestors far back in time.
- We have questions about how our model might explain how there are so many species of penguins (and other organisms) with such different body structures.

Lesson 12 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	8 min	**NAVIGATION** Students connect how populations change over time to the Penguin Timeline with cards. Add new questions about the origin of new variations to the DQB.	A	sticky note, marker, Penguin Timeline with Cards, DQB
2	7 min	**RECALL WHAT WE KNOW ABOUT THE GENETIC BASIS OF TRAIT VARIATIONS AND MUTATION** Review the ideas we have from *Muscles Unit* about alleles, chromosomes, trait variations, and mutations.	B-D	Word Wall card for mutation from *Muscles Unit* or half sheet of paper, marker, and transparent tape to make Word Wall card for mutation
3	5 min	**UPDATE MODEL TO INCLUDE SOURCES OF VARIATION** Update the General Model for Natural Selection to include the source of new variation that natural selection may act on.	E	General Model for Natural Selection, 5" x 8" white index card or paper
4	5 min	**DECIDE TO EXAMINE HORSES' TOES** Orient to changes in horses' toes over time.	F-H	Progress Tracker Copy of Our General Model (updated in Lesson 10), General Model for Natural Selection, 2 sheets of purple paper, markers, transparent tape
5	20 min	**USE THE GENERAL MODEL FOR NATURAL SELECTION TO EXPLAIN A SPECIFIC CASE** Read about the changing environment and the function of multiple and single toes and use this information to work together to fill in the rest of the model.	I-J	*Reading v1: Horses—Ancient and Modern* or *Reading v2: Horses—Ancient and Modern*, half sheet of paper, marker, and transparent tape to make Word Wall card for adaptation by natural selection, General Model for Natural Selection, 1 green paper, 1 blue paper, 1 pink paper, several 5" x 8" yellow sticky notes (as needed), several pieces of white paper (as needed)

End of day 1

Part	Duration	Summary	Slide	Materials
6	5 min	**REVISIT ANCIENT AND MODERN HORSESHOE CRABS** Introduce the next organisms students will attempt to explain using the General Model for Natural Selection.	K-L	*Reading v1: Horseshoe Crabs—Ancient and Modern* or *Reading v2: Horseshoe Crabs—Ancient and Modern*, Small Group Working Copy of Our General Model, 2 purple 3″ x 3″ sticky notes, 1 green 3″ x 3″ sticky note, 1 blue 3″ x 3″ sticky note, 1 pink 3″ x 3″ sticky notes, and several yellow 3″ x 3″ sticky notes
7	17 min	**USE THE GENERAL MODEL FOR NATURAL SELECTION TO EXPLAIN HORSESHOE CRABS** Read about the body structures of horseshoe crabs and use the General Model to explain why their body structures have stayed the same over time.	M	*Reading v1: Horseshoe Crabs—Ancient and Modern* or *Reading v2: Horseshoe Crabs—Ancient and Modern*, Small Group Working Copy of Our General Model, 2 purple 3″ x 3″ sticky notes, 1 green 3″ x 3″ sticky note, 1 blue 3″ x 3″ sticky note, 1 pink sticky note, several yellow 3″ x 3″ sticky notes, General Model for Natural Selection
8	15 min	**SHARE HORSESHOE CRAB EXPLANATIONS** Compare explanations of horseshoe crabs' body armor or telson with another group, then discuss as a class.	N-O	Small Group Working Copy of Our General Model updated with horseshoe crab notes
9	5 min	**NAVIGATION** Make connections between modern whale and modern penguin species.	P-R	

End of day 2

Lesson 12 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• sticky note • marker • science notebook • Progress Tracker Copy of Our General Model (updated in Lesson 10) • *Reading v1: Horses—Ancient and Modern* or *Reading v2: Horses—Ancient and Modern* • *Reading v1: Horseshoe Crabs—Ancient and Modern* or *Reading v2: Horseshoe Crabs—Ancient and Modern*	• Small Group Working Copy of Our General Model • 2 purple 3″ x 3″ sticky notes • 1 green 3″ x 3″ sticky note • 1 blue 3″ x 3″ sticky note • 1 pink 3″ x 3″ sticky note • several yellow 3″ x 3″ sticky notes • 1 pink sticky note • Small Group Working Copy of Our General Model updated with horseshoe crab notes	• Penguin Timeline with Cards • DQB • Word Wall card for mutation from *Muscles Unit* or half sheet of paper • marker • and transparent tape to make Word Wall card for mutation • General Model for Natural Selection • 5″ x 8″ white index card or paper • 2 sheets of purple paper • markers • transparent tape • half sheet of paper • and transparent tape to make Word Wall card for adaptation by natural selection • 1 green paper • 1 blue paper • 1 pink paper • several 5″ x 8″ yellow sticky notes (as needed) • several pieces of white paper (as needed)

Materials preparation (15 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Have a half-sheets of copy paper, marker, and transparent tape ready to add the term *adaptation by natural selection* and mutation to the Word Wall. Do not post this word on the wall until after your class has developed a shared understanding of its meaning. Also, be prepared to repost the word *mutation* from *Muscles Unit* or create a new card for that word, if needed.

Online Resources 

Before day 1 of this lesson (when you will add other notes to it) take a photo or photos (if you have multiple classes) of the General Model for Natural Selection. Test print a copy of each one. Make sure the text is sharp enough to read. If it's not, either reshoot the photo or recreate the model as a digital version. Once you have a readable version, add a title to it indicating what class period it is for. This document will be referred to as the *Small Group Working Copy of Our General Model*.

Print a copy of the corresponding *Small Group Working Copy of Our General Model* for each group in each class period.

Day 1

- **Group size:** 2 (elbow partners would be appropriate)
- **Setup:** Display the Penguin Timeline with Cards and the class poster of the General Model for Natural Selection in a place that is visible to the whole class.
- **Materials**
  - *Reading v1: Horses—Ancient and Modern* (more-complex text) or *Reading v2: Horses—Ancient and Modern* (less-complex text), 1 for each student (handout copy or available in the student edition)
  - 2 sheets of purple paper per class
  - 1 sheet of green paper per class
  - 1 sheet of pink paper per class
  - 1 sheet of blue paper per class
  - several 5" x 8" yellow sticky notes
  - several sheets of white paper

Day 2

- **Group size:** 3 (maximum)
- **Setup**
  - Display the class poster of the General Model for Natural Selection with the notes you added on day 1 in a place that is visible to the whole class.
  - Be prepared to distribute one copy of the *Small Group Working Copy of Our General Model* to each group.
  - You may want to set up an activity "kit" for each group in a class consisting of one copy of the *Small Group Working Copy of Our General Model* along with the multicolor 3" x 3" sticky notes they will use in the activity. Alternatively, these can be distributed separately at the beginning of the activity.
- **Materials**
  - *Reading v1: Horseshoe Crabs—Ancient and Modern* (more-complex text) or *Reading v2: Horseshoe Crabs—Ancient and Modern* (less-complex text): 1 for each student (handout copy or available in the student edition)
  - 2 purple 3" x 3" sticky notes per group
  - 1 green 3" x 3" sticky note per group
  - 1 pink 3" x 3" sticky note per group
  - 1 blue 3" x 3" sticky note per group
  - several 3" x 3" yellow sticky notes per group
  - sheets of white paper as needed

Lesson 12 • Where We Are Going and NOT Going

Where We Are Going

Until this point students have used the General Model for Natural Selection to explain how a population changes over time with regard to trait variations that already exist in the population. Questions may have been raised already about the origin of that variation over the course of the unit, so we uncover that here by recalling and connecting to what we learned about mutation in Lesson 8 of *Unit 8.5: Why are living things different from one another? (Muscles Unit)* and update the General Model for Natural Selection to add the source of new variation. This addition to the model will allow for a more-sophisticated understanding of how traits in populations change over time and will include a gradual, incremental accumulation of adaptations over time in a line of descendants.

Students use their General Model for Natural Selection to develop body structure explanations for horses and horseshoe crabs. These explanations are layered over their updated diagramatic system model for natural selection. This parallel structure of the explanation and the model may make the difference between explanation and model difficult for students to distinguish on the surface. This lesson provides an opportunity to help students recall that explanations are phenomenon-specific accounts for why or how something happened, while models are generalized sets of ideas that describe the parts, interactions, and mechanisms we believe work across a broader class of phenomena.

Finally, we problematize the outcomes of natural selection. Until this point the examples we used in our explanatory models help us see that this mechanism results in organisms becoming more similar to one another. We notice, however, that we need to see if our model can explain how we end up with several different species to explain our whales and penguins.

Where We Are NOT Going

While we do use the idea that mutations are rare, we do not focus on the different types of mutations. We keep the explanation of *mutation* that we learned in *Muscles Unit*: a small change that happens to the structure of a chromosome that can be passed to future offspring but was not there before.

LEARNING PLAN FOR LESSON 12

1. Navigation

8 MIN

Materials: sticky note, marker, Penguin Timeline with Cards, DQB

Reference the questions we thought about in the last class. Present **slide A** and say, *Last class we asked you to think about whether our General Model can be equally powerful in explaining the patterns we have observed in penguins or other organisms.*

- 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 body structure variations that were typical in their population but are different from those of modern penguins?

Reorient students to the Penguin Timeline with Cards. Say, *We know our model works in organisms we've seen adapt over shorter time periods* (point to the part of the timeline that shows the last 100 years or so). *How do we think that applies to and what can it help us explain about longer time spans?* (Refer to the gap of time between the ancient penguins and the modern penguins.) *That's what we really wanted to explain from the beginning. What does our model have to do with Pedro? Do we think natural selection can help us explain how the ancient and modern penguins are connected?* Give students time to share ideas with the class.

Highlight the idea that there are body structures present in some penguins but not others. Refer to the penguins on the Penguin Timeline with Cards. Say, *OK, if we look back at Pedro, we can see he has some prominent body structures like bent wings, but none of our modern penguins have bent wings. What do we think happened to these wings? And many of our modern penguins have different prominent body structures, but where did they come from if Pedro didn't have them? Let's look at this rockhopper for example: its parents had that fancy hairdo, and its parents did, too, but Pedro didn't have a fancy hairdo, so where did that come from?*

Check the DQB for questions about the origin of new variations and add any new questions students have. Review the DQB with students, and if there are new questions students want to add about the origin of variations such as these, add them to the board now. If there are already questions about where the variations came from, point them out.

Ask, *Have there been any other times this year when we have discussed variation?* If your class completed *Muscles Unit*, students should bring up the variation in cattle muscles.

Additional Guidance

The following section is meant to be a quick connection to what students have learned in the previous unit. If your class did not complete *Muscles Unit* or if you are doing these units out of order, consider providing more support to discuss how mutations are connected to phenotype. *Mutation Story from 8.5, the Muscles Unit* is provided if you need to review the story of the myostatin mutation with your students now.

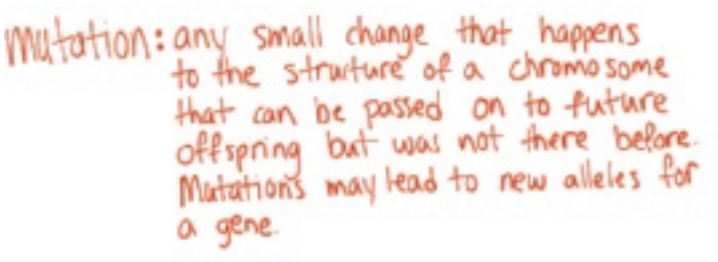
2. Recall what we know about the genetic basis of trait variations and mutation. 7 MIN

Materials: Word Wall card for mutation from *Muscles Unit* or half sheet of paper, marker, and transparent tape to make Word Wall card for mutation

Recall another context where we discussed variation. Show **slide B** and use the image there to connect back to the idea of how the structures of the chromosomes are related to proteins and may lead to changes in body structures.

Suggested prompts	Sample student responses
Let's think about the variation we learned about that caused cattle to either have typical muscles or be heavily muscled. We can see there are alleles on the chromosomes that result in different outcomes. Where did each of those chromosomes come from?	*One of the chromosomes came from each of the individual's parents.* *One chromosome was in the sperm cell, and the other was in the egg cell.*
That explains how individuals get alleles from their parents, but where did the allele from the first heavily muscled calf come from? When it was the first heavily muscled individual, the parents did not have the allele in their body cells.	*There must be a new allele.* *A mutation may have happened to make a new allele.*

Focus on the idea that mutations are relatively rare. Show **slide C**. If you kept your *mutation* Word Wall card from *Muscles Unit*, repost that now. Otherwise, quickly recreate a new one using the definition stated on **slide C**: "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."



Ask students to turn and talk (for two minutes) to discuss the role that they think mutation plays with regard to how the organisms we have been studying have changed over long periods of time and whether mutations are common or rare. Show **slide D** and ask students to share with the class their ideas about the rates of mutation in the organisms listed in the table and how this might be related to the rates of mutation in the organisms we have been learning about in this unit.

Suggested prompt	Sample student responses
What role do you think mutation plays with regard to how the animals we are studying have changed over long periods of time?	*Mutations could cause the different variations we see in populations.* *Natural selection wouldn't be able to happen without variations, so mutations make the new variation.*

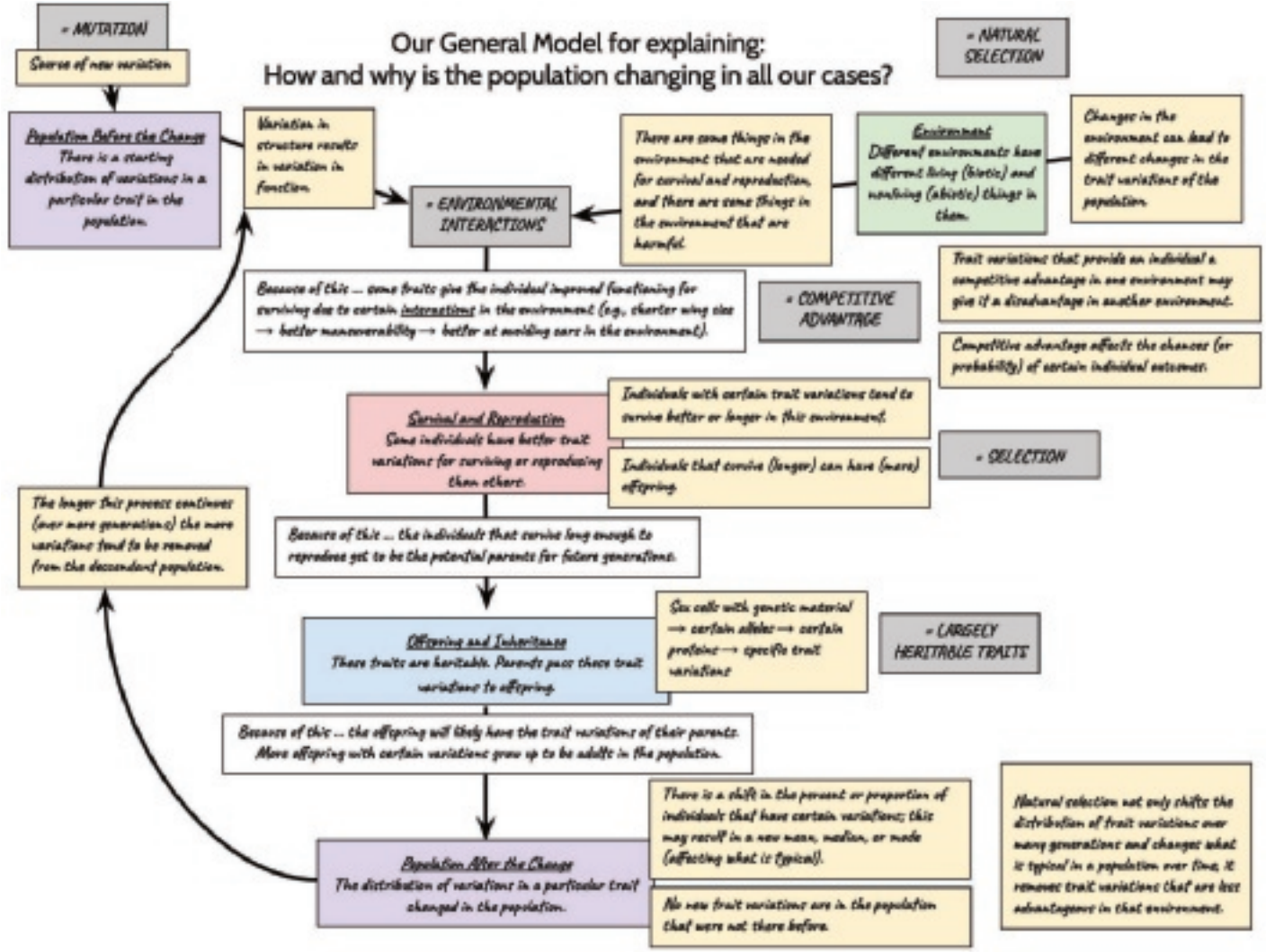
Suggested prompts	Sample student responses
How common do you think mutations are in horses, whales, horseshoe crabs, and penguins?	*Horses and whales are mammals, so their genes probably have about a one in 10,000 chance of having a mutation—that's pretty rare.* *I don't think mutations would be any more common for penguins or horseshoe crabs.* *Mutations are even more rare in bacteria!*
There are many possible ways a mutation in the gene could affect the trait. Do you think all mutations lead to a trait variation that would help the organism survive better?	*No, some could be harmful.* *Some could be neutral, neither helping nor harming the organism.*
If a mutation results in a trait variation that would make an organism survive less well, will we see that variation continue in the population?	*Probably not. They might die right away or have a harder time living.* *They might not survive long enough to reproduce and pass along that mutation.*
What about a mutation that leads to a trait variation that doesn't help or hurt the organism?	*That trait variation could stay in the population.*

3. Update model to include sources of variation.

5 MIN

Materials: General Model for Natural Selection, 5" x 8" white index card or paper

Update the model. Show **slide E**. Point out the class poster of the General Model for Natural Selection. Ask students to weigh in about where it makes sense to add to the model the idea of mutation as the source of variation in the population. Students should suggest that "mutation" be added to the model above the beginning population (the purple Population before the Change paper) because those trait variations (caused by mutations) are in the population to begin with. See the example model shown here.



After adding the = MUTATION card to the General Model for Natural Selection, use the prompts below to ask students if they think this model and the new update can help explain some of the differences we saw in ancient and modern organisms.

Suggested prompts	Sample student responses
Are we satisfied with how well our general model for natural selection can explain what happens in the different organisms we've looked at?	*Yes. It's a general model that explains what happens for all the organisms we've looked at so far.* *We showed that it explains what happened in bacteria in addition to explaining the cases we used to build it.* *It helped us explain how the green anoles have different body structure variations after brown anoles came to their islands.*
Do you think the general model for natural selection would work to explain all changes we see in the body structures of all different organisms?	*Yes. It's very general, and we already saw it work for several different kinds of organisms, so it should work for everything.* *Probably. It works for a lot of different types of organisms so far.* *Maybe. We didn't try it with anything bigger than a bird yet, and we didn't look at any mammals. Maybe they're different.* *I'm not sure. The cases we've explained with it were all within relatively short time periods, not the millions of years we're wondering about with Pedro and the other ancient animals.*
Do you think our model for natural selection could help us explain the cases we've looked at over very long periods of time—the penguins, horseshoe crabs, horses, and whales?	*Maybe. If it works over a short time it might work over a long time.* *Probably. A long time is just a really large number of generations, so it should work the same over long periods of time.*
Let's think about mutations again for a moment. We know mutations are very rare. And mutations that result in a trait variation that helps an organism survive better are even more rare. How does the idea that mutations are so rare come into play differently if we're explaining the results of natural selection over short periods of time compared to long periods of time?	*Since mutations are so rare, there is a lower chance that a mutation would happen over a short time span, but maybe they could happen over long periods of time.* *The more time you have for a mutation to happen, the greater chance there is of one happening.* *It takes a long time for a mutation to happen randomly, so it might take a long time to see bigger differences.*

Say, *Let's look at one of the organisms for which we have ancient and modern species and see if the model could explain what happened.*

4. Decide to examine horses' toes.

5 MIN

Materials: science notebook, Progress Tracker Copy of Our General Model (updated in Lesson 10), General Model for Natural Selection, 2 sheets of purple paper, markers, transparent tape

Reorient to body structures that changed over long periods of time. Display **slide F**. Remind students which organisms we looked at where we have evidence for both ancient and modern species over long periods of time.

Say, *We need to start with an organism in which some interesting body structure changed between ancient and modern species that is pretty easy to see. It would be cool to go back and explain penguins right now, but it might be confusing to do since there are so many different species of modern penguins. Let's wait on penguins a little longer and try explaining a body structure with horses first.*

Focus on horses' toes. Display **slide G**. Ask, *What were some of the interesting body structures that you saw were different over time in horses?* Accept all responses.

Display **slide H** to highlight the horses' forelegs and focus on how the number of toes changed from the most ancient to modern horses. Suggest that we try to explain this change using our General Model for Natural Selection. Have students locate their *Progress Tracker Copy of Our General Model* (updated in Lesson 10) in their science notebook so they can refer to it.

Additional Guidance

If you will be using the upcoming partner work and whole-class participation as an assessment, let students know that their participation will be assessed. See the Assessment callout box for **12.A.1** for details.

Define the change in a body structure over time. Say, *We should first define what body structure change we're going to try to explain.*

Move to the class poster of the General Model for Natural Selection and ask the students to describe the body structure variations of the ancient horse toes. They should mention that the ancient horses had multiple toes. Write "Almost all individuals had 3 (or multiple) toes" on one of the purple sheets of paper and post it over the purple Population before the Change paper on the model.

Ask the students to describe the body structure variations of the modern horse toes. They should mention that the modern horses have only one large toe, or hoof. If necessary, explain to students that a hoof is basically just a large toe with a very thick covering on it, like a really big toe nail. Write "Almost all individuals have a single toe or hoof" on the other purple sheet of paper and post it over the purple Population after the Change paper on the model.*

*** Supporting Students in Engaging in Developing and Using Models**

Students have already worked through developing and refining this model multiple times in the lessons 8-10 and have used it as part of a summative assessment in Lesson 11. The purpose of the next activity in this lesson is to have students think through the elements of the model and how they apply to the case of horses' toes over a long period of time. It is not necessary or desirable to focus on the process of assembling this information. Once students have articulated the general idea for each element and there is general consensus in the class, feel free to quickly summarize or paraphrase and write on the paper yourself, in order to move things along and allow students to focus on the concepts rather than the process.

5. Use the General Model for natural selection to explain a specific case. 20 MIN

Materials: *Reading v1: Horses—Ancient and Modern* or *Reading v2: Horses—Ancient and Modern*, half sheet of paper, marker, and transparent tape to make Word Wall card for adaptation by natural selection, General Model for Natural Selection, 1 green paper, 1 blue paper, 1 pink paper, several 5" x 8" yellow sticky notes (as needed), several pieces of white paper (as needed)

Introduce a short reading. Display **slide I**. Ask students to name the other main elements of the model that we need information about. They should mention that we need to know about the origin of body structure or trait variation, environment of the horses, their survival and reproduction, and offspring and inheritance. Distribute *Reading v1: Horses—Ancient and Modern*. Give students five minutes to read and annotate the information in the reading in order to collect information about those four elements.

Additional Guidance

If you think any or all of your students would benefit from using a less-complex text, *Reading v2: Horses—Ancient and Modern* is provided as an alternate to the more-complex *Reading v1: Horses—Ancient and Modern*. Both texts contain the same information, but the alternate uses simplified sentence structure and vocabulary.

Define the origin of body structure variation in the population. Have students turn and talk with a partner to share information regarding what may have happened to allow for variation in a population of horses with regard to the structure of their toes.

Facilitate a brief discussion using the prompts below to come to consensus about what to add to the = MUTATION element.

Suggested prompts	Sample student responses
What body structure are we focusing on that is changing over time?	*The number of toes that the horses had.*
Did all individuals in the population have the same exact structure with regard to their toes?	*No, there must have been variation if this body structure changes over time in a population.*
What did you and your partner think may have led to the variation in the structure of the horses' toes?	*There was a mutation to make a new allele.* *The new allele resulted in fewer or smaller toes.*
So what should we add to our model to help us understand where this variation came from?	*We could add that there was a mutation in the gene that influences the number of toes.*

Add text the students decide on to a yellow sticky note and add it to the section between the = MUTATION card and the purple Population before the Change paper.

Define the Environment element of the model. Have students turn and talk with a partner to share information regarding what they learned about the horses' environment and what they think should go on the green Environment

*** Attending to Equity**

It is always important that all students' ideas are respected and taken seriously. Even though at this point in the unit there is a preponderance of evidence that supports the claim that natural selection is the mechanism underlying incremental changes in traits that can accumulate to produce large-scale structural changes, dissenting claims should be welcomed into the conversation.

However, it is also critical that scientific claims are always supported with evidence. The arguments supporting natural selection as the mechanism for change occurring over millions of years are solidly based in scientific evidence and reasoning and there is no evidence that contradicts them. The evidence cannot be based on direct observation since ancient organisms no longer exist and the fossil record is incomplete. Therefore, students may feel the support is weak. Ask students to explain the connection between their claims and the evidence that supports them.

paper for the model regarding horses' toes. Facilitate a brief discussion using the prompts below to come to consensus about the green Environment element.

Suggested prompts	Sample student responses
What was the horses' environment like?	*The environments were different for the ancient and the modern horses.*
So we have different environments. What was the environment like for the ancient horses?	*It was like a rainforest.* *It was crowded with a lot of plants and animals.* *The terrain was uneven.* *The predators pounced on animals that wandered by.*
What is the environment like for modern horses?	*It's open grassland.* *It has mostly grass, and it's easy to see long distances.* *The terrain is flat with firm soil.* *The predators chase animals to catch them.*
Why are these environments different?	*The climate changed over long periods of time. Earth cooled and dried out, and the type of environment changed.*

On the green paper, write "The environment changed from rainforest to open grassland" and add a brief description of the biotic and abiotic factors in each environment. Post it over the green Environment paper on the model.

Define the other two main elements of the model. Have students turn and talk with a partner to share information regarding what they learned about the horses' survival and reproduction and their offspring and inheritance. Ask partners to decide what they think should go on those pink and blue papers for the model. Facilitate a brief discussion using the prompts below to come to consensus about those elements. Then record a summary of their ideas on pink and blue papers and post them on the general model over the pink Survival and Reproduction paper and the blue Offspring and Inheritance paper.

Suggested prompt	Sample student responses
Did you find any evidence about the pink Survival and Reproduction element?	*Yes. We think that horses with multiple toes would have survived better in forests where they needed to move around on uneven ground to find food or hide to avoid predators.* *We think that horses with one hoof would have survived better on grasslands where there is no place to hide and they need to run fast to escape predators.*

Suggested prompts	Sample student responses
So as the environment changed to more-open grassland over millions of years, which one of the body structure variations had a competitive advantage?	*Horses with one toe or hoof, or at least horses with fewer toes, would have an advantage in grasslands.*
Did you find any evidence about the blue Offspring and Inheritance element?	*Yes. Horses have to survive for a few years before they can reproduce, so the offspring will come from the ones that survive better.* *It says the number of toes is inherited, so whichever horses survived would pass on the toe structure to their offspring.*
So as the environment changed to more-open grassland over millions of years, which one of the structures was more likely to be passed on?	*Horses with one toe or hoof, or at least horses with fewer toes, would be more likely to pass on their variations to offspring.*

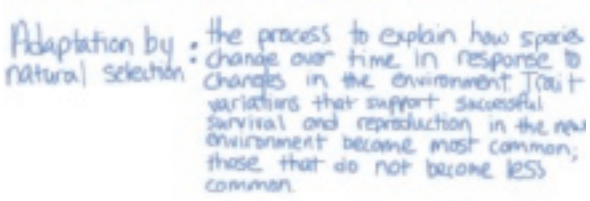
Discuss any other parts of the model that need revising. Display **slide J**. Say, *So let's see if the whole thing works to explain what happened with horses' toes over millions of years.*

Starting at the top of the model, point to each element (each colored paper, sticky note, and "Because of this . . . " statement) and read what is now posted on the model. Ask students whether each element works as written or whether it needs to be modified to explain specifically what happened with the horses' toes. Push students to be as specific as possible for each element, emphasizing what happens in the specific case of the change in the body structure of horses' toes over time. Students may want to rephrase or add specific details to some or all of the elements. Quickly paraphrase or summarize their ideas and make the changes they suggest using white index cards or papers and 5" x 8" yellow stickies.

Define "adaptation by natural selection" as a scientific term. Say, *We just described how mutation provides new trait variation and natural selection works with this trait variation over time to help a species survive in its environment. The scientific term for this process is "adaptation." You might have used the word "adaptation" in earlier grades to name the structures that an organism has that help it survive in its environment. You also may have heard the word used in other ways outside of science. But today we're naming the process of adaptation; and mutation and natural selection are mechanisms that contribute to that process. To be really clear that we are talking about the process we will refer to this as "adaptation by natural selection".*

Add *adaptation by natural selection* to the Word Wall. Here is a suggested definition: "the process to explain how species change over time in response to changes in the environment. Trait variations that support successful survival and reproduction in the new environment become more common; those that do not become less common."

Come to an agreement about whether we think this model might work to explain body structure changes over long periods of time in all organisms. Ask students if they think this model might work to explain body structure changes in organisms over long periods of time.



Most, if not all, students are likely to agree that the General Model for Natural Selection can be used to help explain body structure changes in all organisms over long periods of time. Point out to students that the natural selection mechanism in their model is supported by evidence from many shorter-term studies and that we expect the same mechanisms have worked the same way in the past. If some students do not

think the model could be used to explain body structure changes over long periods of time, have them articulate why they disagree and ask them for evidence to support their claims.*

Ask students if coming to an agreement on how the model might work to explain body structure changes over long periods of time in all organisms raises any questions for them. Allow them to share any questions they have and let them know they will have a chance to practice applying this claim on their own during the next class period using another one of our examples.

Additional Guidance

You will want to refer to these horse-specific notes on your model during day 2. If you have separate model posters for each of your classes, keep the papers you added today stuck on for day 2. If multiple classes are using the same model, you will want to remove these notes after each class and then reattach them in advance of your first class for day 2.

Assessment Opportunity

Building towards: 12.A.1 Construct a scientific explanation for how natural selection acting over generations has caused organisms' body structures to change over time in response to changes in environmental conditions.

What to look and listen for: Circulate among students as they talk with partners and listen closely as students share ideas with the whole class. Students should be actively engaged in connecting specific elements of the General Model for Natural Selection with specific information about ancient and modern horses, the environments they inhabited, and the functions of multiple and single toes. Listen for each student to make an accurate and specific connection between the model and the information about horses. An example of what specific information might be included is in *Student Examples of Using General Model to Explain Body Structures*. However, keep in mind that student language will vary from what is shown in the example. Using specific information is important, but the precise words used to describe connections are not.

What to do: If students are struggling to make connections, point out one element of the model on their *Progress Tracker Copy of Our General Model* and ask them if any part of what they read connects with that element. Encourage them to look at one part at a time to see if it fits the general ideas. Or ask them what they found interesting about what they read and whether they can connect that with some part of the model. Celebrate accurate connections, even if they are tenuous, and encourage persistence.

End of day 1

6. Revisit ancient and modern horseshoe crabs. 5 MIN

Materials: science notebook, *Reading v1: Horseshoe Crabs—Ancient and Modern* or *Reading v2: Horseshoe Crabs—Ancient and Modern*, Small Group Working Copy of Our General Model, 2 purple 3" x 3" sticky notes, 1 green 3" x 3" sticky note, 1 blue 3" x 3" sticky note, 1 pink 3" x 3" sticky note, and several yellow 3" x 3" sticky notes

Reorient to body structures in the horseshoe crabs that changed over long periods of time. Display **slide K**. Say, *Last class we tested our General Model for Natural Selection to determine if we could explain the changes we see in the*

number of toes in ancient horses compared to modern horses. Today, we are going to see if our model still works with an example where we don't see such obvious changes.

Focus on horseshoe crabs' body structures. Display **slide L**. Say, *Let's start with an interesting body structure. What were some of the interesting body structures seen in horseshoe crabs?* Students may mention the telson (tail) or the armor surrounding the horseshoe crabs' bodies, but the general shape and structures of the horseshoe crabs did not really change much over time. Tell students that they can choose either the tail or the armor as a body structure to explain once they are together in groups to do this work. They will use that body structure to work out how our General Model for Natural Selection could explain how these structures did not change over so much time.

Orient to what students will do in the activity. Divide students into groups of no more than three. Distribute a copy of the *Small Group Working Copy of Our General Model* to each group along with 2 purple, 1 green, 1 blue, 1 pink, and several yellow sticky notes. Have students locate their copy of the *Progress Tracker Copy of Our General Model* in their science notebook so they can refer to it, along with any notes they may have written on it.

Ask students what other resources they will need to complete the task of showing how our model for selection could be used to explain the changes in horseshoe crabs' body size or shape. Tell students you will give them complete instructions next. If students identify additional information they will need, distribute *Reading v1: Horseshoe Crabs—Ancient and Modern* which contains information about the environments, survival, reproduction, and offspring for ancient and modern horseshoe crabs. (If they do not identify any information they'll need, wait to distribute *Reading v1: Horseshoe Crabs—Ancient and Modern* and move on to the next activity.) This material is also available in the student edition.

Additional Guidance

If you think any or all of your students would benefit from using a less-complex text, *Reading v2: Horseshoe Crabs—Ancient and Modern* is provided as an alternate to the more-complex *Reading v1: Horseshoe Crabs—Ancient and Modern*. Both texts contain the same information, but the alternate uses simplified sentence structure and vocabulary.

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

17 MIN

Materials: *Reading v1: Horseshoe Crabs—Ancient and Modern* or *Reading v2: Horseshoe Crabs—Ancient and Modern*, Small Group Working Copy of Our General Model, 2 purple 3" x 3" sticky notes, 1 green 3" x 3" sticky note, 1 blue 3" x 3" sticky note, 1 pink sticky note, several yellow 3" x 3" sticky notes, General Model for Natural Selection

Give instructions for the activity. Display **slide M**. Review the instructions and answer any clarifying questions.

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

*** Supporting Students in Engaging in Obtaining, Evaluating, and Communicating Information**

Students combine new information from the reading with text contained in the General Model for Natural Selection in order to explain the horseshoe crabs' telson or body armor.

If you did not distribute *Reading v1: Horseshoe Crabs—Ancient and Modern* or *Reading v2: Horseshoe Crabs—Ancient and Modern* previously, distribute it as soon as students ask for additional information about the horseshoe crabs, but not before they ask for it. Allow students to work in their groups to use the General Model for Natural Selection to explain a horseshoe crab body structure. As they work, circulate among the groups to ensure that each group member is participating and provide assistance as needed.*

Assessment Opportunity

Building towards: 12.A.2 Construct a scientific explanation for how natural selection acting over generations has caused organisms' body structures to change over time in response to changes in environmental conditions.

What to look and listen for

As you circulate among the groups while they work, listen for every student to participate. Conversations should refer to specific information about horseshoe crabs and/or specific parts of the General Model for Natural Selection.

Taken together, the written evidence on the sticky notes on the *Small Group Working Copy of Our General Model* should explain how and why the body structures of ancient horseshoe crabs have not changed much compared to modern horseshoe crabs.

- All the elements in the model should be addressed.
- Notes written on the model should refer to specific information from the reading or from their investigations in earlier lessons. General statements are not sufficient to explain this particular case.
- The "Because of this . . ." statements should describe clear and accurate cause-and-effect relationships.

See *Student Examples of Using General Model to Explain Body Structures* for potential examples. Keep in mind that student language will vary from what is shown in the examples. Using specific information is important, but the precise words used in student explanations are not. Students who thoroughly understand and can apply the General Model for Natural Selection will provide a detailed set of statements containing all the elements specific for the body structure of horseshoe crabs they chose.

What to do

If students are struggling to participate, assign them a particular model element to identify and describe from the *Reading v1: Horseshoe Crabs—Ancient and Modern* reading. Point out if they have missed using an element in the model. Provide support but do not provide answers to specific student questions. Rather, redirect them to the resources they have available and remind them that they have done this kind of analysis before with different cases in this unit. Allow them to proceed independently.

8. Share horseshoe crab explanations. 15 MIN

Materials: science notebook, Small Group Working Copy of Our General Model updated with horseshoe crab notes

Compare horseshoe crab explanations with another group. Display **slide N**. Pair up each small group with another; if the groups focused on different body structures (armor or telson), that would be ideal, but it's not necessary. Have

the groups use their science notebooks and models with horseshoe crab notes and compare their explanations, looking for similarities and differences and also any other noticings and wonderings. They can jot these ideas in their science notebook to share with the class.

Discuss what students noticed during the group sharing time. Have students share some of their similarities, noticings, and wonderings. If any major differences were noticed, facilitate a discussion to resolve those differences.

Suggested prompts	Sample student responses
Was the model able to explain why the body structures in horseshoe crabs have stayed the same over time?	*Yes, since the environment remained so stable, the body structures the horseshoe crabs had were already the most successful.*
How did the idea of mutations play into this explanation? Did mutations still happen?	*Yes, mutations must have happened over these millions of years. But, any mutations that made the horseshoe crab have different structures didn't get passed on to any offspring because those individuals didn't survive as well.*

Add any new insights to the Progress Trackers. Present **slide O**. Ask students to reflect on the question: *How does mutation help our model explain the comparisons in body structures we observe in ancient and modern organisms?* Have students update their Progress Tracker with any additional ideas that they think are important as well.

9. Navigation

5 MIN

Materials: None

Consider using the model to explain how body structure variations in modern whales are different from ancient whales. Say, *This is great, we've explained most of the examples we studied earlier. Let's quickly run through our final example.* Show **slide P** to show some of the large-scale differences between ancient and modern whales, then move to **slide Q** to focus on the differences in the type of teeth whales have.

Suggested prompts	Sample student responses
What do you notice about the skull of the ancient whales?	*Most ancient whales had teeth, and then there's a place in the fossil record where some have teeth and some have baleen.*
What about modern whales?	*There are some whales with baleen and some with teeth.*
Do you see any other differences between the modern whales?	*There are many different species, some are really large and some are smaller.*

Make connections between modern whale species and modern penguin species. Facilitate a discussion to surface the idea that the examples we've examined so far (horse toes and body armor or telson of the horseshoe crabs) seem to represent structures that are very similar between the modern species of horses and between modern species of horseshoe crabs. If we look at other organisms like these whales or the penguins we initially examined, there are many different species of organisms all with some body structures that are more similar to other species and some that are not so similar to other species. We want students to wonder if our model can explain why we have these differences in body structures in so many species.

Suggested prompt	Sample student responses
Wait, this seems a little different. So far, our General Model for Natural Selection has been able to explain how the body structures of ancient organisms may have changed over time to be what we see in modern organisms, but in the case of the whales it seems that there are two different kinds of teeth. Not only that, some whale species have sharp teeth and others have baleen, some are really large and some are smaller. Do you think the General Model can still help us explain how this happened?	*The different species of whales probably eat different things.* *Maybe they live in different environments with different kinds of prey available.* *Maybe some are faster swimmers or dive deeper.*

Say, *In fact, there are nearly a hundred different species of whales alive today and over a hundred more that are extinct. It might be difficult to explain them all, but this new problem—the idea that we have several species we want to explain—is also true of the penguins.* Show **slide R**. *There are fewer modern species of penguins than there are of whales, though, so let's use the case of the penguins to see if our model can explain the different species of penguins we see.*

ADDITIONAL LESSON 12 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.RST.6-8.10: By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.

In order to apply their General Model for Natural Selection to the cases of horses and horseshoe crabs, students need to obtain specific information about the environments, survival needs, and reproductive patterns of these ancient and modern organisms. Two grade-level appropriate texts are provided in this lesson, which students must read and comprehend independently and proficiently in order to make sense of what they are trying to figure out about how natural selection might cause the changes we see in organisms over long periods of time.

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?

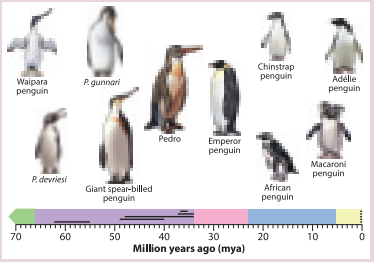
Previous Lesson

We updated our General Model for Natural Selection by adding mutation and then used it to explain differences in body structures in horses and horseshoe crabs over very long periods of time.

This Lesson

Putting Pieces Together

2 DAYS



We use what we know about natural selection and mutation to develop a model to show how modern penguins could be connected to one another and to ancient penguins through common ancestors. We construct possible explanations for how the penguins are connected and compare our explanations with others' and decide that limited evidence means there are many possible explanations.

Next Lesson

We will analyze sketches of embryos at different points in development for a variety of living things. We construct an argument and raise questions about how and why different organisms share so many physical structures in common in their embryological development. We share these arguments and questions as a class.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

13.A Use patterns in shared body structures resulting from natural selection and mutations to develop a model to explain how modern penguins are connected to ancient penguins.

13.B Construct a scientific explanation proposing relationships between all modern penguins and ancient penguins using the similarities and differences in accumulated body structure changes over time to estimate how relatively long ago they shared a recent ancestor.

What Students Will Figure Out

- When populations are in different environments for longer amounts of time, the accumulation of random mutations combined with natural selection leads to differences in body structures in each population.

- Penguins that have fewer differences in body structures shared the same environment (and a common ancestor) more recently than penguins that have more differences in body structures.
- The relationship between the amount of time populations have been separated and the number of differences in body structures can be used to propose which organisms shared the most recent ancestors and to propose explanations for how modern penguins are connected to ancient penguins.

Lesson 13 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Recall where we left off last time and consider how we can apply what we've figured out to explain how penguins are connected.	A-B	both rockhopper cards from *Data Cards for Modern Penguins and Pedro* from Lesson 1, both rockhopper strips from *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* from Lesson 2
2	20 min	**DEVELOP A MODEL FOR COMMON ANCESTRY USING MODERN PENGUINS** Facilitate a Consensus Discussion to begin to develop a model that makes connections between the 18 different species of modern penguins based on shared body structures.	C-D	*Data Cards for Modern Penguins and Pedro*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, 3" x 3" sticky notes, chart paper, markers, Penguin Timeline model from Lesson 1, 2 half sheets of paper and transparent tape for Word Wall
3	18 min	**MODEL HOW MODERN PENGUINS ARE CONNECTED** Work in small groups to organize the modern penguins by lines of descent, showing how they are connected to one another.	E	1 sheet of chart paper or butcher paper, poster from Lesson 3, sticky notes, markers, *Data Cards for Modern Penguins and Pedro*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*
4	2 min	**CONSIDER HOW TO ADD ANCIENT PENGUINS** Introduce the task students will continue next class.	F	

End of day 1

Part	Duration	Summary	Slide	Materials
5	5 min	**PREPARE TO ADD ANCIENT PENGUINS TO THE MODEL** Orient to the data strips for the ancient penguin fossils and think about how to use this information to connect to each group's existing model.	G	classroom consensus Penguin Ancestry Model, markers
6	10 min	**ANALYZE ANCIENT PENGUIN DATA AND ADD TO THE MODEL** Work in small groups comparing information from the ancient and modern penguin data strips to extend their model and create a hypothetical family tree.	H-I	*Extension Reading: Penguin Environments—Ancient and Modern* (optional), *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro, Data strips for ancient penguin fossils*, their own Penguin Ancestry model
7	12 min	**INDIVIDUALLY CONSTRUCT WRITTEN EXPLANATIONS** Use patterns in data we have examined and the processes and mechanisms we have figured out to write an explanation for our unit questions.	J	*Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation*
8	10 min	**GALLERY WALK** Record noticings and wonderings about other groups' Penguin Ancestry Models.	K-L	small-group Penguin Ancestry Model
9	5 min	**SHARE IDEAS FROM THE GALLERY WALK** Share similarities and differences in the groups' models and whether competing models were equally valid.	M	completed *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation*
10	3 min	**NAVIGATION: RELATED PHENOMENA** Recall other organisms where we were wondering about their ancestors.	N	Related Phenomena poster
				End of day 2
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 13, students are ready to read Student Reader Collection 4 and then respond to the writing exercise.		Student Reader Collection 4: *From Ancient to Modern Species*

Lesson 13 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Extension Reading: Penguin Environments—Ancient and Modern* (optional) • *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation* • completed *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation*	• both rockhopper cards from *Data Cards for Modern Penguins and Pedro* from Lesson 1 • both rockhopper strips from *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* from Lesson 2 • *Data Cards for Modern Penguins and Pedro* • *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* • 1 sheet of chart paper or butcher paper • poster from Lesson 3 • sticky notes • markers • *Data strips for ancient penguin fossils* • their own Penguin Ancestry model • small-group Penguin Ancestry Model	• 3″ x 3″ sticky notes • chart paper • markers • Penguin Timeline model from Lesson 1 • 2 half sheets of paper and transparent tape for Word Wall • classroom consensus Penguin Ancestry Model • Related Phenomena poster

Materials preparation (15 minutes)

Online Resources 

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Locate the following cards and strips from earlier lessons:

- Lesson 1: *Data Cards for Modern Penguins and Pedro*—You may want to either separate the two rockhopper species to hand out first or organize cards so those species are on top.
- Lesson 2: *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*—You may want to either separate the two rockhopper species to hand out first or organize the strips so those species are on top.
- Lesson 3: *Ancient Penguin Data Cards* and *Data strips for ancient penguin fossils*

Plan to have students work in the same small groups for this lesson as they had for Lesson 3, and have the posters they made in that lesson available for them to use again.

Have chart paper and markers ready for constructing a new classroom consensus model.

Have the Penguin Timeline model and the Related Phenomena poster from Lesson 1 available for reference.

Each small group will also need chart paper and scrap paper or sticky notes.

If you plan to use it, make one copy per student of *Extension Reading: Penguin Environments—Ancient and Modern* or be prepared to have students access it in their student editions.

Make a copy of either *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation* (scaffolded version) for each student. You may want to have a few extras of the scaffolded version available in case you decide in the moment that students should have that support.

Have two half sheets of paper and tape ready to add *common ancestor* and *species* to the Word Wall. Do not post this word until the class has developed a shared understanding of its meaning.

Lesson 13 • Where We Are Going and NOT Going

Where We Are Going

In the model that they develop in this lesson, students use what they know about natural selection and mutation to make the connection between increased time spent in different environments and a larger number of differences in body structures between species. They work their model back in time to think about how long ago the different species may have lived in the same environment (in which they would have shared a common ancestor).

Students will revisit the penguin data strips used in Lessons 2 and 3 to review the anatomical similarities and differences between various penguins living today and between them and penguins in the fossil record to reconstruct evolutionary history and infer the lines of evolutionary descent.

Where We Are NOT Going

The focus of this lesson is on drawing lines of descent back toward possible common ancestors, not on explaining the details of speciation events. Although students do deepen their understanding of what defines a species in this lesson, the larger set of mechanisms that drive speciation events are not developed until high school.

LEARNING PLAN FOR LESSON 13

1. Navigation

5 MIN

Materials: both rockhopper cards from *Data Cards for Modern Penguins and Pedro* from Lesson 1, both rockhopper strips from *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* from Lesson 2

Refer to the ideas we were thinking about last time. Present **slide A** and say, *We have looked at how traits in ancient species could have changed over time and resulted in the trait variations we now see in modern species. What did we add to our model that helped us support those explanations?* Sample student response might be: We added the idea of mutation—that's how new trait variations can appear, which then may or may not be passed on to their offspring and become more common in a population.

Say, *We figured out that our General Model for Natural Selection does help us explain these changes over really long periods of time, like with ancient and modern horses and ancient and modern horseshoe crabs. But we haven't yet considered how to explain something like the penguins, where we have eighteen species of those penguins today. However, it looks like there may have been fewer species at any one time in the ancient past than there are now, based on the fossil evidence we have. Let's see if we can explain where all eighteen of these modern penguins came from.*

Examine the number of shared body structures of the two species of rockhopper penguins. Show **slide B**. Say, *Let's consider two of the modern species that are really similar, for example, these two different rockhopper penguin species.*

Have students get back into the same groups they were in for Lesson 3. Distribute both rockhopper cards from *Data Cards for Modern Penguins and Pedro* from Lesson 1 and both rockhopper strips from *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* from Lesson 2 to each group. Say, *Take a minute with your group to study the cards and discuss what you notice as similarities and differences between these two species*. Bring the class back together to share ideas using prompts such as these.

Suggested prompts	Sample student responses
What is similar about these penguins?	*Crazy hairdos.* *Same height.* *They're both short.* *Shallow divers.*
When you looked at the data strips, how many body structures did you notice that they have in common?	*All but two.*
What is different about these penguins?	*Where they live.* *Nests made of different materials.* *Different nesting months.*

Suggested prompts	Sample student responses
We know that different environments can result in different outcomes in natural selection, but why in the world would these penguins have so many similarities in their body structures?	*Maybe they are related.*
What do you mean by that? Do you mean related like brothers and sisters?	*No, we know they don't have the same parents.* *Nor grandparents.* *But somehow they could be related, like distant cousins?* *They could have an ancestor in common somewhere back long ago.*

2. Develop a model for common ancestry using modern penguins.

20 MIN

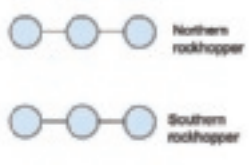
Materials: *Data Cards for Modern Penguins and Pedro*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, 3" x 3" sticky notes, chart paper, markers, Penguin Timeline model from Lesson 1, 2 half sheets of paper and transparent tape for Word Wall

Convene in a Scientists Circle to construct a model to visualize these potential relationships. Display **slide C**. Ask students to bring the *Data Cards for Modern Penguins and Pedro* and *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* with them as they move into a Scientists Circle, sitting near their group mates. Be sure the Penguin Timeline is clearly in view, and have space ready to display three other models you will develop as a class.

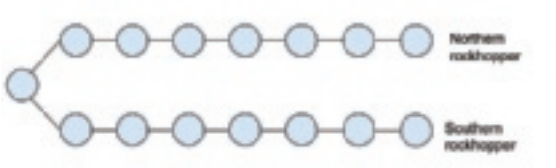
Point to the Penguin Timeline model where there are dots representing the modern penguins, including the northern and southern rockhopper penguins. Say, *Let's start a new model so we have a little more room to focus on just these two penguins for now.*

Add two dots one on top of the other to the far right side of a new piece of landscape-oriented chart paper and label them "Northern rockhopper" and "Southern rockhopper". Then draw one generation back from each dot as you explain that you are transferring some of the information from the first model.

Suggested prompt	Sample student response
The modern penguins are the dots on the far right, and for each of those, the dot connected by a line to the left is the generation before—their parents. If I wanted to show a generation before that—the grandparents of the modern penguins—what would I do?	*Draw another dot and line to the left of each parent dot.*

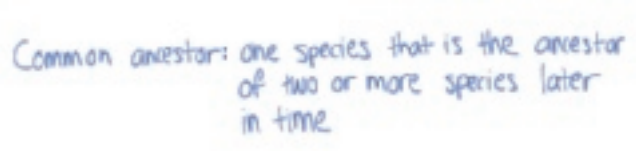


Suggested prompts	Sample student responses
These two species of penguins are descended from different ancestors for at least two generations back, and likely many more because we have records of them. So this doesn't really help me see how they could be related. What do you think?	*Maybe they are more distantly related.* *Go further back, draw even more ancestors.*
We can keep going back (draw more dots with lines between them), but this still looks like two different lines of ancestors. What do we need to be true for them to be related?	*The penguins from each different population would have had to come from the same parent at some point.* *You would have to connect the two lines of dots.*
How could we show that on this model?	*You could connect the two lines to a single dot, showing that's where they shared a parent.*
OK, then I should draw that dot between these lines to represent that shared parent right?	*Right.*
And let's just clarify, we're using these lines and dots on our model to represent these lines of descendants, but do we mean that all the differences between these species developed over only six or seven or eight generations?	*No, we saw with the horse toes that it takes many, many more generations than that for a population to change like that.* *We're representing hundreds of generations here, maybe thousands.*



Add *common ancestor* to the Word Wall. Say, *This is great—it shows how these two species were connected at some time in the past.*

Point to the dot that has two branches coming from it that you just added to the model and say, *There is a specific term for this group of organisms—this species—that were all living in the same place—a population—in the past and whose offspring became these separate species later in time. This is the* ***common ancestor*** *of the two species we just looked at.*



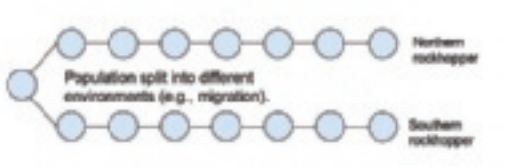
Write "common ancestor" on a half sheet of paper and define it as "one species that is the ancestor of two or more species later in time".

Continue this discussion about common ancestors using prompts such as these.

Suggested prompts	Sample student responses
Wait, let's think a little more about what these two branches mean. What was an important element in our General Model for Natural Selection that accounted for the changes we see between modern species and ancient species?	*They are in different environments.* *Changes to environments can lead to changes in traits because of natural selection.*
So what about the dot where they are connected? What does this common ancestor represent as far as the environment?	*There was a population in the past of at least two penguins of a single species and their offspring that lived in the same environment.*
So how could these populations have ended up in different environments where natural selection would have acted differently on their trait variations?	*Maybe they got in a fight.* *Maybe they moved away.* *Maybe some of them had to find a new place to live because there wasn't enough food.* *Maybe some of them were trying to escape predators.* *Maybe they got separated by some kind of natural disaster, like a flood.*

Say, *So if they moved away from each other, or if part of the group moved to a completely new area to live, the environments that each group would be living in would likely have been different. How can we show that on our model?*

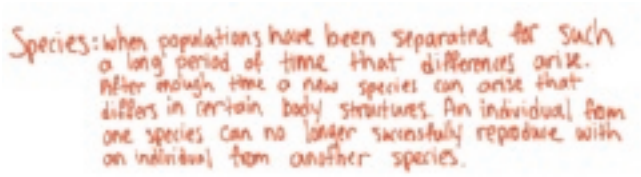
Take suggestions from the class for how to show differing environments (using either pictures, symbols, or labels, such as the example shown here).



Suggested prompts	Sample student responses
Based on what we know about how mutations and natural selection work together over time, what is happening to each of these lines of descendant populations over time?	*They randomly get mutations that could cause a change in a body structure.* *Depending on the environment some of the body structures might make it so individuals survive better and reproduce, passing on those structures.*
Do we think both of these separated populations will have the same mutations?	*No, mutations are random, so they will be different for the different populations.* *Also, not all the mutations will be beneficial, so depending on the mutation, the individuals may look more or less different depending on the environment.*

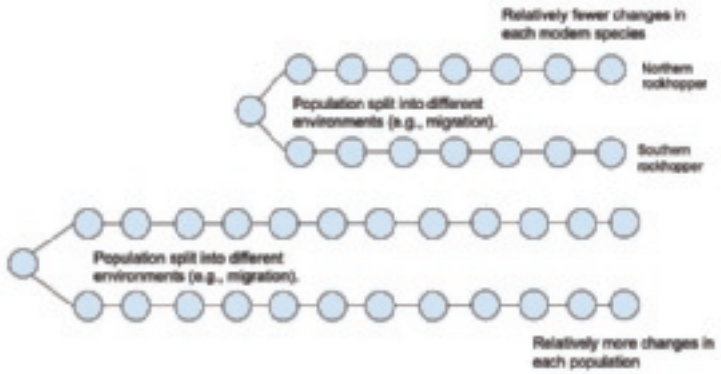
Suggested prompt	Sample student responses
So what does that mean about how similar these two populations are (point to the dots representing the ancestors from each species that just recently migrated) compared to how similar to each other individuals from these two populations are? (Point to the dots representing the modern penguin populations.)	*The two populations were more similar to each other right after they migrated.* *More changes accumulate over time, so the two modern penguin species have more differences from each other than they did right after separating from each other.*

Add the definition of *species* to the Word Wall. Say, *We've been referring to these different groups of penguins and other organisms as different species, and we know a population is made up of organisms of all the same species that live in the same location, but we haven't really stopped to define what a species is. Our model shows us that when these populations have been separated for such a long period of time that differences arise between them. Given enough time we end up with different species. Scientists know they are different species because they differ in certain body structures, but also, an individual from one species can no longer mate with an individual from the other species and have fertile offspring. Parents from two different species might be able to have one generation of offspring, but the offspring would not be able to have any offspring themselves. Too many trait changes have accumulated in each population for the parents to be compatible with each other.*

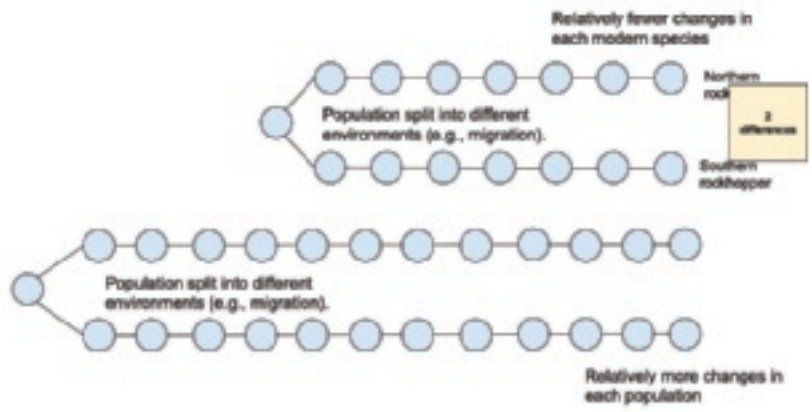


Draw and annotate a second model on the chart paper below the first as you continue this discussion.

Suggested prompts	Sample student responses
So I'm modeling another situation here. We're showing two groups of penguins that each split off from a common ancestor, but at different times in the past. Can you tell which group separated longer ago or farther back in time?	*The groups whose common ancestor is farther to the left separated longer ago than the rockhoppers we looked at first.*
With these two different situations where different populations migrated from each other, would we be able to tell which groups had been in the same environment and shared an ancestor more recently? What evidence could help us figure that out?	*We could see which modern species (plural) had more similarities or differences.* *The species that had a common ancestor longer ago would have more differences.*



Extend the model to examine some other relationships. Display **slide D**. Have students refer to the complete sets of *Data Cards for Modern Penguins and Pedro* and *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* and ask them to find another pair of penguins that share some similarities, yet have more differences between each other than the two rockhopper species have. Add a sticky note to the model next to the labels for the two rockhopper species to remind everyone how many differences (2) the rockhopper species had between them.

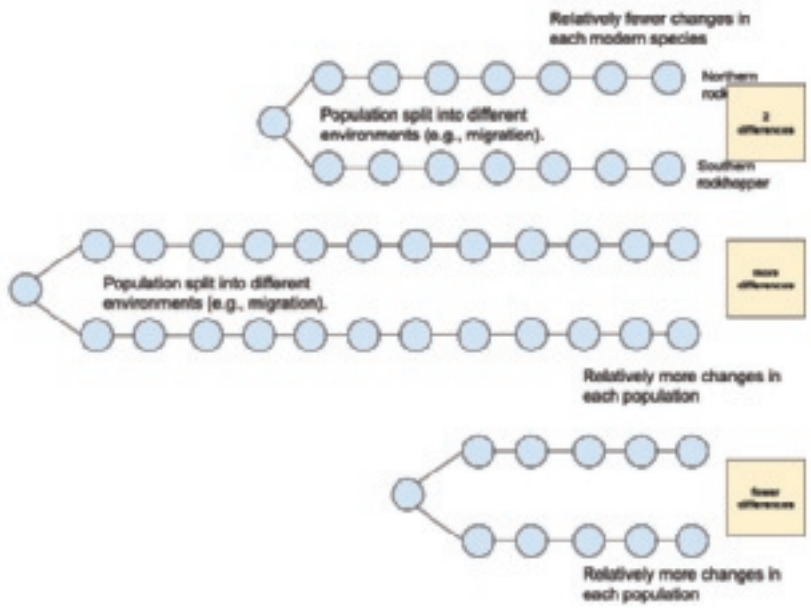


Give students a few minutes to work with their small group (while still in the Scientists Circle) to examine differences on data strips between other pairs of penguin species. Then invite students to share and discuss their findings using prompts such as these.

Suggested prompt	Sample student responses
Were there any two species of penguins you noticed that had more than two body structure differences between them?	*There are nine differences between the Adélie and the yellow-eyed penguin.* *There are six differences between the chinstrap and the yellow-eyed penguin.*

Suggested prompts	Sample student responses
What can you infer about a common ancestor for those species?	*A common ancestor for them must have been farther in the past because they have had more time to have so many differences develop.*
While you were comparing, did you happen to notice any two species of penguins that had fewer differences from each other than the rockhoppers had?	*The emperor and the king penguin differ in only one body structure.* *The Humboldt and the Magellanic only have one body structure difference, too.*
So what does that say about when those species shared a common ancestor?	*Their common ancestor was fewer generations back.*

Add to the model a way to represent these ideas, such as is shown here.



Suggested prompts	Sample student responses
This is a new idea we've developed. We are claiming that two different species of organisms can descend from the same ancestor. Could three different species do that?	*Yes, three different species could also share a lot of similarities.*
So if those three are all descended from the same ancestor species, if they separated at the same branching point in time, then they have all been in different environments for the same length of time. That makes sense if there are other penguins that share the same number of differences as these two rockhoppers. Did you find other penguins that also look pretty similar to the two rockhoppers and have as many or nearly as many body structures in common?	*Wait, the macaroni penguin doesn't have any differences in body structure from the southern rockhopper!* *The northern rockhopper and the Snares penguin also share all the same body structures!*
Wow, that is really interesting. How could we add these species to our existing relationships? What does this seem to say about who shared a more-recent common ancestor with the southern rockhopper?	*The macaroni penguin shares a more-recent common ancestor with the southern rockhopper penguin than the northern rockhopper.*
Could this also be true for the relationship between the Snares penguin and the northern rockhopper?	*Yes, the Snares penguins and northern rockhopper penguins have a more-recent common ancestor than the northern and southern rockhopper penguins do.*

Add other penguins to the existing model. Say, *OK, let's move this to another piece of chart paper—I don't want to lose these ideas and I think we need some more room.*

Move the model to a place where it is out of the way but still visible to all students. Put up the new piece of chart paper in a horizontal orientation and recreate the branch that has the two rockhopper species, leaving a little bit more room around it.

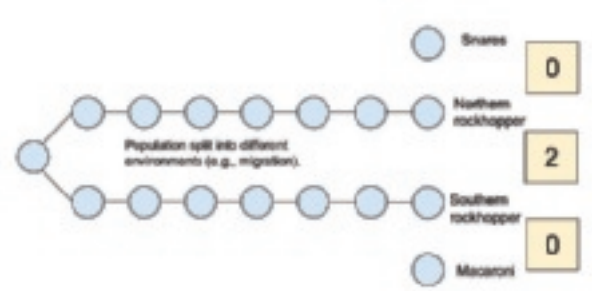


Suggested prompts	Sample student responses
Let's keep using these sticky notes to stay organized. How many differences do our data strips show between the Snares and the northern rockhopper?	*Zero.*
And what about the macaroni penguin and the southern rockhopper?	*Zero.*

Additional Guidance

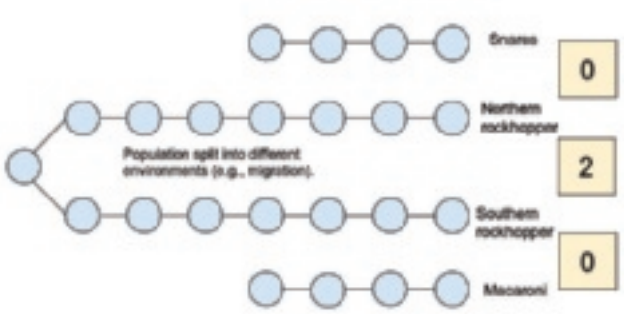
Students may need a reminder (since the last time we used these strips was in Lessons 2 and 3) that the data on these strips are a subset of hundreds of data points about body structures that scientists have compared for all these species. So, while our simplified data set may not show differences between some species, scientists have in fact noted enough differences to classify them as different species.

Add to the chart paper the names of the species of penguins and their dots and sticky notes indicating the number of differences.

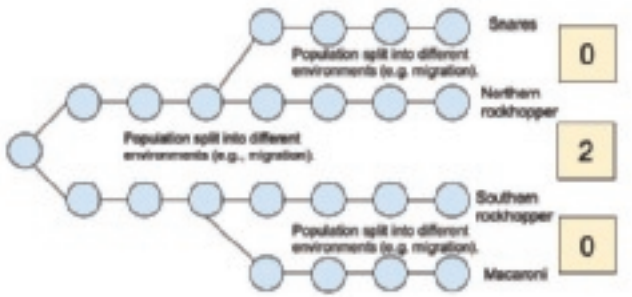


Suggested prompt	Sample student responses
There are fewer differences between these species and either rockhopper, so how far should we go back to where we represent their common ancestor with a rockhopper?	*Fewer generations.* *Maybe only four or five dots, so they're shorter than the rockhopper lines are.*

Draw the dots for the ancestors of the modern penguins just added to the rockhopper branch.



Suggested prompt	Sample student response
We have shown many generations going back in time. Now, how do we show they are connected by a common ancestor?	*We can draw a line connecting the two lines of descendants like we did for the rockhoppers.*



Suggested prompts	Sample student responses
OK, so we have a way to model these relationships when there are fewer differences between the modern species, but how might we show how a species with more differences can be added to this model?	*If there are more differences, there are more generations in the past that were separated in different environments.* *We will have more generations going back in time before they share a common ancestor.*
OK, let's try an example; someone give me an example of a species that has many differences with one we have on the model.	*There are seventeen differences in body structures between emperor penguins and southern rockhopper penguins.* *There are twelve differences between the Gentoo penguin and the macaroni penguin.*

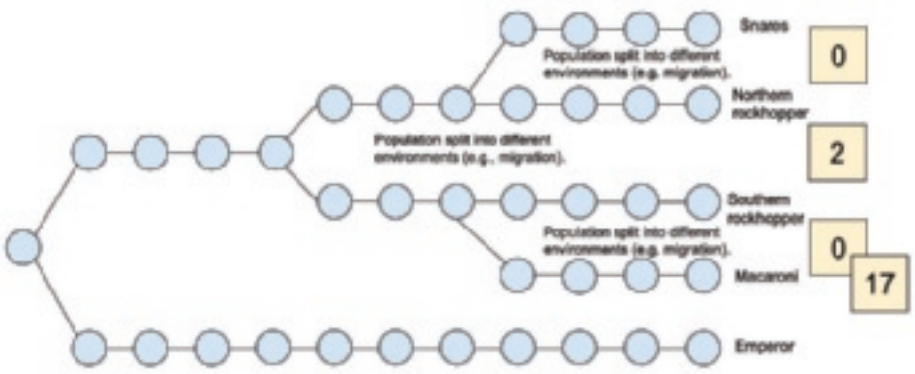
Additional Guidance

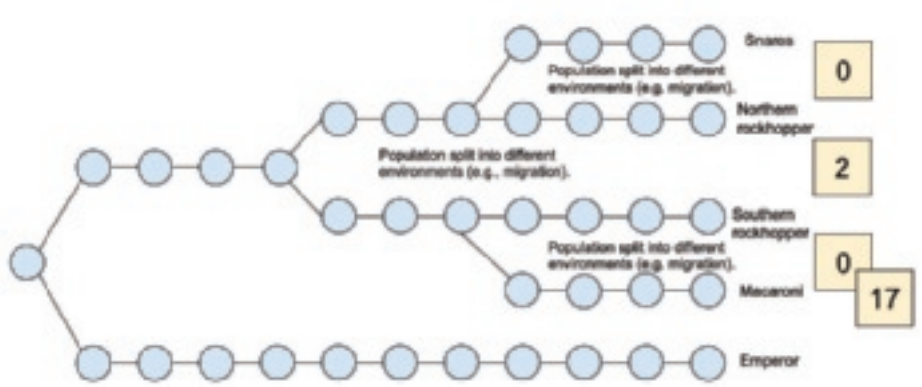
It does not matter which of the penguins students decide to try out here as long as there is a larger number of differences in body structures. See *Body Structure Similarities and Differences between Modern Penguin Species* for a quick check that students are accurately counting the number of differences as they suggest species.

Add to the model the name of a penguin species mentioned by students as well as a sticky note with the number of differences.

Say, *So really, this is nothing more than a pedigree, but for a really, really long timescale—and without the detail of exactly which parents mated like we used in Muscles Unit. In fact, we probably don't want to show dots because it could be mistaken for a pedigree depicting individuals, which could be misleading. And for this model we said these dots and lines actually represent hundreds or thousands of generations. We still want to show branch points to represent the common ancestors and branches to show the modern species, so we can simplify this by just using lines to represent the lines of ancestry.*

Draw a simplified version of this model under the version using the dots. This model is the classroom consensus Penguin Ancestry Model.





3. Model how modern penguins are connected.

18 MIN

Materials: 1 sheet of chart paper or butcher paper, poster from Lesson 3, sticky notes, markers, *Data Cards for Modern Penguins and Pedro*, *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*

Introduce the task. Show **slide E** and say, *OK, this is now your chance to see how our data strips that give us information about several different body structures found in all modern penguins can help us start to develop a "family tree" for how modern penguins might be connected to one another through common ancestors in the distant past.*

Ask students to bring their *Data Cards for Modern Penguins and Pedro* and *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* with them and allow groups to find space where they can build their own small-group, more-complete version of the Penguin Ancestry Model. Distribute posters from Lesson 3, new chart paper, markers, and sticky notes to each group.

Assessment Opportunity

Building towards: 13.A Use patterns in shared body structures resulting from natural selection and mutations to develop a model to explain how modern penguins are connected to ancient penguins.

What to look and listen for: Discussions and models should include the following ideas:

- Species of penguins with the least number of differences on the data strips (and the most similarities) will have lived in the same environment together most recently and will share a more-recent common ancestor than species of penguins with more differences on the data strips.
- Similarities and differences in body structures (on the data strips) are used as evidence to support the relationship between ancient and modern penguins. (Since there are a lot of missing data, there is more uncertainty in these explanations, so it is expected that these proposed relationships will vary greatly among groups.)

What to do: Remind students to use the sticky notes to record the number of differences they count between the species they are comparing. *Body Structure Similarities and Differences between Modern Penguin Species* is available for teachers to be able to quickly see if students are correctly assessing the number of differences in body structures

between each of the species. However, if students have miscounted, don't worry about correcting them; it is more important that they are using the ideas correctly and grouping the organisms based on the number of similarities and differences.

If students are struggling to participate, assign them a pair of species to analyze. Ask questions that require students to think about the patterns they are seeing in the data strips as they organize their Penguin Ancestry Model.

4. Consider how to add ancient penguins.

2 MIN

Materials: None

Navigate to the next class. Show **slide F**. Say, *OK, we have some ideas for how the modern penguins are connected to one another through common ancestors. Do you think this will help us explain how modern penguins are connected to Pedro and the rest of the ancient penguins? That is what we will investigate in the next class.*

Roll up posters with group names on them for use next time.

End of day 1

5. Prepare to add ancient penguins to the model.

5 MIN

Materials: classroom consensus Penguin Ancestry Model, markers

Orient students to the ancient penguin data strips. Display **slide G**. Remind students that we also have strips of data that were collected for structures from ancient penguin fossils. Ask, *How do you think we can use these data strips to help us determine how Pedro and the other ancient penguins might be connected to modern penguins?*

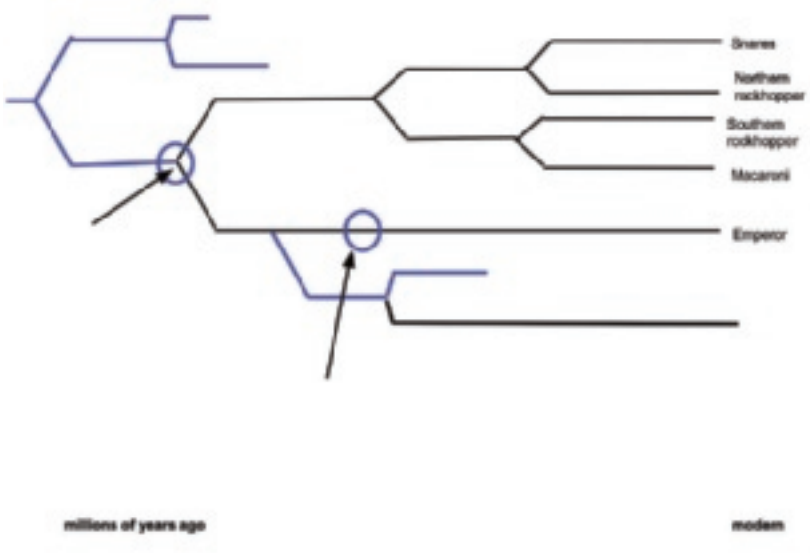
Allow students to share ideas about comparing the similarities and differences in body structures like we did to organize the modern penguins.

Refer to the classroom consensus Penguin Ancestry Model we developed as a whole class last time. Gesture to one of the main branches of the model and ask:

Suggested prompt	Sample student response
How could you determine which branch an ancient species might be more closely related to?	*The species would have more of the structures in common with the descendants in that branch than with the descendants in the other branch.*

Say, *It's possible too that maybe that ancient species is more closely related to the ancestors even further back. Maybe the ancient species was a common ancestor, or they were somewhere in the branch that is in a direct line of ancestors, or maybe in another branch, or maybe it's a branch that went extinct.*

Sketch more branches, including some with stubs that don't continue, onto the existing simplified branched sketch on the classroom consensus Penguin Ancestry Model. Point out or mark some locations on the sketch where students could consider placing the ancient penguin species, but be clear that you are adding these branches only to illustrate some ideas—these examples are not based on any patterns in the data.



Discuss the example ancient ancestor branches using prompts such as those that follow.

Suggested prompts	Sample student responses
Which of the example branches I added shows a species that went extinct the furthest back in time?	*(Students should indicate the line that ends first—the shortest line from the left.)*
What makes you say that species is extinct?	*Because the branch does not extend all the way to the right—to modern times.*
How do you know that was the species that went extinct the furthest back in time?	*Because the end of the branch stops the furthest to the left.*

6. Analyze ancient penguin data and add to the model.

10 MIN

Materials: science notebook, *Extension Reading: Penguin Environments—Ancient and Modern* (optional), *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*, *Data strips for ancient penguin fossils*, their own Penguin Ancestry model

Frame the task. Show **slide H** and say, *OK let's use the data to build a line of likely descendants and likely common ancestors for all penguins that we know of in the history of the world.**

Review these directions:

- 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.

*** Supporting Students in Engaging in Developing and Using Models**

Sometimes models include uncertain or less-predictable factors. Here, students use the data strips for modern penguins and what they know about mutations and natural selection in different

- Take photos or make quick sketches of the arrangements you try in your science notebooks 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.

Have small groups try many possible arrangements then come to a consensus among themselves on their arrangement. Refer to *Student Examples of Penguin Ancestry Model* for guidance about possible student models.

environments to develop their Penguin Ancestry Models to include ancient penguins even though there are fewer body structures to compare due to the limited fossil evidence.

Additional Guidance

Students may be frustrated because there is so little data. Reassure them that making sense of the data we do have is most important, and they should use what they do know to make predictions about possible connections they are less sure about.

You also may notice that groups struggle to agree on the best arrangement. If so, remind students to capture photos or make sketches of arrangements they try. That way, if any students want to use a different arrangement than the group's consensus for the next, individual task they have a reference to use.

Share ideas with the whole class about the small groups' Penguin Ancestry Models. Show **slide I** and give students a moment to think about the following prompt: *What were some parts of the Penguin Ancestry Model you were more certain about than others*?

Allow students to share their ideas with the whole class and accept all responses.

Validate that there is a lot of inference here, but it does seem like we have really common ways of explaining connections over time that we should see in everyone's model, and these models seem like they could help us answer our original questions.

Alternate Activity

Extension opportunity: If you have students who are curious about the environmental factors that influenced changes in the ancient penguins millions of years ago, *Extension Reading: Penguin Environments—Ancient and Modern* is provided. You might also choose to assign this reading as a home learning opportunity. You could also ask students to use these extra details about the environment to support their work on *Version 1: Ancient and Modern Penguin Explanation*.

7. Individually construct written explanations.

12 MIN

Materials: *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation*

Respond individually to prompts to make connections between modern and ancient penguins. Show **slide J**. Give each student a copy of either *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation*.*



Say, *Now you will get a chance to write your own explanation using the model you developed with your small group. Answer these prompts as completely as you are able using what you figured out as you created your Penguin Ancestry Model.*

Consider the Penguin Ancestry Model your small group created as well as the General Model for Natural Selection. What does your model show in terms of answering these questions?

- Where did all the different species of modern penguins come from?
- Where did all the ancient penguins go?
- How could things living today be connected to the things that lived long ago?

Assessment Opportunity

Building towards: 13.B Construct a scientific explanation proposing relationships between all modern penguins and ancient penguins using the similarities and differences in accumulated body structure changes over time to estimate how relatively long ago they shared a recent ancestor.

What to look for: Students' written responses include explanations that use

- natural selection in differing environments as well as the accumulation of mutations to explain the differences in body structures they observe,
- the relationship between differences in body structure and lengths of time to justify which penguin species share recent ancestors, and
- the relationship between differences in body structure and lengths of time to claim a species of penguin was either a direct ancestor of a certain modern penguin or group of penguins or that a species of ancient penguin went extinct.

What to do: If students are struggling to begin, encourage them to focus on how just two species of penguins are connected by a common ancestor, and then they may branch out from there. Make sure students are consulting their Penguin Ancestry Model as well as the General Model for Natural Selection the class developed previously. If you have given students *Version 1: Ancient and Modern Penguin Explanation* and you notice they are not supporting their claims with evidence and reasoning, you may choose to provide them a copy of *Version 2: Ancient and Modern Penguin Explanation* for additional scaffolding. If students are struggling to put their ideas in words, encourage them to include a drawing or model as part of their response to help clarify their writing.

*** Attending to Equity**

Universal Design for Learning: Students will use various forms of *expression* to transfer into a written explanation the ideas they developed while creating their Penguin Ancestry Model. *Version 2: Ancient and Modern Penguin Explanation* is provided for students you think would benefit from additional scaffolding. Also, if students are struggling to put their ideas into words, encourage them to include a drawing or model sketch as part of their response to help clarify their writing.

8. Gallery Walk

10 MIN

Materials: science notebook, small-group Penguin Ancestry Model

Compare models in a gallery walk. Show **slide K.** Arrange the group models around the room such that there is enough space for at least one group to visit and reflect, at at time. Explain to students that with their group they will visit two other groups' models and compare their Penguin Ancestry Models to their own group's model. Have them set up their notebook with a T-chart to record similarities and differences as shown on the slide.

Once students have their table created, display **slide L** to show the other questions they should write about and discuss while doing the gallery walk.

- 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?

9. Share ideas from the gallery walk.

5 MIN

Materials: science notebook, completed *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation*

Review what they noticed during the gallery walk. Show **slide M**. Have students share some of their noticings and wonderings they recorded in their notebook. If any major differences were noticed, facilitate a discussion to resolve those differences.

Suggested prompts	Sample student responses
What were some of the similarities and differences you noticed in the groups' models you compared?	*All the models had branching.* *The branching was different in different groups.* *Some of the models had ancient species going extinct.* *Some models had ancient species changing into modern species over time.*
It sounds like there were a lot of differences. Does this mean some of the models were more valid than others?	*Not really, they were all valid since there wasn't much data to go on. Everyone had to make some best guesses.*
What would you need to help you be more confident about your proposal for how these ancient penguins are connected to modern penguins?	*If we had more data, we would be able to see more similarities and differences between species, which would help us see which of the branches and groupings would be more or less likely.*

Give students a chance after this discussion to make any updates to their written explanations on *Version 1: Ancient and Modern Penguin Explanation* or *Version 2: Ancient and Modern Penguin Explanation*.

10. Navigation: Related Phenomena

3 MIN

Materials: science notebook, Related Phenomena poster

Direct students to the Related Phenomena poster. Display **slide N**. Say, *We have figured out how natural selection, mutation, and migration can explain how we currently have eighteen species of penguins today that are connected through lines of descent from ancient penguins, like Pedro or W. tuatahi. We can trace these penguins back to their ancestors, but one of the questions on the DQB was could we trace back other organisms to their ancestors?*

Ask students, *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?*

Listen for students to say things like insects, other birds, dinosaurs, other mammals (beyond horses and whales). Say, *Wow, that sounds exciting! Let's come back next time and gather more information about these other cases of organisms we could try and trace back to their ancestors.*

SCIENCE LITERACY: READING COLLECTION 4

From Ancient to Modern Species

1 **Settling a Friendly Debate**
2 **Extra Bones? Nope!**
3 **A Sheep Named Dolly**
4 **Unique Humanity**

Literacy Objectives

- ✓ Summarize key points made in a reading selection.
- ✓ Distinguish gradual versus sudden change over time.
- ✓ Organize related details about evolution and genetic technologies.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 11–13.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a well-reasoned paragraph in response to the reading.

Instructional Resources

Student Reader



Collection 4

Science Literacy Student Reader, Collection 4
"From Ancient to Modern Species"

Exercise Page



EP 4

Science Literacy Exercise Page
EP 4

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 11: Can we use our General Model for Natural Selection to explain changes over time in green anole lizards?
- Lesson 12: Can our model explain changes over really long periods of time?
- 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?

Standards and Dimensions

NGSS

Disciplinary Core Ideas: LS4.A: Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record, enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. (MS-LS4-2)

LS4.C: Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. (MS-LS4-6)

Science and Engineering Practices: Obtaining, Evaluating, and Communicating Information; Engaging in Argument from Evidence

Crosscutting Concept: Stability and Change

CCSS

English Language Arts

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

WHST.6-8.2: Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization. No Core Vocabulary terms are highlighted in the text of Collection 4.

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

bioethicist **clone** **dominant genes**
gene therapy **random** **recessive genes**
speciation

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

Exercise Page



EP 4

2. Preview the assignment and set expectations.

(Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Natural Selection and Common Ancestry unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *There are four readings in Collection 4.*
  - *In the first, you'll read a pair of fictional letters. One is from a student asking a scientist whether evolution occurs fast enough to be observed in a human lifetime, and the other is the scientist's reply.*

- *Second, you'll read an article describing a scientific investigation into the age-old question "How did giraffes get their long necks?"*
- *The third reading is an article describing the first-ever cloned mammal and exploring the ethical considerations of human cloning.*
- *The final reading is an op-ed essay answering the question "What makes humans different from other species?" Whether you agree with the author's point of view or not, the question is fascinating!*

- Distribute Exercise Page 4. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a well-structured paragraph about one of the big ideas discussed in this collection or earlier in the unit.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What point did the biologist make in their letter using the example of green and brown anoles in Florida?	*that sometimes people can observe rapid changes in a species*
How does the number of neck bones in a giraffe compare to the number of neck bones in other large grazing animals?	*They all have the same number—seven.*
What is a question an ethicist would ask about cloning?	*Should humans be allowed to clone themselves?* *Is human cloning ever okay?*

Suggested prompt	Sample student response
What methods do humans use to accumulate knowledge and pass it on to future generations?	*language and writing*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
What could you say to Taylor and Rene about evolution, based on our discussions of the green and brown lizards from Lesson 11?	*that, sometimes, species evolve very quickly so that people can see the changes in a brief number of years*
What are some effects of mutations on the necks of the species in the evolutionary tree that includes giraffes?	*Some mutations caused the neck bones to change shape, getting longer.* *Mutations caused some species to evolve short necks, some to evolve medium-length necks, and some to evolve very long necks.*
How much time separates ancient relatives of giraffes from modern giraffes—years, tens of years, thousands of years, millions of years, or billions of years?	*millions of years*

- Refer students to the Exercise Page 4. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The expectation for this assignment is that you will write a well-constructed paragraph demonstrating your understanding of the readings in this unit.*
  - *After choosing your topic, write a strong topic sentence. If your topic sentence sounds weak or uninspiring, choose another topic from the list.*
  - *If it helps, before composing your paragraph, draw a tree map graphic organizer to plan your topic sentence and details.*
  - *The important criteria for your work are that you show understanding of the science of this unit, use scientific vocabulary accurately, and address the theme of stability and change.*
- Explain to students that their paragraphs should use language that signals stability or change, such as *slow*, *rapid*, *gradual*, *sudden*, or *evolve*.
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page



EP 4

4. Facilitate discussion.

Facilitate class discussion about the reading collection and writing exercise. The first of four readings presents an exchange between a student and a biologist. Use this as a teachable moment to reinforce the idea that scientific literacy includes knowing where to find reliable answers to students' science questions.

Student Reader



Collection 4

Pages 36–44 Suggested prompts	Sample student responses
What is the general purpose of the first selection, "Settling a Friendly Debate"?	*to explain how much time evolution by natural selection usually takes and sometimes takes*
If you had to summarize the scientist's answer in one sentence, what would it be?	*Evolution resulting in a new species usually takes millions of years but sometimes can happen over a few years.*
What did the author mean by saying that changes to species are a "random" process?	*that it is a matter of chance, like tossing a dice, and not a matter of choice on the part of the species*
What contextual clues helped you understand what the professor meant by "speciation"?	*I really wasn't sure when I read it, but as I read the rest of the letter, I could infer that it means entirely new species are forming.*
What is the general purpose of the second selection, called "Extra Bones? Nope!"?	*It explains that by looking at the fossil bones of ancient species, you can make inferences about how modern species evolved.*
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first article reveals that it usually takes about a million years for a new species to evolve. The second article details how it took about seven million years for the long neck bones of giraffes to evolve.*
How would you summarize the main conclusion of the investigation described in this article?	*Modern giraffes have long necks because, over millions of years, the seven bones in their necks evolved to change shape, becoming much longer than they are wide.*
What are some other species' traits that you could investigate to learn more about how they evolved?	*an elephant's trunk* *an octopus's eight tentacles* *a raccoon's fur coloring to look like a mask around its eyes* *snakes that can move very fast on land without legs*
What is the general purpose of the third article, "A Sheep Named Dolly"?	*It explains what cloning of mammals means and discusses questions of right and wrong related to whether humans should be cloned.*
How might a bioethicist address the topic of gene therapy?	*by helping patients decide if they want to have the therapy or helping a hospital decide what types of gene therapy to develop*

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

EXTEND—Students will likely be intrigued by Dolly the cloned sheep and cloning in general. Provide links to videos that describe the scientific discovery and related controversy. Have students write and share 30-word social media posts to summarize the content of each video. If students search for videos themselves, remind them to be discerning of the sources they encounter.

Pages 36–44 Suggested prompts	Sample student responses
Recall the scene in the Preface about the teen who wants to be taller. What questions might a bioethicist ask about a gene therapy to make people taller?	*Are you willing to take the risk that the gene therapy might have unwanted side effects?* *What if everyone who wanted it got the same gene therapy to get taller?* *People grow the most when they are kids and teens. Do you think a teen should be allowed to choose having gene therapy?* *What about all the people who have diseases that make them sick or die young? Would it be better to develop gene therapies for them first?*
What is the general purpose of the fourth article, "Unique Humanity"?	*It tries to persuade the reader that humans differ from all other species in our control of our bodies, our environment, and knowledge.*
How would you summarize the author's claim about why humans are unique?	*The author claims that only humans collect knowledge, record it, and preserve it for future generations.*
If humans can alter their traits, such as through gene therapies, how does that change the impact of natural selection?	*It would reduce the effects of natural selection, allowing humans to determine which traits carry forward.*

5. Check for understanding.

Evaluate and Provide Feedback

Use the rubric provided on the Exercise Page to supply feedback to each student.

For Exercise 4, students should, from a chosen topic, write a well-constructed paragraph about evolution and genes, gene therapy, or technology. Students' paragraphs should be organized around the crosscutting concept of "Stability and Change," including gradual or fast changes in organisms and species. Look for supporting details from the readings in Collection 4 but also from the Preface and any other parts of Unit 6. Examples of topic sentences follow, though students' versions are likely to be varied.

- Extinction is the end of adaptation of a species.
- It generally takes millions of years for a new species to emerge from its ancestors but not always.
- Natural selection may not involve humans, but artificial selection always involves humans.
- For the present, gene therapy research should be focused on curing deadly diseases, not helping people get taller.
- The human species may appear very different a million years from now than it is today.

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?

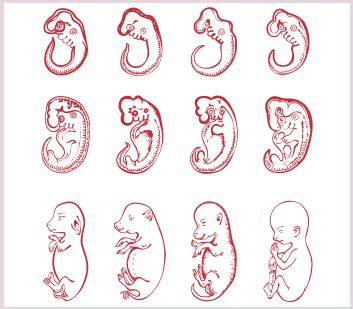
Previous Lesson

We used what we know about natural selection and mutation to develop a model to show how modern penguins could be connected to one another and to ancient penguins through common ancestors. We constructed possible explanations for how the penguins are connected and compared our explanations with others' and decided that limited evidence means there are many possible explanations.

This Lesson

Investigation

2 DAYS



We analyze sketches of embryos at different points in development for a variety of animals, including a chicken, a turtle, a rabbit, and a human. We construct an argument and raise questions about how and why different organisms share so many physical structures in common in their embryological development. We share these arguments and questions as a class.

Next Lesson

We will identify questions from our DQB that we can now answer. We will celebrate all that we have learned in this unit and across the school year. We will spend time identifying the questions that we were not able to answer and will build a new DQB of these questions. We will create a plan to answer some of the questions on our own and during the next school year and beyond.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

14.A Analyze and interpret sketches of different species at different stages of embryological development to identify similarities and differences (patterns) in physical structures not evident in the fully formed anatomy.

14.B Outline a scientific argument for how new model ideas or application of old models could explain and/or ask questions based on patterns in sketches of the physical structures apparent in different species at different stages of embryological development emphasizing new ideas about how different species may be connected.

What Students Will Figure Out

- Early in development, there are similarities in the structures that make up different organisms, including both egg-layers and mammals. These similarities in structures are not always evident later in development.
- Similar structures early in development point to similar processes responsible for growth and development for different organisms.

Lesson 14 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	3 min	**NAVIGATION** Take stock of what we have figured out about connections between organisms and identify the organisms on the Related Phenomena poster from Lesson 1 as ones we have yet to explain.	A-B	Related Phenomena poster from Lesson 1
2	10 min	**USE A NEW MODEL TO MAKE A PREDICTION** Use a model of what an embryo is to make a prediction about what similarities and differences in physical structures we would expect to see in two different egg-laying animals.	C-G	
3	24 min	**PREPARE FOR AN INVESTIGATION AND ANALYZE AND INTERPRET DATA ON EGG-LAYERS** Analyze embryological sketches of egg-laying organisms to look for similarities and differences between organisms.	H-O	*Egg-Laying Embryos*, 8 different-colored pencils
4	8 min	**PREPARE FOR AN INVESTIGATION AND ANALYZE AND INTERPRET DATA ON NON-EGG-LAYERS** Analyze embryological sketches of non-egg-laying organisms to look for similarities and differences between organisms.	L-M	*Live Birth Embryos*, 8 different-colored pencils
				End of day 1
5	8 min	**COMPARE AND INTERPRET DATA ON NON-EGG-LAYERS** Compare with a partner similarities and differences of physical structures in the embryo development of non-egg-laying animals.	N	completed *Live Birth Embryos*

Part	Duration	Summary	Slide	Materials
6	15 min	**CONSTRUCT ARGUMENTS AND ASK QUESTIONS** Using comparisons of sketches of different stages in embryo development, construct an argument for new model ideas and connections between model ideas to explain patterns in the data.	O	*New Ideas and Questions Connected to Embryo Comparisons*
7	22 min	**SHARING ARGUMENTS AND QUESTIONS** Share arguments for new model ideas and/or application of old model ideas to help explain the patterns we uncovered in this lesson and share new questions this raised.	P	completed *New Ideas and Questions Connected to Embryo Comparisons*

End of day 2

Lesson 14 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Egg-Laying Embryos* • science notebook • *Live Birth Embryos* • completed *Live Birth Embryos* • *New Ideas and Questions Connected to Embryo Comparisons* • completed *New Ideas and Questions Connected to Embryo Comparisons*	• 8 different-colored pencils	• Related Phenomena poster from Lesson 1

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Have the Related Phenomena poster in a visible location for the class.

Two versions of the non-egg-laying (live-birth) embryos are provided for you to use. Choose one of these to use with your classes. The default handout is *Live Birth Embryos*. The alternate handout, *Alternate: Non-egg-laying Embryos*, includes three animals, but not humans.

Online Resources

Make 1 copy of each of the following for each student:

- *Egg-Laying Embryos*
- *Live Birth Embryos* (or the alternate) *Alternate: Non-egg-laying Embryos*
- *New Ideas and Questions Connected to Embryo Comparisons*

Lesson 14 • Where We Are Going and NOT Going

Where We Are Going

The lesson has an embedded assessment that targets NGSS PE MS-LS4-3. That PE is targeted at analyzing displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.

The clarification statement for this PE is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures. The assessment boundary for this PE limits comparisons of embryological development of different organisms to a macroscopic analysis of the anatomical structures.

Where We Are NOT Going

Though we are not trying to definitively argue for shared common ancestors across the different animal species that students analyze in this lesson, we are looking for students to raise that possibility in the draft ideas that they document or share and/or in the questions they raise by the end of the lesson. In addition, we are not trying to definitively argue for shared cellular processes (e.g., differentiation) or shared genetic information across species. However, this idea is likely to be one you see students starting to suggest in their draft ideas that they document or share and/or in questions that they raise. Both of these sets of draft ideas and questions will lay a strong foundation for delving more deeply into target DCIs in high school related to macroevolution, DNA, and cellular processes.

LEARNING PLAN FOR LESSON 14

1. Navigation

3 MIN

Materials: Related Phenomena poster from Lesson 1

Take stock of what we have figured out about connections between organisms. Display **slide A**. Say, *Wow, we have made a lot of connections in our unit about different organisms that are living today and were living long ago. If we look back at our Related Phenomena poster, what are some types of organisms we have listed that we haven't yet investigated to look for the kind of connections we discovered in penguins, whales, horses, and horseshoe crabs?* Cue students to look back at that poster and share some examples.

Continue the discussion by saying, *Up to this point in the unit, we have used heritable physical trait variations as a key line of evidence for determining how closely related one species of penguin might be to another.* Display **slide B** and ask, *If we had sufficient data about some of these modern and ancient organisms listed on our poster, do you think we might find similar connections between them?* Accept all answers. Tell students, *Questions regarding how modern and ancient types of organisms might be connected are ones that scientists began to consider even before genetic material had been discovered in the scientific community. Before chromosomes and genes and alleles were understood, physical structures in living things and in fossils were the only line of evidence scientists had for exploring these types of connections. This led scientists to consider whether similarities and differences in physical structures between organisms even before they were born could give them clues about our lesson question, "What do the patterns in embryo development tell us about how things living today could be connected to the things that lived long ago?"*

2. Use a new model to make a prediction.

10 MIN

Materials: None

Introduce what an embryo is. Display **slide C**. Say, *An animal before it is born is referred to as an "embryo". Let's think about what an embryo is in terms of these two types of organisms: a penguin and a green anole. In both cases they start out as a single, microscopic, fertilized egg cell inside a large shell packed with food—an egg yolk and egg white. Then that single cell develops over many days into a multicelled organism made of trillions of cells. The length of time that development takes is different for these two organisms. For penguins it takes between 65 and 75 days for it to hatch, while for green anoles it takes between 35 and 49 days. When the baby is fully developed it hatches out of its shell.*

Generalize this process to other animals. Say, *This is a process that other animals besides egg-layers go through too, though in these cases they are not in a shell but in the womb of the mother.* Display **slide D**. Direct students to take a minute to look through the related data on the slide.

Continue by saying, *Since all these organisms share this process of going from a fertilized egg to a fully developed baby before being born or hatched, scientists wondered whether additional similarities and differences in the physical structures they notice as the animal goes through this process could also tell them something about our driving question: "How could things living today be connected to the things that lived long ago?" When scientists looked at the physical structures in embryos of living things, they were surprised at some of the similarities and differences they saw that were not as apparent in*

adults or babies. Let's analyze some of the data for these animals ourselves. But first, let's make some predictions about what might be similar or different if we were to look at embryos of two different types of animals.

Display **slide E**. Say, *Turn and talk with a partner. What physical similarities and differences do you predict you might see between a newly hatched chicken and a chicken embryo midway through its development, about 10 days after fertilization?* Give students 1.5 minutes to discuss this question with a partner.

Then display **slide F**. Say, *Now discuss a similar question for the salamander. What physical similarities and differences do you predict you might see between a newly hatched salamander and a salamander embryo midway through its development, which would be 65 to 70 days after fertilization?* Give students 1.5 minutes to discuss this question with a partner.

Invite a few students to share their or their partner's ideas with the class.

Suggested prompts	Sample student responses
What are some of the similarities you and your partner predicted you would see between the embryo and the hatched baby chicken or anole?	*The embryo will look like a very small version of the hatched chicken or anole with many of the same physical structures, just smaller.*
What are some of the differences you and your partner predicted you would see between the embryo and the hatched baby?	*The embryo might not have all the physical structures that the hatched organisms does, like the embryo might not have feathers or scales yet.* *Some of the physical structures might be harder to distinguish or see in the embryo.*

Compare predictions about both embryos. Display **slide G**. Read through the question and tell students you want to take a class poll:

How do you think the embryos of these organisms would compare to each other midway through their development?

Then read through the three possible choices:

A. They would have just as many physical structures in common as embryos as they do when they hatch.

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 whey they are born.

Take a poll and accept all responses.

3. Prepare for an investigation and analyze and interpret data on egg-layers. 24 MIN

Materials: *Egg-Laying Embryos*, science notebook, 8 different-colored pencils

Introduce the embryological data available to analyze. Display **slide H**. Say, *Before we begin analyzing the embryological data, let's set up a page in our notebook. Let's first record the question we are trying to answer through analyzing these data, which will be in the form of different sketches of embryos.*

Suggested prompt	Sample student response
What are we hoping to figure out by looking for similarities and differences between embryos of various organisms at different points in time between fertilization and birth?	*We are trying to figure out how things alive today are connected to things alive long ago.*

Set up notebooks. Write the student response as a question on the whiteboard or in a space where students can see it. Tell students to record this question at the top of a new blank page in their notebook. Then tell them to create on that page a table like the one on **slide H**, being sure to leave enough room so they can record what they find during their analysis of the different embryo sketches.

Orient to the scale of the organism sketches. Distribute *Egg-Laying Embryos* to each student and 8 different-colored pencils or crayons to pairs of students.

Orient the students to the sketches. Say, *You have sketches there from a turtle, a chicken, a salamander, and a fish. If you look at the sketches of the animals right before hatching, would you say they are to scale, or represent the actual size of the animals?*

Students should say that, no, the sketches are much smaller than the actual animal.

Continue by saying, *None of these sketches are drawn to scale or are the actual size of the organism at those different stages of the process. When these sketches were made, scientists were more concerned with representing the physical structures than the actual size of the animal. As a result, for the earlier stages, the sketches have actually been scaled up in order to better represent other differences and similarities in their physical structures.*

Review what we are looking for. Display **slide I**. Tell students, *So far in this unit, when we were looking for connections between animals, one thing we would look for was similarities in physical structures. Patterns in those similarities led us to consider not just where living things today come from but which living things today may have shared common ancestors more recently in the past than others. When scientists started to compare embryos, this led them to have new ideas about how living things might be connected to each other. Take a few minutes on your own to analyze the sketches on Egg-Laying Embryos. Look for similarities and differences between the different sketches and highlight or annotate these using the colored pencils or crayons.*



Give students 5 minutes to individually analyze and annotate the different sketches.

Assessment Opportunity

Building towards: 14.A.1 Analyze and interpret sketches of different species at different stages of embryological development to identify similarities and differences (patterns) in physical structures not evident in the fully formed anatomy.

What to look and listen for: Listen for students to say something like the following:

- In the early phases of development, there are many similarities in the structures of each of the organisms.
- It is difficult to tell the organisms apart early in development, but by later in development their physical structures begin to look more different.
- All the organisms early in development have a tail-like structure, an eye, an earhole or ear, and nubs where arms, fins, or legs will eventually develop.

What to do: If students struggle making comparisons between the different structures found in the embryo sketches, encourage them to think of an external structure that they know all the animals have, such as eyes. Then encourage them to look for evidence of this structure in the different sketches and color code it. Then prompt them to look for other common structures and color code if it is found in all or some of the embryo sketches. You will have a second opportunity to assess students in the following step.

Analyze and interpret the data with a partner. Display **slide J**. Say, *Now work with a partner to compare what you both identified for the similarities and differences in the physical structures of the different animals. Record these in your notebook in the table you set up.* You may wish to reproject **slide H** with the data table for students.

Give partners 8 minutes to compare their findings and fill in their data tables.

Bring the class back together. Display **slide K** and ask, *What did you and your partner discuss?*

Suggested prompts	Sample student responses
What were some similarities you discovered in the physical structures of the organisms at different stages of development?	***Note:*** *Some examples are included here, but these are not exhaustive. Accept all student responses, encouraging them to explain the similarities specifically for each stage of development.* *Early in development, all four looked very similar. They each have a spot that looks like an eye and an ear hole.* *They each have five little nubs, or bumps where arms and legs and the stomach grow.* *They all have a tail.* *The tail looks like it has ridges on it, like where the backbone will be?* *Later in development, the fish and salamander look more similar to each other and the chicken and turtle look more similar to each other.*
What were some differences you discovered in their physical structures at different stages of development?	***Note:*** *Some examples are included here, but these are not exhaustive. Accept all student responses, encouraging them to explain the differences specifically for each stage of development.* *Later in the development, all four animals look different from each other.* *By the time the animals are right before hatching, they all look very different from each other and more similar to adult animals.*

4. Prepare for an investigation and analyze and interpret data on non-egg-layers. 8 MIN

Materials: science notebook, *Live Birth Embryos*, 8 different-colored pencils

Set up notebooks. Display **slide L**. Tell students to create a table in their notebook like the one on **slide L** for non-egg-layers (live-birth animals), being sure to leave enough room so they can record what they find during their analysis of the different sketches.



Display **slide M**. Distribute *Live Birth Embryos*. Give students 5 minutes to individually analyze and annotate the different sketches.

Additional Guidance

Live Birth Embryos includes sketches of a human embryo in addition to other mammals: a calf, a rabbit, and a pig. This is the recommended handout to use. There is an alternate handout, *Alternate: Non-egg-laying Embryos*, without the human embryo sketches, if needed.

Assessment Opportunity

Building towards: 14.A.2 Analyze and interpret sketches of different species at different stages of embryological development to identify similarities and differences (patterns) in physical structures not evident in the fully formed anatomy.

What to look and listen for: Listen for students to say something like the following:

- In the early phases of development, there are many similarities in the structures of each of the organisms.
- It is difficult to tell the organisms apart early in development, but by later in development their physical structures begin to look more different.
- All the organisms early in development have a tail-like structure, an eye, an earhole or ear, and nubs where arms, fins, or legs will eventually develop.

What to do: If students struggle making comparisons between the different structures found in the embryo sketches, encourage them to think of an external structure that they know all the animals have, such as eyes. Then encourage them to look for evidence of this structure in the different sketches and color code it. Then prompt them to look for other common structures and color code if it is found in all or some of the embryo sketches.

End of day 1

5. Compare and interpret data on non-egg-layers. 8 MIN

Materials: completed *Live Birth Embryos*, science notebook

Compare embryo sketches of non-egg-laying animals. Display **slide N**. Cue students to take out their completed *Live Birth Embryos* handout. Give them 8 minutes to compare with the partner they worked with on the previous day

what they annotated on their handout and to record their findings in their notebook in the data table they set up in the last class.

6. Construct arguments and ask questions. 15 MIN

Materials: *New Ideas and Questions Connected to Embryo Comparisons*

Review our lesson question. Display **slide O**. Ask the class to recall what our lesson question is. ("What do the patterns in embryo development tell us about how things living today could be connected to the things that lived long ago?")

Point out that the analysis they have done so far has undoubtedly raised new ideas about how to answer this question as well as led to new questions. Suggest that we capture those ideas and questions now since they may help us see how much our ideas and questions have shifted since the start of the unit. Emphasize that this is an important assessment since it gives us a chance to reflect on what we've figured out in the whole unit. Distribute *New Ideas and Questions Connected to Embryo Comparisons*.

Give students 10-12 minutes to complete this.

Assessment Opportunity

Building towards: 14.B.1 Outline a scientific argument for how new model ideas or application of old models could explain and/or ask questions based on patterns in sketches of the physical structures apparent in different species at different stages of embryological development emphasizing new ideas about how different species may be connected.

What to look for: Guidance for evaluating the progress and shift in focus of student explanations and questions from the start of the unit is provided in *Key: How could things living today be connected to the things that lived long ago?*.

What to do: See the guidance provided in *Key: How could things living today be connected to the things that lived long ago?*.

7. Sharing Arguments and Questions 22 MIN

Materials: completed *New Ideas and Questions Connected to Embryo Comparisons*

Convene a Scientists Circle. Ask students to bring their completed *New Ideas and Questions Connected to Embryo Comparisons* and meet in a Scientists Circle. Frame the goal of this discussion: we will go public with our ideas but not to develop to consensus. Rather, it is more like an Initial Ideas Discussion. We may be bringing to the table new model ideas or new applications of previous ideas. Emphasize that it's likely that these ideas will also raise a lot of new questions, which are also important to go public with as they give us a good measure of how much our thinking and wonderings have shifted at the end of our unit compared to where we started.



Key Ideas

Purpose: Treat this as an Initial Ideas Discussion, where you are mainly looking for shifts in the types of ideas and questions that all students are bringing to the discussion now compared to where they started the unit. *Key: How could things living today be connected to the things that lived long ago?* provides some guidance of what to listen for, but this document is not exhaustive.

Below are a few suggested prompts you may use to begin the discussion:

- What are some of the new ideas you have?
- What are some of the new questions this raises for you?
- How are your new ideas connected to the data you collected from the embryo sketches?

Advise students that when they share their new idea(s) to also share how it is connected to the data analysis they did (part C of *New Ideas and Questions Connected to Embryo Comparisons*).

Ask student volunteers to share initial ideas or questions. Emphasize the importance of first restating what others have shared to check for understanding before following up with a related idea or question. It is suggested that at this point in the unit and year, you step more to the side and join the class as part of the circle. Encourage and support the students to discuss with and coordinate calling on each other. View this discussion similar to a forum where the space is open to hearing all ideas and working to link into each other's ideas, whether to agree, disagree, or build onto the new ideas on the table. Encourage and support students in using the productive talk strategies they have been using all year as they listen to and respond to their peers' ideas (e.g., I agree with _____'s idea because . . .; I disagree with _____'s ideas because . . ., and so forth).

Assessment Opportunity

Building towards: 14.B.2 Outline a scientific argument for how new model ideas or application of old models could explain and/or ask questions based on patterns in sketches of the physical structures apparent in different species at different stages of embryological development emphasizing new ideas about how different species may be connected.

What to look for and listen for: Focus on how students engage in the Scientists Circle discussion. Look for evidence of the following:

- Using productive talk strategies they have been practicing all year
- Respectfully providing and/or receiving critiques on scientific arguments by probing reasoning and evidence
- Challenging ideas and conclusions (raising related questions)
- Responding thoughtfully to diverse perspectives
- Determining additional information required to resolve contradictions (and articulating the question this would help answer)

What to do: If students are struggling to get the discussion started, remind them of the productive talk moves we have been using all year. In addition, refer them to the class norms, particularly the ideas about moving our science thinking forward and equitable representation (e.g., recruit neighbors to go public that we haven't heard from).

Reflect on the progress made. Reserve 3 minutes at the end of this discussion to celebrate as a class. Emphasize how valuable it is to be still generating more questions and more ideas at this point in our work and how much this reflects the nature of science. Suggest that even though we appear on the cusp of being ready to form an entire new DQB, that this line of questions and ideas might be most productive to pursue in future years, such as in high school. Encourage students to keep marinating on these ideas and questions over the summer. Suggest that we return to our unit DQB next time to see if we can close up most if not all of our initial questions on it. Say, *So let's wrap up our DQB next time and really celebrate what we have figured out.*

Collect *New Ideas and Questions Connected to Embryo Comparisons*.

ADDITIONAL LESSON 14 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.8.1.C: Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas.

CCSS.ELA-LITERACY.SL.8.1.D: Acknowledge new information expressed by others, and, when warranted, qualify or justify their own views in light of the evidence presented.

At the end of this lesson, while they are in the Scientists Circle, students share and acknowledge new information expressed by others and, when warranted, qualify or justify their own views in light of the evidence presented. They also pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas.

LESSON 15

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

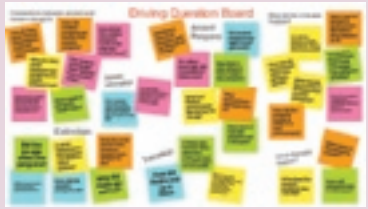
Previous Lesson

We analyzed sketches of embryos at different points in development for a variety of living things. We constructed an argument and raised questions about how and why different organisms share so many physical structures in common in their embryological development. We shared these arguments and questions as a class.

This Lesson

Putting Pieces Together

1 DAY



We identify the questions from our DQB that we can now answer. We celebrate all that we have learned in this unit and across the school year. We spend time identifying the questions that we did not answer and build a new DQB of these questions. We create a plan to answer some of the questions on our own and during the next school year and beyond.

Next Lesson

There is no next lesson.

Building Toward NGSS

MS-LS1-4, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4, MS-LS4-6

What Students Will Do

15.A Ask questions that arise from careful observation of phenomena, models, or unexpected results to clarify and/or seek additional information regarding cause and effect relationships and stability and change in lines of evolutionary descent.

What Students Will Figure Out

- We can answer many of our DQB questions, but now we have more questions.

Lesson 15 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	10 min	**EVALUATE OUR DRIVING QUESTION BOARD (DQB) QUESTIONS** Evaluate our list of questions in pairs and determine ones we think we have made progress on. Indicate those questions on our DQB and move into the Scientists Circle.	A-B	*Reviewing Our Driving Question Board*, 10 sticky dots, Driving Question Board
2	10 min	**REVISIT THE DQB** Revisit the DQB with the whole class and take stock of all the questions we have now answered.	C	DQB
3	5 min	**ADD TO OUR PROGRESS TRACKERS (OPTIONAL)** Update Progress Trackers, if time permits.	D	
4	20 min	**CELEBRATING OUR YEAR OF SCIENCE LEARNING** Reflect on science learning through a "Tweet Blizzard." Build a new Driving Question Board.	E-F	piece of scrap paper, sticky notes, marker, chart paper

End of day 1

Lesson 15 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• science notebook • *Reviewing Our Driving Question Board* • 10 sticky dots • piece of scrap paper • sticky notes • marker		• Driving Question Board • DQB • chart paper • marker

Materials preparation (25 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

There are several options provided in this lesson, and doing all of them will require 2 full class periods. Read through the *Teacher Guide*, judge the time you have remaining, and modify this lesson accordingly.

- If you have 2 full class periods, complete all steps and give each step more time than is allotted in the Learning Plan.

- If you have only one class period, skip the Evaluate Our Driving Question Board partner work using *Reviewing Our Driving Question Board* and the Add to Our Progress Trackers activity. Instead, move straight to the Revisit the DQB activity in a Scientists Circle. Allow students to post sticky dots on questions that they believe are answered and to discuss those. Complete the Celebrating Our Year of Science Learning activity, which involves a tweet blizzard reflection and building a new DQB of questions.

If completing the Evaluate Our Driving Question Board activity in small groups, type up the questions from the DQB or take a high-resolution photograph of all the questions on the DQB. If typing up the questions, modify the handout, *Reviewing Our Driving Question Board*, with the questions. If you take a photograph, insert the photograph in place of the table on the handout. If using the table format, add as many rows as needed to the table. Make a copy of *Reviewing Our Driving Question Board* for each student prior to the lesson.

Make sure the DQB is displayed and space is available for the class to gather in a Scientists Circle. Display around the room all the unit classroom consensus models such as the Penguin Timelines and General Model for Natural Selection.

Lesson 15 • Where We Are Going and NOT Going

The goal of this lesson is to not only celebrate the progress we made on our initial questions but to also revel in new lines of questions that have now opened up. This lesson is designed to help students reflect on the nature of science and their own journey through the middle school program. They should see themselves as active agents in the knowledge building they have participated in and recognize that scientific inquiry can be exciting and rewarding, in part because it doesn't always end with answers, rather it often "ends" with setting up new lines of questions for further, future investigation.

LEARNING PLAN FOR LESSON 15

1. Evaluate our Driving Question Board (DQB) questions. 10 MIN

Materials: science notebook, *Reviewing Our Driving Question Board*, 10 sticky dots, Driving Question Board

Connect to the last lessons. Say, *In our last few lessons we were successful at describing the connection between ancient and modern penguins and other organisms. And in our last class, we were surprised that we ended up with even more questions about how ancient animals could be connected to animals of today after looking at the embryological sketches. Today let's return to the questions we have from earlier in our unit and see what we can now answer.*

Work in pairs to evaluate what questions the class has answered from the DQB. Display **slide A**. Provide each student with a copy of *Reviewing Our Driving Question Board*, which you created to contain all the student questions from the DQB, and have students tape it into their science notebook. Have students work with a partner to mark how they think the class has answered the questions:

- 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: ✓✓

(Optional, depending on time) **Answer three self-selected questions.** Have students pick three questions they have marked as the class having answered. Tell students to use the space on the handout *Reviewing Our Driving Question Board* to write answers to those questions. If you choose to have students do this, you may wish to have them wait to tape this into their notebook so that you can collect it and use it as an assessment.

*** Attending to Equity**
Revisiting the DQB is important for students to feel as though their questions are valued and recognized. While not all questions will have been addressed (it's more likely that 50-75 percent will be at least partially answered), this helps students see that they have done this hard work to answer many of their own questions.

Assessment Opportunity

If you choose to do this optional step, this provides a good individual assessment opportunity looking back across other unit lesson level performance expectations.

What to look/listen for:

- evidence from the activities and lessons they have done in the unit to support their answers
- logical reasoning connecting the evidence to their answers

What to do:

- If students struggle to provide the evidence and reasoning, give students examples and use questions to guide them. Ask them, *How do you know that? What did we do in class that made you answer that way? How did that activity change your thinking?*
- If students need more challenges, ask them to connect their answers to the models or sketch the part of the model that their answer is about.

Review and share the questions that students think we have answered. Present **slide B** and have students mark on the class DQB with sticky dots the questions that they think we have made progress on.* Then have students move into their Scientists Circle.

2. Revisit the DQB.

10 MIN

Materials: science notebook, DQB

Look for patterns using the sticky dots. In the Scientists Circle, focus on the questions that have the most number of sticky dots.*

Discuss as a class the questions that the class can now answer. Present **slide C** if needed. Have the class discuss the answers to those questions. If you have space, you might make a "Take-aways" board that has a record of the answers with which the class comes up.*



Pose the unit question. To close out the discussion, pose the DQB question, *How could things living today be connected to the things that lived long ago?* Elicit students' new ideas to this question to prime students' thinking for adding a final entry to their Progress Tracker.

Assessment Opportunity

Building towards: 15.A Ask questions that arise from careful observation of phenomena, models, or unexpected results to clarify and/or seek additional information regarding cause and effect relationships and stability and change in lines of evolutionary descent.

What to look/listen for:

- We can clearly answer many of the questions through ideas learned throughout the unit.
- Some questions we can partially answer with some of our ideas learned, but they require more information or evidence.

What to do: If students struggle to answer questions from the DQB, place them in partners or small groups with one question or cluster of similar questions assigned to each group. Have them (1) locate where the questions most closely relate to the class's consensus models from Lesson 4 (Penguin Timeline with Cards) or Lesson 8 (General Model for Natural Selection) and then (2) examine their science notebook and other documents to search for evidence that could answer or partially answer the question. Ask the group to coconstruct, in writing or orally, an explanation to the question(s) using evidence from their previous work. Remind students what makes a good explanation is a how or why causal account that can be supported with evidence.

*** Supporting Students in Engaging in Asking Questions and Defining Problems**
Revisiting the DQB at the end of the unit helps students see the progress they have made toward answering questions that were important to them. In this unit, students were tasked with asking questions about some very complex phenomena. Their questions are likely to reflect sophisticated thinking they would not have been capable of as younger students. Through the investigations in the unit and individual and whole-group sensemaking, they can now answer many of these complex questions.

3. Add to our Progress Trackers (optional).

5 MIN

Materials: science notebook

Add any new insights to the Progress Trackers. If time permits, have your students add a final entry to their Progress Tracker. If time does not permit, skip this activity and complete the whole-group reflection, which comes next.

Present **slide D** and modify the slide depending on the entry you want students to complete**.** Have students either make an entry about new insights about the unit question *or* add an entry about new ideas or insights that may have surfaced during the DQB discussion. Have the students update their Progress Tracker with any additional ideas that they think are important.

4. Celebrating Our Year of Science Learning

20 MIN

Materials: science notebook, piece of scrap paper, sticky notes, marker, chart paper

Participate in a Tweet Blizzard reflection. Display **slide E**. Have students take 2-3 minutes to reflect on their own highlights and take-aways for the year in the format of writing a "tweet" on a piece of scrap paper, complete with hashtags of their choosing. Tweets can be about

- 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.

Have students crumple up their tweet into a "snowball," and when everyone is ready, toss the snowball in the air, and pick up a new snowball to share with the class. Facilitate a sharing of tweets in a Scientists Circle.

Alternate Activity

If classroom conditions do not permit the blizzard activity, modify it so that students complete the reflection as a quick write in their science notebook or virtual learning space. Ask students to write their reflection as a "tweet" with hashtags. If you are in a remote learning setting, have the students write their tweet in a Jamboard space or create a slide deck where each student is assigned a slide. If using slides or Jamboard, students can also add images of their favorite activity in the unit or the school year. Play the slide deck as a celebration of learning.

Generate new DQB.* Ask students to think about the questions that remain unanswered in the unit or across the school year. Display **slide F**. Remind students that they will continue their science learning in high school next year. Their science learning in high school will allow them to continue to revise their scientific knowledge in light of new evidence they will encounter. Pose the question, *What questions did we pose this year that we didn't answer but we want to carry forward into future science learning?*

Give students time to write on sticky notes 1-2 new questions. Encourage students to write down questions that went unanswered in previous units and/or new questions that came up about phenomena they have observed in the world and want to explain. Have students post their questions to a new DQB.

Cluster the questions by units taught this year and/or phenomena-based clusters. Include a cluster of topics that have not been addressed in units but that they might address in high school.

Ask students to share their questions and how they may go about answering those questions on their own and/or as part of their science learning in future years.

*** Supporting Students in Engaging in Asking Questions and Defining Problems**
Generating a new DQB allows students to revisit the element of this practice around asking questions that require empirical evidence that is sufficient and appropriate to answer. In science asking and answering questions often leads to generating new questions to explore, even at the end of a unit of study. This reflection and generating a new DQB gives students a moment to raise new questions or highlight questions they are still curious to explore in later grades.

Teacher Resources

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Assessment System Overview

Each unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self-assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the "Assessment Icon" in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	*Initial Explanations* Driving Question Board	**Pre-assessment** The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas that your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. This initial explanation can be used as a baseline pre-assessment for three areas of your students' thinking: • initial student understanding of connections between penguins of today and penguins of long ago (For example, do students think they are two different types of organisms, or do students think they are related somehow?) • initial student ability to know what kind of evidence would be needed to support or refute specific claims • initial ideas about types of mechanisms students think could be the cause of the changes in penguin populations The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as "how" and "why" questions, to post to the board, but celebrate any questions that students share even if they are close-ended questions. If your students are asking mostly closed questions, you can provide a copy of a photo of the questions on the Driving Question Board and ask them to work on refining three or more of these questions so that they become "how" or "why" questions. Listen for questions that address parts of the initial Penguin Timeline model, and if a part of the model has few or no questions, prompt students to generate more questions in this space so that each part of the model has a set of questions with which to guide investigations.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 4	*Three Explanations* *Lesson 4: Three Explanations*	**Formative Assessment** Students construct three mini explanations in response to 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 body structures of modern and ancient penguins?" To construct these explanations, students use various representations in the Penguin Timeline Model with Cards they are developing as a class to represent the similarities and differences in body structures. The first two of these explanations provide you a good opportunity to look for evidence for how students' thinking has shifted since Lesson 1, in which these questions were introduced. Coupled with the third explanation, these work together to give students practice developing an explanation based on preliminary evidence to illustrate that changes over time occur in the existence, diversity, and disappearance of different kinds of penguins throughout history. Such an explanation is closely aligned to MS-LS4-1. Though some students may not yet be proposing evolutionary relationships between ancient and modern organisms, it is likely you will see draft ideas of these relationships being proposed in many students' explanations. These ideas will include things like the following: • Some ancient penguins and all their descendants either died off and disappeared entirely. • Different species of modern penguins must have descended from different lines of penguin ancestors that stretch back many, many generations. • The lines of descent for modern penguins may have split from a common ancestor at some point in the past. • Something may be changing in a line of descent from some ancient penguins to modern penguins—either changing within individuals, their offspring, and/or the entire population.
Lesson 6	*"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment* *Key: Argument for "How are penguins today connected to penguins from long ago?"*	**Formative Assessment** Students complete an argument and have a Consensus Discussion to make and defend a claim about whether ancient penguins (and other organisms) are the ancestors of modern penguins (and other organisms). This argument provides another opportunity to see how students' ideas have shifted since Lessons 1 and 4. Students should be converging on an explanation that is closely aligned to MS-LS4-1. At this point you should be seeing students arguing for the following idea: • There must have been some population(s) of ancient organisms that had offspring that were lines of descendants that led to modern organisms.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 8	*How can we use our model to make predictions?* *How can we use our model to make predictions?*	**Formative Assessment** This is an embedded assessment as students complete an exit ticket to use our General Model for Natural Selection to make predictions about how natural selection leads to a change in the distribution of trait variations in a population over time, while heritable trait variations of each individual remain stable. Students' responses can be used in planning additional support or interventions, for use in the upcoming lessons, that may be needed by classes or by specific individuals.
Lesson 10	*Different Environmental Conditions and Results Key for Different Environmental Conditions and Results* *My Model for Changes in Bacteria Populations* *My Model for Changes in Bacteria Populations*	**Formative Assessment** This two-part assessment is embedded as students work through the lesson. The first part of the assessment is well aligned to MS-LS4-4. In this part students plan and carry out investigations in a simulated environment to collect data derived from analysis of the generated graphical data representations and use that evidence to explain how and why environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population. Their data analysis is recorded in *Different Environmental Conditions and Results*. The second part of the assessment is well aligned to MS-LS4-6. In this part students construct an explanation based on evidence collected from running a simulation and using science ideas included in our General Model for Natural Selection for how and why small changes in an environment may cause large changes in trait variations in a population over long periods of time. Their explanation will be recorded on *My Model for Changes in Bacteria Populations*, which you will collect at the end of day 2.
Lesson 11	*Green Anole Lizard Explanation* *Key: Green Anole Lizard Explanation*	**Summative Assessment** This assessment is a transfer task that asks students to use their General Model for Natural Selection to explain a new phenomenon tailored to MS-LS4-4. Allow students to choose how to share their understanding through oral presentation, written response, pictorial response, or a combination of both. In this assessment, students construct an explanation using the key parts of the General Model for Natural Selection (developed in Lessons 8-10). Look for how students apply these key parts of the General Model as well as how they incorporate data from the task to support a specific explanation for why the green lizard population is changing over time. Specifically, students use their understanding of natural selection and of the population before and after the change; changes in the environment; and the effect on survival, reproduction, offspring, and inheritance to explain how a trait variation in a population changes over time.
Lesson 13	*Version 1: Ancient and Modern Penguin Explanation* *Version 2: Ancient and Modern Penguin Explanation* *Key for Ancient and Modern Penguin Explanation*	**Summative Assessment** This individual assessment is well aligned to MS-LS4-2. Students use their General Model for Natural Selection acting over generations combined with the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships and to construct a scientific explanation to account for how natural selection (cause) could explain how modern penguins are connected by common ancestry.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 14	*New Ideas and Questions Connected to Embryo Comparisons* *Key: How could things living today be connected to the things that lived long ago?*	**Formative and Summative Assessment** This is an embedded task pertaining explicitly to MS-LS4-3 where students use the practice of analyzing trait data in a new context with this performance expectation. Individually and then in pairs, students analyze and interpret sketches of different types (species) of animals at different stages of embryological development to identify similarities (patterns) in physical structures not evident in the fully formed anatomy. Later in the lesson, using comparisons of the embryo sketches of different stages in development, students construct an argument for new model ideas and connections of model ideas to explain patterns in the data.
After each lesson	*Lesson Performance Expectation Assessment Guidance*—See below.	**Formative Assessment** Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in some lessons	Progress Tracker	**Formative and Student Self-Assessment** The Progress Tracker is a thinking tool that was designed to help students keep track of important discoveries that the class makes while investigating phenomena and what the class figures out about how to develop a model to explain phenomena. It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment in time. In this way, the Progress Tracker can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Tracker is meant to be a thinking tool for students, we strongly suggest it is not collected for a summative "grade" other than for completion. The Progress Tracker is embedded into several lessons, however it can also be used at teacher discretion during any lesson to help students process their thinking individually and in a space that will not be evaluated for a grade. There also are many formal exit tickets at the end of lessons. Since this unit calls for fewer Progress Tracker entries than other units have, consider returning the exit tickets to students and having them adhere them to the Progress Tracker section in their science notebook as a record of what they have figured out.
Anytime after a discussion	*Student Self-Assessment Discussion Rubric* *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment* *Argumentation Self-Assessment*	**Student Self-Assessment** Lessons 6 and 8 give students specific opportunities for self-assessment in this unit. Additionally, The *Student Self-Assessment Discussion Rubric* provided in the Teacher Handbook can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive

When	Assessment and Scoring Guidance	Purpose of Assessment
After students complete substantial, meaningful work	*Peer Feedback Facilitation: A Guide*	**Peer Feedback** There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. We suggest that peer review happens at least two times per unit. Use the *Peer Feedback Facilitation* guidance provided in the Teacher Handbook to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process. Peer feedback is most useful when there are complex and diverse ideas visible in student work and when not all work is the same. Student models or explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work, rather, peer feedback will be more valuable to students if they have time to revise after receiving peer feedback. It should be a formative, not a summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback. For this unit, peer feedback works best for Lessons 5 and 11 during the moments where students are sharing their models and explanations or after an investigation where students share with peers what they figured out.

For more information about the approach to assessment and general program rubrics, visit the Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross-cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Analyze and interpret data using data cards containing photos, maps, charts, measurements, and descriptive text to find patterns in penguins that are alive today. **1.B** Develop an initial explanation and identify evidence needed to determine what caused the observed changes in the existence, diversity, and disappearance of different kinds of penguins throughout history. **1.C** Ask questions that arise from initial observations of patterns in the images depicting anatomical similarities and differences of penguins that are alive today and of a fossil of a penguin from long ago.	**1.A Analyzing and Interpreting Data; Patterns** **When to check for understanding:** On day 2, when students are looking for connections in the data across penguins on *Data Cards for Modern Penguins and Pedro* **What to look and listen for:** Each student taking the lead for at least one of the three ways their small group tries to sort the cards and co-facilitating the discussion about the patterns they notice as they do this **1.B Constructing Explanations; Cause and Effect** **When to check for understanding:** After they develop their initial explanations on day 3, it may be helpful for your students to leave their notebooks in the classroom for you to assess their work. **What to look and listen for:** Students (1) make more than one claim about what happened to the penguins from long ago and where modern penguins came from, (2) support their claims by providing a possible mechanism, and (3) articulate evidence needed to either support or refute their claims. **1.C Asking Questions; Patterns** **When to check for understanding:** On day 4, students are directed to develop open-ended questions for the DQB using how and why prompts. It is important that *all* questions posed by students be placed on the DQB regardless of whether they are open-ended or close-ended. **What to look and listen for:** For students' DQB questions, make note of any close-ended questions and use navigation time throughout the unit to turn close-ended questions into open-ended ones that necessitate a need to examine additional evidence. As you move into the discussion of ideas for future investigations and data we need, have students focus on categorizing their questions and then identifying the kinds of data and additional information that would be helpful in answering each category of questions.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	**2.A** Analyze and interpret data to find patterns across heritable body structures and behaviors among different species of modern penguins and an ancient penguin. **2.B** Ask questions about ancient ancestors of modern penguins based on close analysis of patterns in the body structure and behavior data for modern penguins and Pedro; describe the type of data that would be needed in order to answer some of these questions.	**2.A Analyze and Interpret Data; Patterns** **When to check for understanding:** 1. On day 1, when students record their groupings of penguins based on similarities in the data 2. On day 2, when students make a claim about whether Pedro is related to modern penguins **What to look/listen for:** 1. Some types of structures and behaviors are shared across all the penguins and/or certain species of penguins share many more structures and behaviors in common than others. 2. Any claim is acceptable (e.g., Pedro is an ancestor, is not an ancestor, is related in some other way to modern penguins or other ancient penguins, and so forth). Justification should include citing patterns in the heritable structure and behavior data. See examples in the related assessment callout box. **2.B Asking Questions and Defining Problems; Patterns** **When to check for understanding:** 1. On day 1, when students record their new questions 2. On day 2, when students record their new questions **What to look/listen for:** 1. Look for a line of new questions that emerge from the sources of data they investigated on day 1. This is likely to include questions based on either of the following: a. how similar internal structures are in the penguins (or in other organisms) b. how internal structures might be related to function 2. Look for any line of new questions that emerge related to how similar internal structures are in the ancient penguins (or in other organisms). This implies the need for comparing the same sort of data next time that they looked at today, but for more ancient fossils.
Lesson 3	**3.A** Develop and use a timeline of a large data set to identify patterns in variations in body structures found in different penguins across different points in time.	**3.A Analyzing and Interpreting Data; Patterns** **When to check for understanding:** At the end of day 1 as students are constructing an organization of the ancient penguins on their timeline poster **What to look/listen for:** Placement of the following groups of penguins over the corresponding horizontal section of their timeline: • all 18 modern penguins at the far right side of the timeline (0 mya or to the right of it) • each ancient penguin placed within the corresponding ancient time period matching its data strip • clustering of penguin species within each time period based on the number of body structure similarities

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
	3.B Analyze and interpret data from data tables, images, maps, and descriptive text to identify patterns of similarities and differences in variations in body structures, environments, and geographic locations of ancient penguin fossils across time.	**3.B Analyzing and Interpreting Data; Patterns** **When to check for understanding:** At the end of the lesson, when students use their Progress Tracker (from the gallery walk) to help them complete the *Ancient Penguin Sorting Exit Ticket* **What to look/listen for:** • None of the ancient penguins have all the same body structure variations in common with any modern penguins. • Ancient penguin fossils tend to have more body structure variations in common with each other the closer they are in time. • Modern penguins have more body structures in common with less-ancient penguin fossils than with more-ancient ones. • The overall size of many but not all ancient penguins was larger than the largest modern penguins; the beak size and shape of many ancient penguins was longer and/or more curved than modern penguins. • Penguins living at different times experienced differences in Earth's climate, the positions of the continents, and sea levels. • Ancient penguins lived in South America, Antarctica, and New Zealand. Depending on where the penguins lived and when they lived there, the other organisms that lived in these areas varied.
Lesson 4	**4.A** Develop an explanation based on preliminary evidence to illustrate that changes over time occur in the existence, diversity, and disappearance of different kinds of penguins throughout history. **4.B** Develop an explanation that predicts what the variation in a chosen body structure or behavior of Galápagos penguins and king penguins looks like at different scales (between species versus between individuals within a population).	**4.A Constructing Explanations; Stability and Change** **When to check for understanding:** On day 1 when students complete *Three Explanations* **What to look/listen for:** Use *Lesson 4: Three Explanations* for additional guidance and what to look for in student responses. **4.B Constructing Explanations; Stability and Change** **When to check for understanding:** On *Exit Ticket - Trait Variation* **What to look/listen for:** Students should include the following ideas in their predictions: • At different scales of penguin groups (between species versus between individuals within a population of a species), the variation we are accounting for is different. • Within a population of the same species of penguin we can also look at variation within a trait (a body structure or behavior that species has)—this variation makes individuals within a population different from one another. • We look at variations of body structures or behaviors that are shared among all individuals in a species of penguin, and we look for differences in these variations of body structures or behaviors between different species of penguins.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 5	**5.A** Analyze and interpret data from images to identify patterns of similarities and differences in modern organisms and the fossil record and use the patterns to look for relationships between ancient and modern organisms. **5.B** Respectfully provide and receive critiques about models of the similarities and differences (patterns, stability, and change) in some of the body structures of organisms observed over time and in different environments based on evidence from the fossil record.	**5.A Analyzing and Interpreting Data; Patterns** **When to check for understanding:** 1. On day 1, listen in while students work in their groups to identify patterns based on similarities and differences in body structures and then adjust their models. 2. On day 2, students will reassess their body-structures-patterns model by analyzing and interpreting new data sets. **What to look/listen for:** 1. Students will have some ideas about connections of ancient and modern organisms, but their understanding will be incomplete and they may be confused by differences between their group's analysis and organization and that of other groups. 2. After examining additional data on day 2, students should recognize that the further back in the fossil record organisms go, the more dissimilar they are to modern organisms. Also, in some cases similarities or differences in body structures may be connected to the environmental conditions in which an organism lived. **5.B Engaging in Argument from Evidence; Stability and Change** **When to check for understanding:** 1. During the gallery walk to compare models on day 1 2. On day 2, when groups who examined changes in body structures of the same organism come together and share their ideas and models 3. On day 2, when students form triads to share their thinking and models showing relationships among body structures, time in which organisms live(d), and environments in which organisms live(d) for all three organisms they investigated **What to look/listen for:** By this final unit of 8th grade, students should be very familiar with classroom norms that guide respectful conversations. Closely listening and trying to make sense of their peers' ideas should be a well-established practice in small-group argument sharing. Students should be posing and responding to questions to elicit additional details or to clarify the patterns in these models when there is something they don't understand.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 6	**6.A** Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support an explanation for whether the types of things that lived long ago are ancestors to the modern organisms we see today (stability and change). **6.B** Ask questions related to what is causing changes in a whole population of organisms.	**6.A Constructing an Argument; Stability and Change** **When to check for understanding:** First individually and then in the whole group, students make and defend a claim about whether ancient penguins (and other organisms) are the ancestors of modern penguins (and other organisms): 1. On *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment* 2. During the Consensus Discussion **What to look/listen for:** 1. As students are completing *"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment*, circulate to check in to see if claims are aligned with the idea that penguins alive today descended from penguins that lived long ago and somehow the variations in their body structures have changed. 2. During the Consensus Discussion listen for students to support their ideas by using evidence that there are variations present in populations already. **6.B Asking Questions; Cause and Effect** **When to check for understanding:** Students add to their DQB to ask questions about *how* populations of organisms could have changed over time. **What to look/listen for:** Students should articulate ideas that include wondering about • variation in a population, • where new traits come from, and • *how* things change, such as learning or acquiring new traits versus inheriting the traits from parents.
Lesson 7	**7.A** Analyze and interpret data representing mean, median, mode, or variability to examine patterns of changes over time that affect the predominance of certain traits in a population.	**7.A Analyzing and Interpreting Data; Patterns** **When to check for understanding:** On day 1 students focus on analyzing various subsets of data collected about one of five different organisms. On days 2 and 3 individuals will join with their group members to reinterpret the data in the context of a more complete understanding of each case. **What to look/listen for:** For specific details of what to check for in each section of the cases, look at *Key for All Data Packets*.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
	7.B Communicate and evaluate scientific information about a system of cause and effect relationships to explain how traits that support successful survival and reproduction become more common and those that do not become less common. **7.C** Using models, construct an explanation of changes over time in the distribution of traits in a population in response to changes in environmental conditions.	**7.B Obtaining, Evaluating and Communicating Information; Cause and Effect** **When to check for understanding:** Students will complete *Using the CCC Lens* on day 2. There are multiple additional times throughout the lesson to assess students' understanding. They are enumerated in the corresponding assessment callout regarding 7.B in day 2 of the lesson. **What to look/listen for:** For specific details of what to check for in each section of the cases in *Using the CCC Lens*, look at *Key for Using the CCC Lens*. **7.C Constructing Explanations and Designing Solutions; Stability and Change** **When to check for understanding:** Assess groups' Revised Case System Models on day 3. There are multiple additional opportunities throughout the lesson to assess students' explanations of stability and change. They are enumerated in the corresponding assessment callout regarding 7.C in day 3 of the lesson. **What to look/listen for:** Each group's Revised Case System Model should explain the following ideas: • explicit cause-and-effect connections among elements of their system • a clear statement that the population at the end shows a difference in the *distribution* of the trait of interest • stability of the set of trait variations present at the beginning through to the end of the study • environmental changes are a primary cause that affects the population at the beginning • some kind of indication that time is passing (dates, number of years, number of generations, and so forth) • an indication that the direct effect on survival and reproduction at the individual level is what results in the changes at the population level
Lesson 8	**8.A** Respectfully provide and receive critiques about one's explanations and model ideas related to what in the system is remaining stable (e.g., traits within individuals and patterns of inheritance) and what is changing (e.g., distribution of traits) and what causal mechanisms (e.g., competitive advantages, selection events) are at work on different populations in different (eco)systems.	**8.A Arguing from Evidence; Stability and Change, Cause and Effect** **When to check for understanding:** 1. As students follow the discussion protocol on slide D at the end of day 1. 2. When you review the *Argumentation Self-Assessment* from the end of day 1 to get a measure of each student's own perceptions of their role and contributions in the argumentation work so far. **What to look/listen for:** 1. Every student cites broad patterns in the evidence from their cases and proposes general statements about cause-and-effect relationships between some parts of their system; every student provides and responds to feedback to and from their partner as to whether those mechanisms apply across both systems. 2. See details in the assessment guidance boxes for 8.A.1 and 8.A.2.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
	8.B Use a model that includes unobservable mechanisms describing more than one cause and effect relationship between different parts and components in a system to make predictions about how natural selection leads to a change in the distribution of traits in a population over time, while heritable traits of each individual remain stable.	**8.B Developing & Using Models; Stability and Change, Cause and Effect** **When to check for understanding:** On the *How can we use our model to make predictions?* exit ticket at the end of day 2 **What to look/listen for:** See *How can we use our model to make predictions?*.
Lesson 9	**9.A** Construct an argument that changes in environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population, using evidence derived from analysis of graphical data representations generated from an investigation using a computer simulation.	**9.A Engaging in Argument From Evidence; Patterns; Cause and Effect** **When to check for understanding:** 1. On day 1 in students' individual copies of *Investigation 1* when students describe how and why the population changed in the particular environment 2. On day 2 in the second set of class discussions (small group and whole group) comparing the results of both investigations **What to look/listen for:** 1. Look for at least one of these two sets of related lines of evidence and new model ideas: • Evidence: There was a shift in the distribution of the proportion of bacteria that have a particular trait variation; over time it shifts toward a larger proportion of individuals with more flagella. Reasoning: This is because more flagella allow bacteria to move faster, which gives them a competitive advantage for surviving (and reproducing). • Evidence: There is some variability in results between simulation results. Reasoning: This is due to some elements of chance or randomness in the environment. 2. Listen for the following ideas: • There was a shift in the distribution of the proportion of bacteria that have a particular trait variation; over time it shifts toward a larger proportion of individuals with fewer flagella. • This was a shift in a different direction than in the previous investigation. • Loss of trait variation occurs over time. • There is some variability in outcomes due to some elements of chance or randomness in the environment.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 10	**10.A** Plan and carry out an investigation in a simulated environment to collect data about how environmental conditions may increase or decrease the probability of specific trait variations being passed on in a population, using evidence derived from analysis of graphical data representations generated from a computer simulation in two different investigations. **10.B** Construct explanations based on evidence collected from running a simulation and using science ideas included in our General Model for Natural Selection for how and why small changes in an environment may cause large changes in trait variations in a population over long periods of time.	**10.A Planning and Carrying Out an Investigation; Patterns; Cause and Effect** **When to check for understanding:** In students' completed data table on *Different Environmental Conditions and Results* **What to look/listen for:** Look for students using all the model ideas from the General Model for Natural Selection and evidence from their investigation in their explanations for both environments. Look specifically to see how students are explaining that small changes in the environment can have large changes in the system for trait variation within that population of bacteria. An example student response is available in *My Model for Changes in Bacteria Populations*. **10.B Constructing Explanations and Designing Solutions; Cause and Effect; Stability and Change** **When to check for understanding:** In students' explanations on *My Model for Changes in Bacteria Populations* (It is recommended that you assess these at the end of day 2.) **What to look/listen for:** Look for students using all the model ideas from the General Model for Natural Selection and evidence from their investigation in their explanations for both environments. Look specifically to see how students are explaining that small changes in the environment can have large changes in the system for bacteria trait variation. An example student response is available in *My Model for Changes in Bacteria Populations*.
Lesson 11	**11.A** Construct and revise an explanation using a model to explain why a change to the environment (cause) leads to a predominance of certain genetic variations of traits in a green lizard population that increase some individuals' probability of surviving and reproducing (effect).	**11.A Constructing Explanations and Designing Solutions; Cause and Effect** **When to check for understanding:** When students are completing *Green Anole Lizard Explanation*, giving and receiving feedback, and revising (Additional feedback can be given after collecting *Green Anole Lizard Explanation*.) **What to look/listen for:** The task includes a scoring guide located in *Key: Green Anole Lizard Explanation*. Scoring guides are meant to highlight important ideas students should include in their responses. If students share these ideas at other points in the assessment, it is up to you to decide if that understanding is sufficiently demonstrated. Students will continue to use these ideas in the next two lesson sets.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 12	**12.A** Construct a scientific explanation for how natural selection acting over generations has caused organisms' body structures to change over time in response to changes in environmental conditions.	**12.A Constructing Explanations and Designing Solutions; Cause and Effect; Stability and Change** **When to check for understanding:** 1. On day 1, during both partner conversations and whole-class discussion as students work on building an explanation for the changes in horses' toe structure by using the General Model for Natural Selection. 2. On day 2, as students work to explain what they have figured out about horseshoe crabs using the General Model for Natural Selection **What to look/listen for:** 1. Students should accurately connect specific elements of the General Model for Natural Selection with specific information about ancient and modern horses, the environments they inhabited, and the functions of multiple and single toes. 2. Oral (in preparatory conversations) and written (on the sticky notes used on the *Small Group Working Copy of Our General Model*) evidence explaining what they observe when comparing the body structure variations of ancient horseshoe crabs to the body structures of modern horseshoe crabs • All the elements in the model are used. • Specific information from sources is used. • Accurate cause-and-effect relationships are described.
Lesson 13	**13.A** Use patterns in shared body structures resulting from natural selection and mutations to develop a model to explain how modern penguins are connected to ancient penguins. **13.B** Construct a scientific explanation proposing relationships between all modern penguins and ancient penguins using the similarities and differences in accumulated body structure changes over time to estimate how relatively long ago they shared a recent ancestor.	**13.A Developing and Using Models; Patterns** **When to check for understanding:** As students are contributing to the Consensus Discussion to build the Penguin Ancestry Model and in small groups when they continue to build on the model to explain how all modern penguins are connected **What to look/listen for:** Discussions and models should include the following ideas: • Species of penguins with the least number of differences on the data strips (and the most similarities) will have lived in the same environment together most recently and will share a more-recent common ancestor than species of penguins with more differences on the data strips. • Similarities and differences in body structures (on the data strips) are used as evidence to support the relationship between ancient and modern penguins. (Since there are a lot of missing data, there is more uncertainty in these explanations, so it is expected that these proposed relationships will vary greatly among groups.) **13.B Constructing Explanations and Designing Solutions; Stability and Change** **When to check for understanding:** On *Version 1: Ancient and Modern Penguin Explanation* **What to look/listen for:** See the *Key for Ancient and Modern Penguin Explanation* for sample student responses and scoring guidance.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 14	**14.A** Analyze and interpret sketches of different species at different stages of embryological development to identify similarities and differences (patterns) in physical structures not evident in the fully formed anatomy. **14.B** Outline a scientific argument for how new model ideas or application of old models could explain and/or ask questions based on patterns in sketches of the physical structures apparent in different species at different stages of embryological development emphasizing new ideas about how different species may be connected.	**14.A Analyzing and Interpreting Data; Patterns** **When to check for understanding:** On day 1, when students analyze embryological sketches of egg-laying animals and mammals, and on day 2 when they compare their analyses with a partner. **What to look/listen for:** Students' responses should include the following: • In the early phases of development, there are many similarities in the structures of each of the organisms. • It is difficult to tell the organisms apart early in development, but by later in development their physical structures begin to look more different. • All the organisms early in development have a tail-like structure, an eye, an earhole or ear, and nubs where arms, fins, or legs will eventually develop. **14.B Engaging in Argument from Evidence; Asking Questions and Defining Problems; Patterns** **When to check for understanding:** On day 2, when students complete *New Ideas and Questions Connected to Embryo Comparisons* and again when they go public with their thinking and build off the thinking of others in the Scientists Circle. **What to look/listen for:** Use the guidance provided in *Key: How could things living today be connected to the things that lived long ago?* for evaluating the progress and shift in focus of students' thinking and questions from the start of the unit. Then, focus on how students engage in the Scientists Circle discussion. Look for evidence of the specific points listed in the assessment guidance callout in this lesson.
Lesson 15	**15.A** Ask questions that arise from careful observation of phenomena, models, or unexpected results to clarify and/or seek additional information regarding cause and effect relationships and stability and change in lines of evolutionary descent.	**15.A Asking Questions and Defining Problems; Cause and Effect, Stability and Change** **When to check for understanding:** During the Evaluate Our Driving Question Board activity **What to look/listen for:** Students can clearly answer some of the questions using ideas learned in this unit. Some questions can be partially answered, but they require more information or evidence.

LESSON 1: TEACHER REFERENCE

Unit Materials Planning

In order to support students as they work with very large data sets, the printing needs of this unit may require more advance planning than other units do. We've listed here lessons with printing needs beyond typical copies of handouts so that you can plan ahead and have materials ready for students when they need them.

Note that if you have purchased a materials kit, it likely includes these materials for you, but this reference can be used to replace consumable, damaged, or lost items as needed.

Lesson	Special print items	Details (also found in each lesson's teacher guide)
1	*Data Cards for Modern Penguins and Pedro*	Print 1 set of *Data Cards for Modern Penguins and Pedro* for each group of 3 students in your largest class in color on cardstock. Cut into half-sheet cards. Consider laminating the cards for future use. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally. Use a binder clip to keep each set of these together. These are nonconsumables that you collect and reuse in all classes.
2	*Data Strips: External Structures in Modern Penguins and Pedro*	Print enough *Data Strips: External Structures in Modern Penguins and Pedro* for half of your largest class. Cut out the strips. Secure each set with a binder clip. Consider laminating the strips since you will reuse them for each class you teach and can keep them year to year.
2	*Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro*	Print enough *Nonconsumable Lesson 2 Data Strips: Internal and External Structures in Modern Penguins and Pedro* for half of your largest class. Cut out the strips. Fold each strip in half so that the external structures and behavior data are on one side of the strip and internal data are on the other side of the strip. Secure each set with a binder clip. Consider laminating the strips since you will reuse them for each class you teach and can keep them year to year.
2	*External Structures and Behaviors Key; Internal Structures Key*	If your class is using the student editions, students will reference *External Structures and Behaviors Key* and *Internal Structures Key* during this lesson. If you do not have student editions, prepare these keys as nonconsumable handouts. Print one of each of the following for every student in your largest class: *Reference: External Structures and Behaviors Key* and *Reference: Internal Structures Key.* Consider printing these on cardstock and/or laminating them since you will reuse them for each class you teach and can keep them year to year.
2	*Penguin Stickers*	Print in color two sticker strips per student of Penguin Stickers onto ¾" x ¾" square labels using a zero-inch margin. Cut four vertical strips of stickers out of each letter-sized sheet. Each strip will contain 20 total (¾" x ¾") stickers: 19 different penguin (modern and Pedro) labels and one blank. Each student will use 1 of these strips on day 1 and 1 more of these strips on day 2 when they organize and annotate the patterns they see.

Lesson	Special print items	Details (also found in each lesson's teacher guide)
3	*Ancient Penguin Data Cards*	Print one color copy for every 3 students and then cut the copies into half-page cards. If possible, print on cardstock and/or laminate. Use a binder clip to keep each set of these together. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally. Consider laminating these cards since you will reuse them for each class you teach and can keep them year to year.
3	*Maps of Earth's Surface Over the Last 50 Million Years*	Print and laminate one color copy of *Maps of Earth's Surface Over the Last 50 Million Years* per student in your largest class.
3	**Optional:** *Extension: Data strips for more-incomplete ancient penguin fossils*	**Optional:** Make a color copy of *Extension: Data strips for more-incomplete ancient penguin fossils* for each pair of students in your largest class. Cut the strips out of these and clip each set of strips together with a binder clip. Since these are supplementary material for students who are interested, it is recommended that you collect and reuse these for all your classes if you choose to selectively distribute them to groups that request them. Consider laminating these strips since you will reuse them for each class you teach and can keep them year to year.
3	*Data strips for ancient penguin fossils; Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro*	Print black and white copies of *Data strips for ancient penguin fossils* and *Consumable Lesson 3 Data Strips: Internal and External Structures in Modern Penguins and Pedro* for every pair of students in every class. Decide if you think you will have time in class to have students cut their own strips at the start of the activity. If not, cut the strips ahead of time. After they are cut, use a binder clip to secure each set. Students will use these to build their poster.
3	*Timeline Sections*	Print one color copy of *Timeline Sections for* every 2 groups (of three) in your classes. Cut out the two identical sections from every sheet. Tape the three different sections of the color timeline together for each group. Students will be using these to build their poster.
3	*Reference: Internal Structures Key*	Print black and white copies of *Reference: Internal Structures Key* for every pair of students (which is how they are initially used). Students may wish to use these in the construction of their posters (which will be done in groups of 3 students), so this printing is treated as consumable.
5	*Day 1: Horseshoe Crab Data Cards*; *Day 1: Horse Data Cards*; *Day 1: Whale Data Cards*	Print *Day 1: Horseshoe Crab Data Cards, Day 1: Horse Data Cards,* and *Day 1: Whale Data Cards* in color on cardstock, if available. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally. Print sets of organism cards and their cover sheets from *Day 1: Horseshoe Crab Data Cards, Day 1: Horse Data Cards,* and *Day 1: Whale Data Cards*. Cut each set into half-sheet cards. Each set will have a cover sheet explaining common characteristics. You will need two or more sets for each organism (horseshoe crabs, horses, and whales): one set for each group that is working on that particular organism. Make enough sets for groups in your largest class. You may choose to laminate the cards. Clip the cover sheet and all cards for the same organism together in sets. These are nonconsumables that you will collect and reuse in all classes.

Lesson	Special print items	Details (also found in each lesson's teacher guide)
5	*Horse Stickers* *Horseshoe Crab Stickers* *Whale Stickers*	Print each of *Horse Stickers, Horseshoe Crab Stickers,* and *Whale Stickers* in color onto a letter-sized sheet of ¾" x ¾" square labels using a zero-inch margin. Print sufficient copies of *Horse Stickers, Horseshoe Crab Stickers,* and *Whale Stickers* so each student can have two sets of stickers. (Note that each student will need one set of stickers for their organism for this day 1 activity and one set of stickers for their organism for an activity on day 2 in this lesson. There are 8 sets of stickers per sheet, so each sheet is enough for 4 students). Cut sets of stickers from each sheet for easy distribution to students.
5	*Day 2: Horseshoe Crab Data Cards*; *Day 2: Horse Data Cards*; *Day 2: Whale Data Cards*	Print in color all data cards from *Day 2: Horseshoe Crab Data Cards, Day 2: Horse Data Cards,* and *Day 2: Whale Data Cards*. You will need two or more sets for each organism (horseshoe crabs, horses, and whales): one set for each group that will be working on that particular organism. If you cannot print in color, print the cards in grayscale for sorting and students can access a color version of the cards for reference in the student edition or digitally. Make enough sets for groups in your largest class. Cut each set into half-sheet cards. You may choose to laminate these cards, also. Clip the cover sheet and all cards for the same organism together in sets. These are nonconsumables that you will collect and reuse in all classes.
5	*Maps of Earth's Surface 150 and 100 Million Years Ago*	Each group working with horseshoe crabs will need access to a copy of *Maps of Earth's Surface 150 and 100 Million Years Ago,* either in the student edition or as handouts which can be reused for all classes.
7	*Finch Data Packet;* *Peppered Moth Data Packet;* *Cliff Swallow Data Packet;* *Mustard Plant Data Packet;* *Stickleback Data Packet*	Print and staple sufficient copies of the case study data packets so every student in each case study group will have their own copy for that case (for example, every group of 5 students will need 5 copies of one of the following: *Finch Data Packet, Peppered Moth Data Packet, Cliff Swallow Data Packet, Mustard Plant Data Packet,* and *Stickleback Data Packet.*
7	*Overview: Finch Beaks;* *Overview: Peppered Moth;* *Overview: Cliff Swallow Wings;* *Overview: Mustard Plant Time to Flowering;* *Overview: Stickleback Armor*	Prepare nonconsumable color overviews as follows: Print on cardstock one color Overview for each group working on that case. Consider laminating these pages since you will reuse them for each class you teach and in future lessons, and you can keep them year to year. You will reuse these color copies for all your classes. Each group will need one copy of the Overview for their assigned case. Note that this Overview is included in the data packet for each case so students can annotate a copy, but it will be printed in grayscale. This color copy allows them a clearer view of maps and other images.

Extended Key for Penguin Structures and Behaviors

OLD REF ID refers to the ID used for this structure or behavior in this source material: *Fossil Evidence for Evolution of the Shape and Color of Penguin Feathers*, published 12 November 2010 in *Science,* DOI: 10.1126/science.1193604

NEW REF ID refers to the id used for this structure in this source material: the appendix published along with Paleogene equatorial penguins challenge the proposed relationship between biogeography, diversity, and Cenozoic climate change. Proceedings of the National Academy of Sciences, July 2007, 104(28): 11545-11550; DOI: 10.1073/pnas.0611099104

	OLD REF ID	NEW REF ID		Structures and behaviors	Variations			
Feathers	20	22	A	scale-like feathers	absent (0)	present (1)		
	21	23	B	shape of the central shaft of the feathers	cylindrical (0)	flat and broad (1)		
	54	56	C	pattern on underside of flipper edge	white (0)	incompletely dark (1)	completely dark and wide (2)	
	26	28	D	crown feather color (top of head)	black (0)	yellow (1)		
	27	29	E	head plumes	absent (0)	present (1)		
	28	30	F	compactness of head plumes, if present	compact (0)	fluffy (1)		
Beak	74	76	G	shape of the top of beak tip	pointed (0)	weakly hooked (1)	strongly hooked (2)	
	9	9	H	bottom of the beak color	black (0)	reddish (1)	pink (2)	yellowish (3)
	12	12	I	top of the beak color	black (0)	red (1)	orange (2)	

	OLD REF ID	NEW REF ID		Structures and behaviors	Variations			
Eye	36	38	J	white eyebrow	absent (0)	narrow, behind eye (1)	narrow, in front of eye (2)	wide, in front of eye (3)
	34	36	K	fleshy eye ring	absent (0)	present (1)		
	35	37	L	white eye ring	compact (0)	fluffy (1)		
Feet	64	66	M	top of foot color	dark (0)	pinkish (1)	orange (2)	whitish (3)
	65	67	N	soles of the feet are darker than the tops	no (0)	yes (1)		
	66	68	O	foot nail shape	flat (0)	compressed (1)		
Nest, eggs, and chicks	69	71	P	nest	no nest, incubation over the feet (0)	nest placed in rock cracks or buried in sand (1)	open nest in a shallow depression (2)	
	72	74	Q	egg shape	oval (0)	conical (1)	spherical (2)	
	67	69	R	clutch size (number of eggs at a time)	two eggs (0)	one egg (1)		
	60	62	S	chicks have feathers	yes (0)	no (1)		

	OLD REF ID	NEW REF ID		Structures	Variations		
Beak and skull	74	76	AA	shape of the top of the beak tip *(culminicorn)*	pointed (0)	weakly hooked (1)	strongly hooked (2)
	79	82	BB	structure of depression on the side of the skull *(os squamosum, fossa temporalis)*	separated by a wide surface (0)	less separated: almost meeting at midline of skull (1)	
	80	83	CC	depth of the shallow depression on the side of the skull (*os squamosum, fossa temporalis*)	flat (0)	shallow (1)	deep (2)
Shoulder blade	125	134	DD	shape of the shoulder blade	blade-like (0)	slightly expanded (1)	broadly expanded, paddle-shaped (2)
	128	138	EE	size of the projection on the shoulder blade (*extremitas sternalis coracoidei*), where the biceps are attached	greatly expanded (0)	moderately expanded (1)	
	129	139	FF	shape of the projection on the shoulder blade (*extremitas sternalis coracoidei*), where the biceps are attached	convex (0)	concave (1)	flat (2)
Leg and foot	167	188	GG	kneecap (*patella*)	shallow groove (0)	deep groove (1)	perforated (2)
	170	191	HH	ratio of length to width [R] for lower leg bone	slender (0)	shortened (1)	very shortened (2)
	176	197	II	opening(s) in the upper foot for an artery	a single opening on the inner side of the upper foot (0)	openings on both sides of the upper foot—inner and outer foot (1)	a single opening on the outer side of the upper foot (2)

	OLD REF ID	NEW REF ID		Structures	Variations		
Humerus (upper wing bone)	142	153	JJ	humerus shaft width	thins or maintains width as you move toward the end of it (0)	widens as you move toward the end of it (1)	
	145	156	KK	humerus shaft curvature	absent or weak (0)	strong (1)	
	146	157	LL	shape of a bony projection (avian spur) on the middle front of the humerus	absent (0)	compact (1)	long (2)
	132	143	MM	slope on the top rounded surface of the humerus (*caput humeri*)	in line with the midline of the body (0)	slanted toward the front of the body (1)	
	139	151	NN	shape and direction of a scar on the humerus (*imperssio insertii m. supracoracoideus*) where a pectoral muscle (*deltopectoralis*) is attached	not elongated, semicircular (0)	greatly elongated, with long axis parallel to the long axis of humerus (1)	greatly elongated, with long axis not parallel to the long axis of humerus (2)

Penguin Taxon vs. Common Name or Nickname

Taxon	*Abreviatiated taxon name,* common name, or alternate nickname used in the unit
Spheniscus urbinai	*S. urbinai*
Marplesornis novaezealandiae	Harris' penguin
Palaeospheniscus patagonicus	Slender-footed penguin
Eretiscus tonnii	Tiny rower penguin
Platdyptes marplesi	Simpson's penguin
Paraptenodytes antarcticus	*Pa. antarcticus*
Archaeospheniscus lowei	Lowe's penguin
Archaeospheniscus lopdelli	Lopdell's penguin
Icadyptes salasi	Giant spear-billed penguin
Palaeeudyptes klekowskii	Colossus penguin
Palaeeudyptes gunnari	*P. gunnari*
Inkayacu paracasensis	Water king penguin / Pedro
Perudyptes devriesi	*P. devriesi*
Waimanu tuatahi	*W. tuatahi*

Lesson 4: Three Explanations

The first two of these explanations provide you a good opportunity to look for evidence for how students' thinking has shifted since Lesson 1, where these questions were introduced. Coupled with the third explanation, these work together to give students practice developing an explanation based on preliminary evidence to illustrate that changes over time occur in the existence, diversity, and disappearance of different kinds of penguins throughout history. Such an explanation is closely aligned to MS-LS4-1. Though some students may not yet be proposing evolutionary relationships between ancient and modern organisms, it is likely you will see draft ideas of these relationships being proposed in many students' explanations.

In purple text below are possible student responses. In this lesson, students are using these responses as time to think prior to the class discussion, and they should be considered to be in draft, thinking form.

Question 1: *Where did all the ancient penguins go?*

Explanation (in words or pictures):

The ancient penguins could have completely died off or gone extinct, likely because of an environmental change.

Optional: Some lines of descendants from one or more groups of ancient penguins could have changed so much that they were no longer recognizable. They could have somehow changed into modern penguins. Note: don't assume that the entire class is in agreement on "change" yet if the class isn't pushing for it now.

Evidence from our penguin groupings:

Our evidence for this is that modern penguins have different trait variations from ancient penguins.

Evidence we need:

We need additional evidence from penguins in the time period between ancient and modern penguins.

Question 2: *Where did all the different species of modern penguins come from?*

Explanation (in words or pictures):

At least one species of ancient penguins has descendents that are alive today. This/these species of penguins can be similar to one of the fossils that we have seen or to fossils that we have not seen because they are assumed to be undiscovered.

Different species of modern penguins must have descended from different lines of penguin ancestors that stretch back many, many generations.

Optional: The modern penguins could have come from some species of ancient penguin(s) that changed so much that they were no longer recognizable. Note: don't assume that the entire class is in agreement on "change" yet if the class isn't pushing for it now.

Evidence from our penguin groupings:

Our evidence for this is that we know some traits are heritable and in modern penguins we can see direct descendants. We can assume the fossils we looked at also had direct descendants.

Evidence we need:

We need additional evidence or more fossils from related penguins.

Question 3: *Why are there similarities and differences in the body structures of modern and ancient penguins?*

Explanation (in words or pictures):

- Penguins that are closer to one another in time share more body structure variations in common.
- They might share similar traits because the penguins might share common environments.
- We think that there might be differences in traits in different groups of penguins due to different possible causes:
  - environment changes or differences such as
    - climate
    - availability and distribution of food, water, shelter
    - type and number of predators
    - availability of mates
    - disease or absence of disease
  - changes in genes or something inherited
  - something that happens within the individual in response to the environment
  - something that happens to some or all the members of the population or group of penguins within a lifetime or over multiple generations
  - something that time causes (e.g., long periods of time always lead to some change, change is constant)
  - something that is random
- They are ancestors, related somehow, e.g., distant cousins.
- Optional: The species of different penguins might be slowly changing over time.

Evidence from our penguin groupings:

- Our evidence includes our penguin cards with penguins that share trait variations.

Evidence we need:

- We need to examine additional evidence of penguins between modern and ancient penguins.
- We need to examine additional evidence of penguins who lived in different environments.

Key: Guiding Questions to Compare Our Models

Discussion questions	Horseshoe crabs	Horses	Whales
How does your model incorporate <u>when</u> these organisms lived?	Crabs got bigger over time. The smallest ones lived the furthest back in time. Other than size, they didn't change much over time, though.	The horses with the most toes and the pointiest teeth lived longer ago in time. The ones that lived closer together in time were more similar in their types of toes and teeth.	Mostly, whales got bigger over time, but there were exceptions. Also, more ancient whales had teeth. Some of the more-recent fossils and one of the modern whales don't have teeth at all. More ancient whales had small hind limb bones. More modern whales don't.
How does your model incorporate <u>where</u> these organisms lived?	There wasn't any relationship to the geographical area because very similar-looking ones lived in a lot of different places. But they all lived in the exact same local environment, so maybe that's why their body structures are so similar.	All the fossil horses were in North or South America. The modern ones are only in Asia and Africa. The ones that lived in or near forests seemed to have more toes or hooves. The ones that lived on grasslands had fewer toes or only one hoof. Also, if they lived on grasslands, they had more big, flat molar teeth.	Geographically, they live everywhere, so there's no clear pattern. Mostly colder oceans have bigger whales and warmer oceans have smaller whales. But there are exceptions. The whales with teeth and the whales without teeth are both found all over the world.
What similarities did you notice across all three organisms as students shared their arguments for the patterns shown in their models?	Usually, their body structures are more alike when they're closer together in time. They all had different sizes over time. Their body structures are more similar if their local environments are more similar. There can be exceptions to every rule. They all were different throughout time, but some were less different from each other (horseshoe crabs) and some were more different from each other (whales).		
What new questions do you have?	Answers will vary.		

Name: _____ Date: _____

"How are penguins today connected to penguins from long ago?" Argument and Self-Assessment

Part 1

Based on the model you have developed so far, make a claim about how ancient and modern penguins are connected over time. Use words and/or drawings to construct an argument in support of your claim. Support your argument with evidence that we have from the unit so far and scientific reasoning.

Part 2: Discussion Self-Assessment

Complete the following self-assessment after our Consensus Discussion.

A. Read each statement and mark YES or NO for whole-class discussions and/or partner discussions.

Today, I. . .	In whole-class discussions		In small-group or partner discussions	
	YES	NO	YES	NO
. . . **shared my thinking** by sharing new ideas, asking new questions, or asking for clarification from others.				
. . . **listened actively to others** by rephrasing, repeating, and/or reusing the ideas of others and/or by asking others to repeat their statements or to clarify ideas when they are difficult to hear or understand.				
. . . **respectfully gave critiques** to others about their explanations, models, investigation plans, or questions by using observations, data, or evidence and asking questions.				
. . . **invited others to share** their thinking.				

B. Choose one statement for which you checked NO or a statement that you think you can improve on and write down 2 ideas for what you can do to improve in the next discussion.

Part 3

Revisit the argument you created in part 1. In a different color, use words and/or drawings to revise or add to your argument based on the discussion you had with your peers. We will use these revised arguments to launch the discussion in our next class. You can either edit in the argument you have above in part 1, or use the lines below for your revision.

Key: Argument for "How are penguins today connected to penguins from long ago?"

This assessment can be used to evaluate student progress on the following Lesson Level Performance Expectation (LLPE). The LLPEs are an integration of elements from the three dimensions, so look for these three aspects working together across the students' responses to the three prompts.

6.A Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support an explanation for whether the types of things that lived long ago are ancestors to the modern organisms we see today (stability and change).

SEPs	DCIs	CCCs
7.3 Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. Evidence that demonstrates students are using this practice in their written response includes the following: • The evidence that students provide to support their ideas comes from the fossil record and from modern organisms that show variations and differences present in the population already.	LS4.B Natural selection leads to the predominance of certain traits in a population, and the suppression of others. LS4.C Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. LS4.A Anatomical similarities and differences between various organisms living today, and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. Evidence that demonstrates students are using these science ideas in their written response includes the following: • Modern organisms we see alive now are descendants of the organisms from millions of years ago that we find fossil evidence of. • Each type of modern penguin descended from an ancient one (or something like one found in the fossil record). • Organisms must have changed somehow over time. • Penguins alive today descended from penguins that lived long ago, and somehow their body structures have changed.	7.1 Explanations of stability and change in natural or designed systems can be constructed by examining changes over time and forces at different scales, including the ~~atomic scale~~. Evidence that demonstrates students are using these concepts in their written response includes the following: • Connections are made between the patterns of differences in the body structures of certain types of organisms over really long periods of time (multiple generations) and across different environments.

Scoring Guidance: The scoring guidance provided below uses a + notation that can help you identify different ideas that students should (or could) include in their responses.

- If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether they are struggling with a science practice, science idea, or both.

- If all or almost all of the ideas marked with a + are present in a student's response, this may indicate the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

Optional Student Choice: Allow your students to choose the modality for communicating their thinking. They can construct their argument through written words, in pictures, or orally. Guidance is provided based upon writing; however, these same ideas could be communicated orally or in pictures.

Part 1: Based on the model you have developed so far, make a claim about how ancient and modern penguins are connected over time. Use words and/or drawings to construct an argument in support of your claim. Support your argument with evidence that we have from the unit so far and scientific reasoning.

Possible Claims

- Modern organisms we see alive now are descendants of the organisms from millions of years ago that we find fossil evidence of.
- Each type of modern penguin descended from an ancient one (or something like one found in the fossil record).
- Organisms must have changed somehow over time.
- Penguins alive today descended from penguins that lived long ago, and somehow their body structures have changed.

Possible Evidence

- Evidence is given from the fossil record and modern organisms that show variations and differences present in the population already.

Part 2: Discussion Self-Assessment Complete the following after our class consensus discussion.

A. Read each statement and mark YES or NO for whole-class discussions and/or partner discussions.

Today, I …	In whole-class discussions		In small-group or partner discussions	
… **shared my thinking** by sharing new ideas, asking new questions, or asking for clarification from others.	YES	NO	YES	NO
… **listened actively to others** by rephrasing, repeating and/or reusing the ideas of others, and/or by asking others to repeat their statements or to clarify ideas when they are difficult to hear or understand.				
… **respectfully gave critiques** to others about their explanations, models, investigation plans, or questions by using observations, data, or evidence and asking questions.				
… **invited others to share** their thinking.				

B. Choose one statement for which you checked NO—or a statement that you think you can improve on—and write down 2 ideas for what you can do to improve in the next discussion.

Part 3: Revisit the argument you created in part 1. In a different color, use words and/or drawings to revise or add to your argument based on the discussion you had with your peers. We will use these revised arguments to launch the discussion in our next class.

+ Student responses will vary based on their initial argument. Look to see that students have revised or added to their arguments after discussion with the class.

LESSON 7: ANSWER KEY 1

Key for All Data Packets

Finch Beaks Data Subset 1: Studies of the Population of Finches at the Beginning

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the range of variations for this trait in the population?
- What is the median value for this trait in the population?

Your summary:

The trait of interest is the length of the finches' beaks. The beak length ranges from 9.0 to 14.4 mm in 1976 (or 8.9-14.35 mm). The median value is 10.5-10.9 mm based on the Dry 1976 histogram. (Note that the median can be determined by counting up how many finches are in each category on the x-axis and determining what category contains the middle value.)

B. Interpret: What does this mean?

- Is this a trait with many variations?
- What do you think might be the effect of having a longer beak for finches living on Daphne Major?
- What do you think might be the effect of having a shorter beak for finches living on Daphne Major?

Your summary:

There are many variations in beak length. Longer beaks can eat larger seeds, so birds with longer beaks could eat larger seeds than birds with shorter beaks. They might not all be able to eat the same kinds of seeds.

Finch Beaks Data Subset 2: Environmental Studies

A. Identify: What do I see in the data?

- What patterns do you notice in seeds available over these years?
- What patterns do you notice in temperature and rainfall data over these years?

Your summary:

There were fewer seeds in the dry season of each year. There were way fewer seeds in 1977 than other years. In Dry 1977 data of the three seed graphs, there were only the big tribulus seeds left. The temperature is cooler in the dry season but doesn't change that much each year. There is less rain in the dry season every year, but in the dry season of 1976 and in 1977 there was barely any rain in any season.

B. Interpret: What does this mean?

- What change in the environment could have caused the change in the seeds available?
- How do you think this might have affected the finches?

Your summary:

There was less rain at the same time there were fewer seeds, so probably the plants didn't get enough water to grow seeds. Since the finches eat seeds and there were fewer seeds, they might have gotten very hungry. There might not have been enough seeds for all the finches.

Finches Beaks Data Subset 3: Survival and Reproduction Studies

A. Identify: What do I see in the data?

- What is the trend in the data for the survival of the finches?
- What is the trend in the data for the number of offspring?
- What is the trend in the data in the characteristics of survivors?

Your summary:

The number of finches surviving dropped between Wet 1976 and Dry 1977 from 60 to 10. After that it was steady. Also, there are usually more survivors in the wet seasons, but there wasn't much difference between the seasons in 1978. The number of adults and offspring were about the same each year, except in 1977 when there were no offspring. The median wing length didn't change, but the median beak length increased by 2 mm from 1976 to 1978.

B. Interpret: What does this mean?

- What do you think might be causing the effects on survival that you saw?
- What do you think might be causing the effects on the number of offspring produced?
- What do you think might cause the trend in the characteristics of survivors?

Your summary:

Maybe something happened in 1976 or 1977 like a predator came or they ran out of food or there was a disease that killed a lot of them. Maybe they were too busy or sick or hungry to mate, so they didn't have offspring. Maybe they grew longer beaks so they could fight off predators or get over the disease better.

Finches Beaks Data Subset 4: Offspring and Inheritance Studies

A. Identify: What do I see in the data?

- What is the trend in the data over time for the number of offspring?
- Do the characteristics of offspring show evidence that beak length is heritable in finches? Explain.
- Do the gene studies show evidence that beak length is heritable in finches? Explain.

Your summary:

The number of offspring was about the same as the number of breeding adults each year except 1977 when there were 0 offspring. The offsprings' characteristics were similar to their parents, so they might have been inherited. Also, it seems like the environment didn't affect them after the birds were adults. There is a gene that can help determine how long a bird's beak is, so beak length is heritable in finches.

B. Interpret: What does this mean?

- Would the weight or the beak length be more likely to be passed from parent to offspring?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

The beak length is more likely to be passed on. The weight changes with the season, but the beak length has a gene, so it's passed on from parents to offspring. Parents pass on inherited traits to offspring over generation after generation. So beak length could be passed on for many generations. But the environment might change characteristics like weight more, so that could be different from parents and grandparents.

Finches Beaks Data Subset 5: Studies of the Population of Finches at the End

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the range of variations in 1976? What is the range in 1978?
- What is the median value for this trait in 1978?
- Describe any differences in the distribution of the trait in 1976 and 1978.

Your summary:

The trait of interest is beak length. In 1976 the range of beak lengths was 9.0-14.4 mm. In 1978 the range was 10.5-13.9 mm. The median value in 1978 was 11.5-11.9 mm. In 1976 there were a lot of finches with beaks shorter than the shortest beak in 1978. In 1976 there was one bird with a beak longer than the longest beak in 1978. In 1976 the most common beak length (mode) was 10.0-10.4 mm, but in 1978 the mode was a millimeter longer. The distribution was about the same in 1977 and 1978.

B. Interpret: What does this mean?

- What change occured?
- What do you think might be the effect of having a longer beak for finches living on Daphne Major?
- What do you think might be the effect of having a shorter beak for finches living on Daphne Major?

Your summary:

Most finches have longer beaks in 1978 (and 1977) than in 1976. There aren't any with beaks shorter than 10.5 mm. Longer beaks let them eat bigger seeds, so maybe in 1978 they wanted to eat bigger seeds. Shorter beaks eat smaller seeds. But where did all the smaller-beaked birds go between 1976 and 1977?

Peppered Moths Color Data Subset 1: Studies of the Population of Peppered Moths at the Beginning

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What are the variations for this trait in the population?
- What is the proportion of those variations in the population in 1973?
- What is the difference in proportions in different areas?

Your summary:

The trait of interest is the color of the moths. There are black ones (carbonaria) and speckled ones (typical). In 1973 there were 12% typical and 88% carbonaria in one place. But in another industrial place in 1974-1979, it's 30% typical and 70% carbonaria. Either way, in industrial areas there are way more carbonaria, and in rural areas there are way more typical ones. Intermediate areas show closer to the same amount of both forms.

B. Interpret: What does this mean?

- What do you think might be the effect of having a lighter, speckled color (typical) for moths in each area?
- What do you think might be the effect of having a darker color (carbonaria) for moths in each area?

Your summary:

In an industrial area, maybe the darker moths like it better because it's darker there (like in the picture) because of the pollution. And the speckled moths like it better in the rural areas where it's lighter, like they are. A lighter color probably makes them fit in with the background better in the lighter area, while a darker color makes them fit in better with the background in a darker area. In the intermediate area, they both fit in about the same.

Peppered Moths Color Data Subset 2: Environmental Studies

A. Identify: What do I see in the data?

- What patterns do you notice in air pollution over 1973-1997?
- What pattern do you notice in lichen coverage on trees that relates to pollution levels?

Your summary:

The air pollution was decreasing a lot between 1973 and 1997. When there's more pollution in an area, there's less lichen coverage on the trees. So, lower pollution means more lichen coverage.

B. Interpret: What does this mean?

- How do you think any changes might have affected the peppered moths' survival?
- How do you think any changes might have affected the peppered moths' ability to find mates and reproduce?

Your summary:

With less pollution, there will be more lichen. We know the lichen on trees makes them lighter and speckly. So the speckled moths could probably camouflage better on trees with lichen, and then the birds won't eat as many of them. It might be harder for them to find mates if they are camouflaged, but they could probably still find mates and reproduce in any location.

Peppered Moths Color Data Subset 3: Survival and Reproduction Studies

A. Identify: What do I see in the data?

- What is the trend in the data for survival of each form of moth in different areas?
- What is the trend in the data for the offspring?
- What is the trend in the data for the forms of the moth over time?

Your summary:

In unpolluted areas, more of the typical ones survive. In polluted areas, more of the carbonaria ones survive. Over the time of the study, there were fewer and fewer carbonaria offspring and more and more typical offspring. In a polluted area of industrial England, in 1973 there were way more carbonaria and in 1997 there were way more typical.

B. Interpret: What does this mean?

- What do you think might be the effect of coloration on survival in polluted areas?
- What do you think might be the effect of coloration on survival in unpolluted areas?
- What do you think might explain the change in reproduction of each form over time?

Your summary:

Darker ones survive better in polluted areas, and lighter ones survive better in unpolluted areas. Maybe the darker ones can hide from predators better in the darker, polluted areas? Maybe the lighter ones do better in the lighter, unpolluted areas. Maybe the reproduction changed over time because darker ones couldn't find enough dark ones to mate with, so they mated with the lighter ones and less of their offspring were dark (and vice versa for the lighter ones).

Peppered Moths Color Data Subset 4: Offspring and Inheritance Studies

A. Identify: What do I see in the data?

- Do the characteristics of offspring show evidence that the coloration is heritable in peppered moths? Explain.
- What patterns provide evidence for your claim?

Your summary:

There is evidence that the coloration is heritable because when there is a dark parent, there are more dark offspring, and when there are no dark parents, there are no dark offspring. This is what we would expect to see if the typical gene is recessive and the carbonaria gene is dominant.

B. Interpret: What does this mean?

- Would color be passed from parent to offspring?
- Which color would be more likely to be passed down from parent to offspring?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

Color should pass from parent to offspring. The data show that carbonaria color is more likely to be passed down as long as there is at least one dark parent. The parents pass down half their genes to their offspring, so the next generation can only have whatever genes are in their parents. So their color would be passed down from generation to generation. But why aren't there more and more carbonaria if carbonaria is dominant?

Peppered Moths Color Data Subset 5: Studies of the Population of Peppered Moths at the End

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What are the variations for this trait in the population?
- What are the proportions of those variations in the population in 1997?
- What is the difference in proportions of those variations in the population in different areas in 1997?
- How do the proportions of those variations in the population shift over time?

Your summary:

Color is the trait of interest in this study. There are black (carbonaria) and speckled (typical) forms of the moths' color. In 1997, there were about 10% carbonaria and 90% typical in one industrial place. In the other industrial place, there were 20% carbonaria and 80% typical. But there are way fewer carbonaria in the rural areas than the industria areas—probably none. In the top graph it seems like it started out with way more carbonaria than typical, and now there are way more typical than carbonaria.

B. Interpret: What does this mean?

- What change occured?
- What do you think might be the effect of having a lighter, speckled color (typical) for moths in each area?
- What do you think might be the effect of having a darker color (carbonaria) for moths in each area?
- What do you think might be the effect of each color over time?

Your summary:

During the study, it went from mostly carbonaria to mostly typical color form. A lighter color will match the more-open rural areas, so the typical moths might be able to find more places to hide from birds in the rural areas. In the industrial areas it is probably more polluted and more crowded, so the darker ones can find more places to hide in the darker areas. Maybe they decided to change their colors over time to match where they wanted to live?

Cliff Swallows Wings Data Subset 1: Studies of the Population of Cliff Swallows at the Beginning

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the range of variations for this trait in the population?
- What is the median value for this trait in the population?

Your summary:

We're interested in the length of wings of the cliff swallows. The length ranges from 100 to 115 mm. The median value is probably 107 mm or maybe 108 mm. (Note that the median can be determined by estimating how many birds are in each category on the xaxis and determining what category contains the middle value. Exact answer is unnecessary here; an estimate will suffice.)

B. Interpret: What does this mean?

- How many different categories of variation are there in this trait?
- What do you think might be the effect of having longer wings for the swallows living under highways?
- What do you think might be the effect of having shorter wings for the swallows living under highways?

Your summary:

There are a lot of variations. Every different mm of length could be a different variation, so 16. Longer wings help them fly longer distances, so it might make it easier for them to move to highways from the cliffs where they used to live. Shorter wings make it easier to maneuver, so they might be able to fly around obstacles better.

Cliff Swallows Wings Data Subset 2: Environmental Studies

A. Identify: What do I see in the data?

- How did the cliff swallows' environment change?
- What was the greatest difference between their previous environment and their new environment?

Your summary:

Cliff swallows moved from nesting in cliffs to nesting under bridges near highways. There were way more cars near their nests in their new location.

B. Interpret: What does this mean?

- What change occurred in the traffic over the time scientists were studying the cliff swallows?
- How do you think this might have affected the cliff swallows over time?
- What would swallows need to be able to do to survive in their new environment?

Your summary:

The traffic seemed to increase between 1983 and 2012. More traffic would probably make them move away from the bridges and back to the cliffs, or maybe more of them would be hit by cars if there was more traffic in their area. If they stayed under the bridges, they would have to learn to avoid cars.

Cliff Swallows Wings Data Subset 3: Survival and Reproduction Studies

A. Identify: What do I see in the data?

- What is the trend in the data for the survival of the swallows?
- What is the trend in the data for the reproduction of the swallows?
- What is the trend in the data in the characteristics of the population at large?

Your summary:

There are more and more swallows surviving and not being hit by cars. There are more and more swallows being born in the bigger number of nests. The population of swallows has shorter wings on average over time.

B. Interpret: What does this mean?

- What do you think might be causing the change in survival in the population over time?
- What do you think might be causing a change in overall population size over time?
- What do you think might cause a change in the characteristics of survivors in this population over time?

Your summary:

The swallows could be finding more food or learning to live better in their new place. Maybe they are learning to get better at avoiding getting hit by cars. There are more of them because they are adjusting to their new home and getting better at living there. They might be inviting their friends to join them. Their wings might be getting shorter because that helps them get used to their new home, somehow. Maybe having shorter wings helps them avoid getting hit by cars as much.

Cliff Swallows Wings Data Subset 4: Offspring and Inheritance Studies

A. Identify: What do I see in the data?

- Do the characteristics of offspring show evidence that wing length is mostly heritable in swallows? Explain.
- Do the genetic studies show evidence that wing length is mostly heritable in swallows? Explain.

Your summary:

The characteristics show that offspring had wings pretty similar to their parents, and when the parents had different wing lengths, the offspring had a length in between. That is similar to what we saw in our genetics unit—offspring are similar to their parents because they inherit a lot of their genes. The genetic studies show that 60% is due to genetics, so it's mostly heritable.

B. Interpret: What does this mean?

- Would the weight or the wing length be more likely to be passed from parent to offspring?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

Wing length is more likely to be passed down because that is genetic. Weight seems to change a lot, so it's probably about how much food they eat. If a trait is heritable, it gets passed down to offspring. Since a line of descendants is just offspring and then their offspring and then their offspring, the heritable traits would be passed down more.

Cliff Swallows Wings Data Subset 5: Studies of the Population of Cliff Swallows at the End

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the most common value for this trait for roadkill birds? What is the most common value for the population at large?
- What is the trend in the average value for this trait over time for the population at large?
- What is the average value for this trait in the population at large in 1983? What is the average value in the population at large in 2010?

Your summary:

The trait of interest is wing length. The mode for roadkill is 110 mm, and for the population at large, the mode is 108 mm. Over time, the average length of wings of road-killed birds gets bigger, and in the population at large, it gets smaller. The average wing length in the population in 1983 is almost 111 mm. The average wing length in the population in 2010 is just a little less than 107 mm.

B. Interpret: What does this mean?

- What change occurred in this trait over time in the population at large?
- What do you think might be the effect of having longer wings for the swallows living under highways?
- What do you think might be the effect of having shorter wings for the swallows living under highways?

Your summary:

The birds' wings got shorter on average over time. That could mean every bird's wings got shorter or that more of the birds in the population had shorter wings over time. Longer wings let them fly farther, so maybe those birds could go further to get food. Shorter wings help them maneuver better, so maybe they'd be better at catching food or maybe they could get out of the way of cars better.

Mustard Plants Time to Flowering Data Subset 1: Studies of the Population of Mustard Plants at the Beginning

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the range of variations for this trait in the population?
- What is the median value for this trait in the population?

Your summary:

The trait of interest is flowering time. 90% of the plants flower between 40 and 78 days after they sprout. The median value is 58 days.

B. Interpret: What does this mean?

- Is this a trait with many variations?
- What do you think might be the effect of having a shorter time to flowering for mustard plants?
- What do you think might be the effect of having a longer time to flowering for mustard plants?

Your summary:

Every day could be considered a different variation, so there are more than 38 variations. If plants have a shorter time to flowering they might get a head start on the other plants. If they have a longer time to flowering, the lack of water later in the season could cause those plants to die before they flower and make seeds.

Mustard Plants Time to Flowering Data Subset 2: Environmental Studies

A. Identify: What do I see in the data?

- What happened in the environment over the time of the studies on the mustard plants (1997-2004)?
- What was the greatest difference between the mustard plant's environment in 1997 and in 2004?

Your summary:

In 1997 there was more than the average rainfall, and every year after that there was barely the average or less than average. It was especially less in 2004. In 1997 it would have been a wetter area, and in 2004 it had been drier for several years, like in a drought.

B. Interpret: What does this mean?

- How do you think this might have affected the mustard plants' survival?
- How do you think this might have affected the mustard plants' ability to produce seeds?

Your summary:

Plants need water to survive, so probably they didn't do as well in the later years. If they're not growing well, they might not make seeds, so they probably made fewer or no seeds when they didn't have enough water.

Mustard Plants Time to Flowering Data Subset 3: Survival and Reproduction Studies

A. Identify: What do I see in the data?

- What is the difference in the survival of the mustard plants from the 1997 population compared to the 2004 population?
- What is the difference in the ability of the mustard plants to reproduce in the 1997 population compared to the 2004 population?

Your summary:

Both 1997 and 2004 plants survived well in a long growing season, but the 2004 plants survived more (75%) than the 1997 plants (50%) in a short growing season. The 2004 plants could make flowers sooner than the 1997 plants, and therefore they could make seeds sooner than the 1997 plants.

B. Interpret: What does this mean?

- If water is available only for a short growing season, which flowers will be most likely to reproduce and make seeds for the following year?
- If water is available for a long growing season, which flowers will be most likely to reproduce and make seeds for the following year?

Your summary:

In a short growing season, more of the 2004 plants will survive and they'll make seeds sooner, so more of the 2004 plants will reproduce in a short growing season. If there is a long growing season, both types will survive the same, but 2004 plants will still make seeds sooner. But they might still all make seeds eventually in a long growing season.

Mustard Plants Time to Flowering Data Subset 4: Offspring and Inheritance Studies

A. Identify: What do I see in the data?

- What is the pattern of survival in a short growing season for the three offspring populations?
- Do the characteristics of the three offspring populations show evidence that the ability to survive in a short growing season is heritable in mustard plants? Explain.
- What is the pattern of time to flowering for the three offspring populations?
- Do the characteristics of the three offspring populations show evidence that time to flowering is heritable in mustard plants? Explain.

Your summary:

The 2004 purebreds survived the best. The 1997 purebreds survived the worst. The hybrid was in between. This shows that survival in a short growing season is heritable because the hybrid was in between, and because the purebreds had mostly the same phenotype as their parents. It's the same with flowering time. The 2004 purebreds have the shortest, the 1997 purebreds have the longest, and the hybrids are in the middle. This shows it is heritable because the hybrids are in the middle and the purebreds had mostly the same phenotype as their parents.

B. Interpret: What does this mean?

- Are there structural differences between the populations?
- If a trait is heritable, how does that affect the traits of the offspring in the next generation?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

There are structural differences in some of the proteins related to flowering time. Heritable traits are passed on. So if a trait is heritable, it will be passed on to offspring in the next generation and they'll have similar traits to their parents. If we want to know about descendants, we know that heritable traits will make the descendants be similar to their parents. So we can be sure that heritable traits will be passed down and show up in the offspring for many generations.

Mustard Plants Time to Flowering Data Subset 5: Studies of the Population of Mustard Plants at the End

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the range of variations in the 1997 plants? What is the range in the 2004 plants?
- What is the median value for this trait in the 2004 plants?

Your summary:

We're interested in days to first flowering as a trait. In 1997, the range was 40 to more than 78 days. In 2004, the range was less than 37 to more than 67 days. The median value in the 2004 plants is about 46 days.

B. Interpret: What does this mean?

- What change occured?
- What do you think might be the effect of having a shorter time to flowering for mustard plants?
- What do you think might be the effect of having a longer time to flowering for mustard plants?

Your summary:

The median time to flowering got shorter in the population from 1997 to 2004. That means more of the plants were blooming sooner in 2004 than in 1997. Shorter flowering time will let them get a head start on the other plants, so they might make more seeds or their seeds might grow better. Longer flowering time means a plant will need more resources like water and sunlight to be able to make seeds.

Sticklebacks Armor Data Subset 1: Studies of the Population of Sticklebacks at the Beginning

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What are the variations for this trait in the population?
- What is the proportion of those variations in the population in 1991?

Your summary:

The trait of interest is the number of bony armor plates on the sides of stickleback fish. There are high numbers (27-35) and low numbers (4-10). Somewhere between 35% and 75% of fish have a high number of plates. In 1991, about 75% of fish have a high number of plates, and about 15% have a low number of plates.

B. Interpret: What does this mean?

- What do you think might be the effect of having fewer bony armor plates for the stickleback in Loberg Lake?
- What do you think might be the effect of having more bony armor plates for the stickleback in Loberg Lake?

Your summary:

Fewer armor plates would make it easier for them to hide from predators in the lake, but if they had more plates, they would be able to survive better if they were attacked by predators in the lake.

Sticklebacks Armor Data Subset 2: Environmental Studies

A. Identify: What do I see in the data?

- How did the environment of the sticklebacks change when they arrived in Loberg Lake?
- What was the greatest difference between their previous environment and their new environment?

Your summary:

They came from the ocean where it's wide open and there aren't a lot of plants and things to hide behind like in the lake. Also, the lake is freshwater, but the ocean is saltwater.

B. Interpret: What does this mean?

- How do you think the change in environment might have affected the sticklebacks' ability to survive?
- How do you think the change in environment might have affected the sticklebacks' ability to find mates and reproduce?

Your summary:

They might be affected by it being freshwater, but we don't have any information about how that would affect them. If they were used to the open ocean, it might be harder for them to survive in a lake. In a lake they don't group together in shoals like they do in the ocean, so it might be harder for them to find mates if they're farther apart.

Sticklebacks Armor Data Subset 3: Survival and Reproduction Studies

A. Identify: What do I see in the data?

- What fish were more likely to survive being caught by a predator?
- What is the trend in the data for the number of bony plates on the fish over time?

Your summary:

Fish with more armor plates were more likely to escape and survive if they were caught. The trend in the data for the number of bony plates over time is that there were more and more offspring that had fewer armor plates over time.

B. Interpret: What does this mean?

- What do you think is the effect of the number of bony plates on survival of the fish in Loberg Lake?
- What do you think might explain the change in which fish were reproducing over time?

Your summary:

If they have more bony plates, they're more likely to survive being grabbed by a predator in the lake. Only fish that are surviving will be able to reproduce. Over time the population had more fish with fewer armor plates, but it seems like it should be opposite because fish with more armor plates survive better when grabbed by a predator.

Sticklebacks Armor Data Subset 4: Offspring and Inheritance Studies

A. Identify: What do I see in the data?

- Do the characteristics of offspring show evidence that the number of bony armor plates is heritable in sticklebacks? Explain.
- What patterns provide evidence for your claim?

Your summary:

Yes, the number of bony plates is heritable. The high number and the low number are passed on from parents to offspring. This supports the claim that they're heritable. If low and high parents breed together, it's more complicated.

B. Interpret: What does this mean?

- Would the number of bony armor plates be passed from parent to offspring?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

Yes, the number of bony plates should be passed from parents to offspring (though sometimes it's more complicated because there is more than one gene involved). The parents who pass their traits on to their offspring determine which traits stay in the population.

Sticklebacks Armor Data Subset 5: Studies of the Population of Sticklebacks at the End

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What are the variations for this trait in the population?
- What is the proportion of those variations in the population in 2001?
- How does the proportion of those variations in the population shift over time?

Your summary:

The trait of interest is the number of bony armor plates on the sides of stickleback fish. There are fish with high numbers (27-35) and fish with low numbers (4-10). In 2001, about 72% have low numbers and 10% have high numbers. Over time, the population shifts from having mostly fish with high numbers of plates to having mostly fish with low numbers of plates.

B. Interpret: What does this mean?

- What change occurred?
- What do you think might be the effect of having fewer bony armor plates for the stickleback in Loberg Lake?
- What do you think might be the effect of having more bony armor plates for the stickleback in Loberg Lake?
- What do you think might be the effect on plate numbers in the population over time?

Your summary:

The proportion of fish in the population with high or low numbers of plates changed over time. If they have fewer bony plates, they can probably swim through the vegetation and hide better in the lake. If they have more bony armor, they can probably defend themselves against predators. I think the number of armor plates will stay about the same because some fish will avoid predators and most will be able to hide.

Key for Using the CCC Lens

Use the crosscutting concepts below to help you think more deeply about your case. Respond to the prompts and record your thoughts in each section by writing or drawing.

Structure and Function				
What structure(s) is relevant to your case study? What specific functions are affected by variation in that structure?				
Finch structure - Beaks, the length of beaks **Finch function -** Length affects what size seeds they can eat. Birds with longer beaks can eat bigger seeds. Only long beaks can eat tribulus seeds.	**Swallow structure** - Wings, wing length **Swallow function -** How well they fly is affected. Shorter wings can avoid cars better. Longer wings can't.	**Moth structure -** Color of their wings and body **Moth function -** Helps them hide on different parts of the surface of the trees so they can camouflage and birds can't see them to eat them	**Stickleback structure -** Bony plates on the sides of the body, the number of bony armor plates **Stickleback function** - Affects how easy they are for predators to eat and how well they can avoid predators by hiding. More bony plates allows them to survive attacks better. Fewer plates allows them to move and hide among lake plants better.	**Mustard plant structure** - Proteins that help growth and flowering **Mustard plant function** - Affects when they flower (bloom), which affects how fast they make seeds, affects how many seeds survive

Trait of interest:	
Cause and Effect on Individuals	
How does having a specific trait variation affect the individual? **Finches -** Longer beak allows them to eat the bigger seeds so they can get food when it's scarce. **Swallows** - Shorter wings allows them to maneuver better and avoid getting hit by cars more easily. **Moths -** Color makes it possible for moths to camouflage better. **Sticklebacks -** Fewer bony plates allows them to hide among the lake weeds better. **Mustard plants** - Blooming earlier makes it easier for them to make seeds before the dry season and for the plants from those seeds to grow during the next season. Would that specific trait variation always affect every individual the same way? **Finches -** No. They still might not have enough food and some wouldn't get any. **Swallows -** No. They're more likely to avoid cars, but they might still get hit. **Moths -** No. They try to hide, but they might still be found and eaten. **Sticklebacks -** No. They try to hide, but they might still be found and eaten. **Mustard plants -** No. Some plants might still not get pollinated, or their seeds might not grow.	How does having a specific trait variation affect the offspring that an individual can produce? **Finches -** Beak length is inherited, so they're likely to have offspring with the same beak length as them. **Swallows -** Wing length is inherited, so they're likely to have offspring with the same wing length as them. **Moths -** Color pattern is inherited, so they're more likely to have offspring with the same color pattern as them. **Sticklebacks -** Number of plates is inherited in a complicated way, so offspring probably will have a similar number of plates as them. **Mustard plants -** Blooming time is inherited, so the offspring are likely to have seeds with the same blooming time as them. Does the trait variation affect how likely the individual would be to produce offspring? **Finches -** Yes. If they don't have enough food that they can eat with a smaller beak, they die. And you have to be alive to reproduce. **Swallows -** Yes. If they get hit by a car and die, they can't reproduce. **Moths -** Yes. If they get eaten, they can't reproduce. **Sticklebacks -** Yes. If they can't hide, they'll probably get eaten and then they're dead, and dead fish can't reproduce. **Mustard plants -** Yes. If they bloom earlier, they have more access to water and the things they need to make seeds, so they're more likely to reproduce when there's a drought.

Trait of interest:	
Cause and Effect on Populations	
How does having different trait variations affect the whole population? **Finches -** Because longer beaks affect who lives and who dies, more longer-beaked birds will survive in the population when there are no small seeds to eat. **Swallows -** Because more shorter-winged birds will not die from cars, more shorter-winged birds will survive in the population. **Moths -** Because more moths that can camouflage on the trees in a particular area will survive, there will be more moths of that color in the population in that area. **Sticklebacks -** Because fewer bony plates allow fish to hide better in the weeds in the lakes, more fish with fewer plates will survive in the population. **Mustard plants -** Because blooming earlier affects which plants can make more seeds, in the next year more plants that bloom earlier will grow from the seeds.	How does having different trait variations in the population affect the trait variations that appear in the offspring produced by that population? **Finches -** Only survivors can reproduce, so offspring will mostly have the variations of the ones that survive, such as longer beaks. **Swallows -** Only survivors can reproduce, so offspring will mostly have the variations of the ones that survive, such as shorter wings. **Moths -** Only survivors can reproduce, so offspring will mostly have the variations of the ones that survive, such as whichever color matches the trees in their area. **Sticklebacks -** Only survivors can reproduce, so offspring will mostly have the variations of the ones that survive, such as fewer bony plates. **Mustard plants -** Only survivors can reproduce, so offspring will mostly have the variations of the ones that survive the best, such as earlier blooming time.

LESSON 7: ANSWER KEY 3

Key for Developing a System Model

We want to develop a system model to represent what is happening that can explain how and why the population changed over time in the ways we identified. A system model includes key **parts (components)** of the system, and it includes **interactions** among those parts. A system model can be **used to help us explain** how the whole system works.

CCC: Systems and System Models

Parts (components)

- The population
- What are other key parts (components) that need to be in your system model?

Finches	Moths	Swallows	Sticklebacks	Mustard plants
Beaks, variations, rainfall, 3 plants especially tribulus, death, HMGA2 gene alleles, wing lengths, offspring, Daphne Major, the Grants	Color of wings; trees; lichen; pollution; birds; clean air laws; scientists; rural, intermediate, and industrial woodlands; caterpillars; pupae; offspring	Wings, variations, bridges, cliffs, cars, people driving, highways, generations, mud nests, the Browns, insects, offspring	Bony armor plates, variations, vegetation, predator fish, lake, ocean, offspring, scientists	Number of days to flower, seeds, rain, a lab, scientists, wet soil and dry soil, a calendar, dead plants, flowers, hybrids and purebreds, offspring

Interactions: What are some key interactions going on between those parts (components) that need to be included in your model?

Finches	Moths	Swallows	Sticklebacks	Mustard plants
Beaks eating seeds	Colors causing camouflage	Birds moving from cliffs to bridges	Fish moving from the ocean to the lake	Rain making plants grow
Rain growing plants	Pollution causing less lichen on trees	Cars killing swallows	Predators eating sticklebacks	No rain making plants die, soil dry
Plants making seeds	Pollution making trees darker	Cars driving on highways	Sticklebacks hiding in vegetation in the lake	Plants making flowers
Drought killing plants and birds	Birds eating moths they can find	Birds nesting under bridges	Sticklebacks with fewer plates hiding better than those with a lot of plates	Flowers making seeds
Alleles causing beak length	Clean air laws reducing pollution	People driving cars		Days going by
Parents having offspring	Moths having caterpillar offspring	Generations changing		Hybrids grow differently than purebreds
Offspring having alleles	Caterpillars becoming pupae	Birds eating insects		Scientists in a lab
Grants going to Daphne Major		Browns counting birds		

Use the model to explain phenomena: What will you need to explain using your model?

Finches

Why there wasn't enough food for the finches (because fewer plant seeds because less rain)

Why longer beaks let them live (they could eat the big seeds that survived the drought)

Why the distribution changed (the shorter-beaked birds died so no offspring, so only longerbeaked offspring)

How we know that the trait is genetic

Moths

Why the trees and the moths are different in polluted vs. unpolluted areas

Why it's more polluted in industrial areas

How the lichen colors the trees

How the different colors of moths can hide on trees with more or less lichen

Why there are a lot of typical when carbonaria is dominant

How we know that the trait is genetic

Swallows

Why birds with shorter wings survived better (because short wings means more maneuverable which means less getting hit by cars)

Why there were more and more shorter-winged birds over time

Why cars killed fewer shortwinged birds

Why the birds moved to the highways in the first place

How we know that the trait is genetic

Sticklebacks

How the environment is different in the ocean and in the lake

How fewer plates lets fish hide more in the lake vegetation

How the predators bite and eat the sticklebacks

Why there were more and more sticklebacks with fewer bony plates over time

How we know that the trait is genetic

Mustard plants

Why less rain means a shorter growing season

How plants make offspring

There was less rain for a few years

How come some survived and some didn't

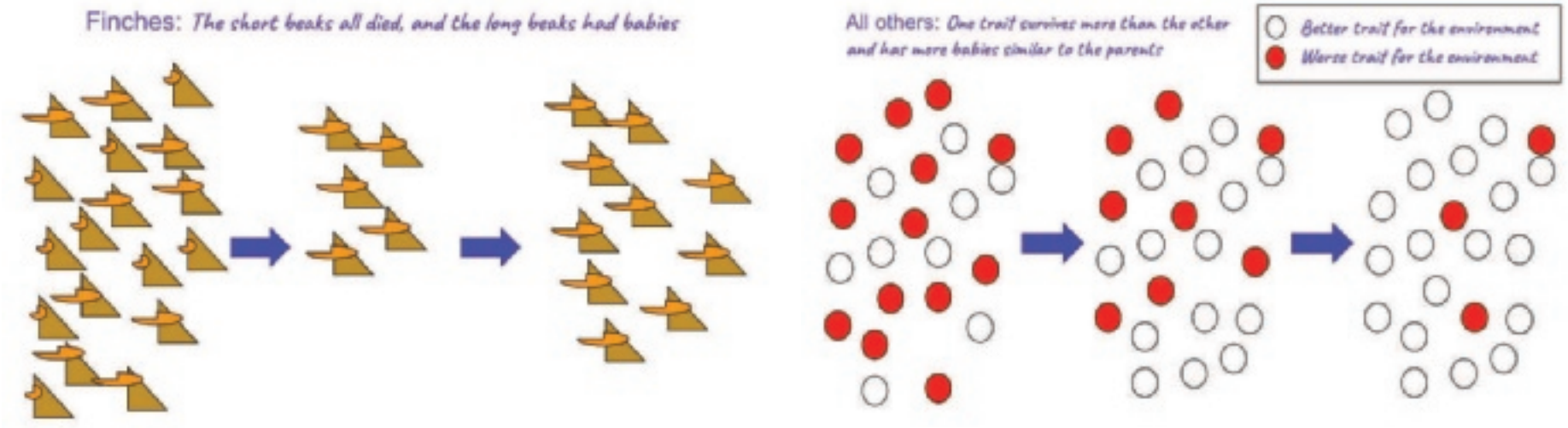
Why the scientists grew them in a lab

How we know that the trait is genetic

Our system model helps us explain how and why the population changed from the beginning to the end of the study. In each case there are effects on the **quantity** of individuals in the population and the proportion of individuals with a particular trait.

CCC: Scale, Proportion, and Quantity

Sketch a diagrammatic model that shows a population of your organisms at the start of your case study. Then show what happens to the population over the next couple of generations. Be sure to represent effects on **quantity** and **proportion**.



Summary of Natural Selection Cases

	Finches	Moths	Swallows	Plants	Fish	*Common for all cases*
Studies of population at the beginning	Distribution of beak length in 1976	Distribution of two color morphs in 1959	Distribution of wing length in 1992 and 1996	Distribution of time to flower in 1997	Distribution of bony armor plate numbers in 1991	Trait variation in the population in the past
Environmental studies	Drought Decreased food plants available (only hard, spiny seeds left)	Pollution reduction Increased lichen cover	New highways built Nesting along highways Increased traffic along the highways over time	Drought, a time of much below average rainfall	Fish relocated from the ocean to a freshwater lake.	Environmental change
Survival and reproduction studies	Birds that died Field notes describe the behavior of survivors	Predation rates of different-colored moths on particular tree surfaces	Fewer dead swallows over time Surviving swallows have shorter wings	Survival rates under low-moisture conditions Average time to flower (reproduce) is shorter	Fish with more bony plates survive being caught by predators. Population that includes offspring shows a shift in proportion of plate numbers.	The environmental change affects available resources needed for survival, and some variations survive or reproduce better.
Offspring and inheritance studies	Specific offspring of survivors have the same trait as parents.	Mendelian genetics studies show a pattern consistent with inheritance.	Inheritance is inferred from known inheritance of skeletal structures in other birds.	Hybrid offspring have intermediate trait variations.	Patterns of inheritance Specific proteins involved	The traits that grant an advantage for surviving or reproducing can be passed on to their offspring.
Studies of population at the end	Shifted histogram	Shifted bar charts	Shifted average (scatter plot)	Shifted the average and the box plot	Shifted histogram	Distribution shows more individuals with the trait that allows them to survive or reproduce better.

Name: _____ Date: _____

Argumentation Self-Assessment

Thinking about what we did in class today as a whole class and in partners, mark YES or NO to reflect on your participation in whole-class and partner discussions. Then think about what you might do differently next time and share your thinking below the table.

Today, I. . .	In whole-class discussions		In partner discussions	
	YES	NO	YES	NO
. . . **shared my thinking** by sharing new ideas, asking new questions, or asking for clarification from others.				
. . . **listened actively to others** by rephrasing, repeating and/or reusing the ideas of others, and/or by asking others to repeat their statements or to clarify ideas when they are difficult to hear or understand.				
. . . **respectfully gave critiques** to others about their explanations, models, investigation plans, or questions by using observations, data, or evidence and asking questions.				
. . . **invited others to share** their thinking.				
. . . **figured out something that helped me** make progression on ideas that I think apply to explaining changes in traits in **any** population over time.				

Choose **one** statement for which you checked NO or a statement that you think you can improve on and write down **2 ideas** for what you can do to improve in the next whole class, small group, or partner discussion.

_____

_____

_____

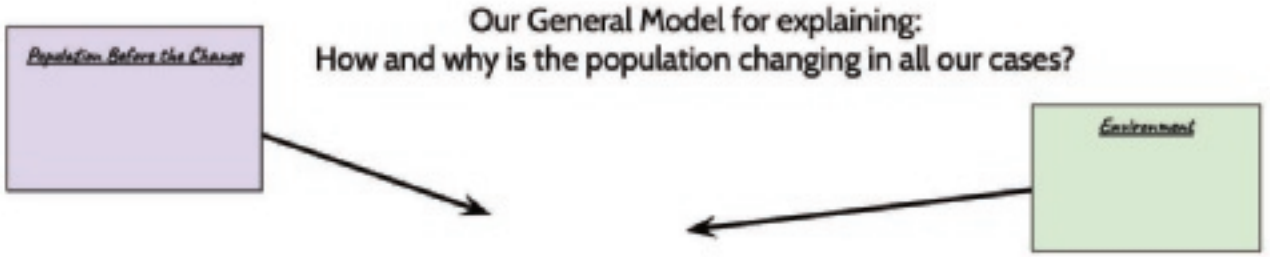
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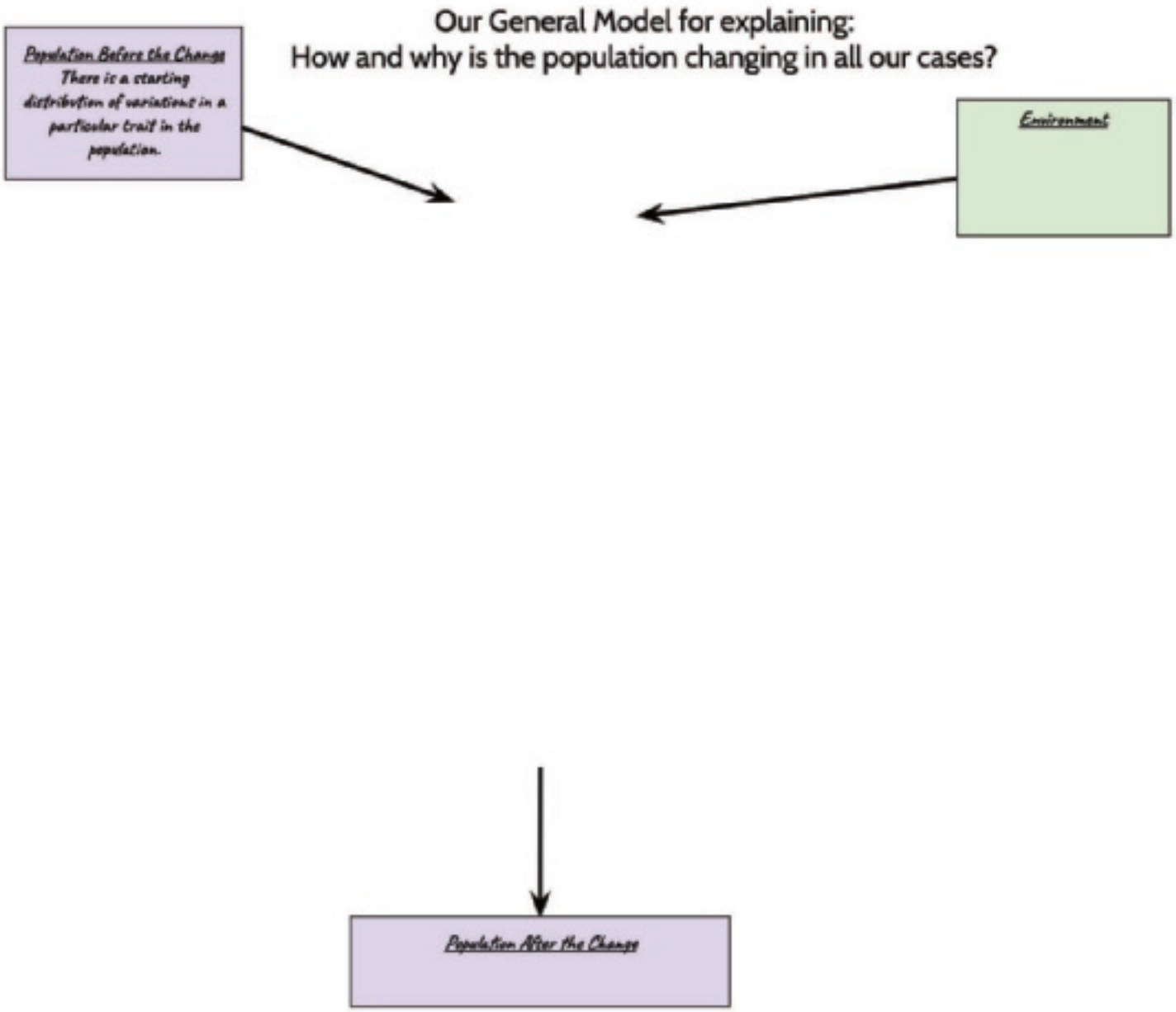
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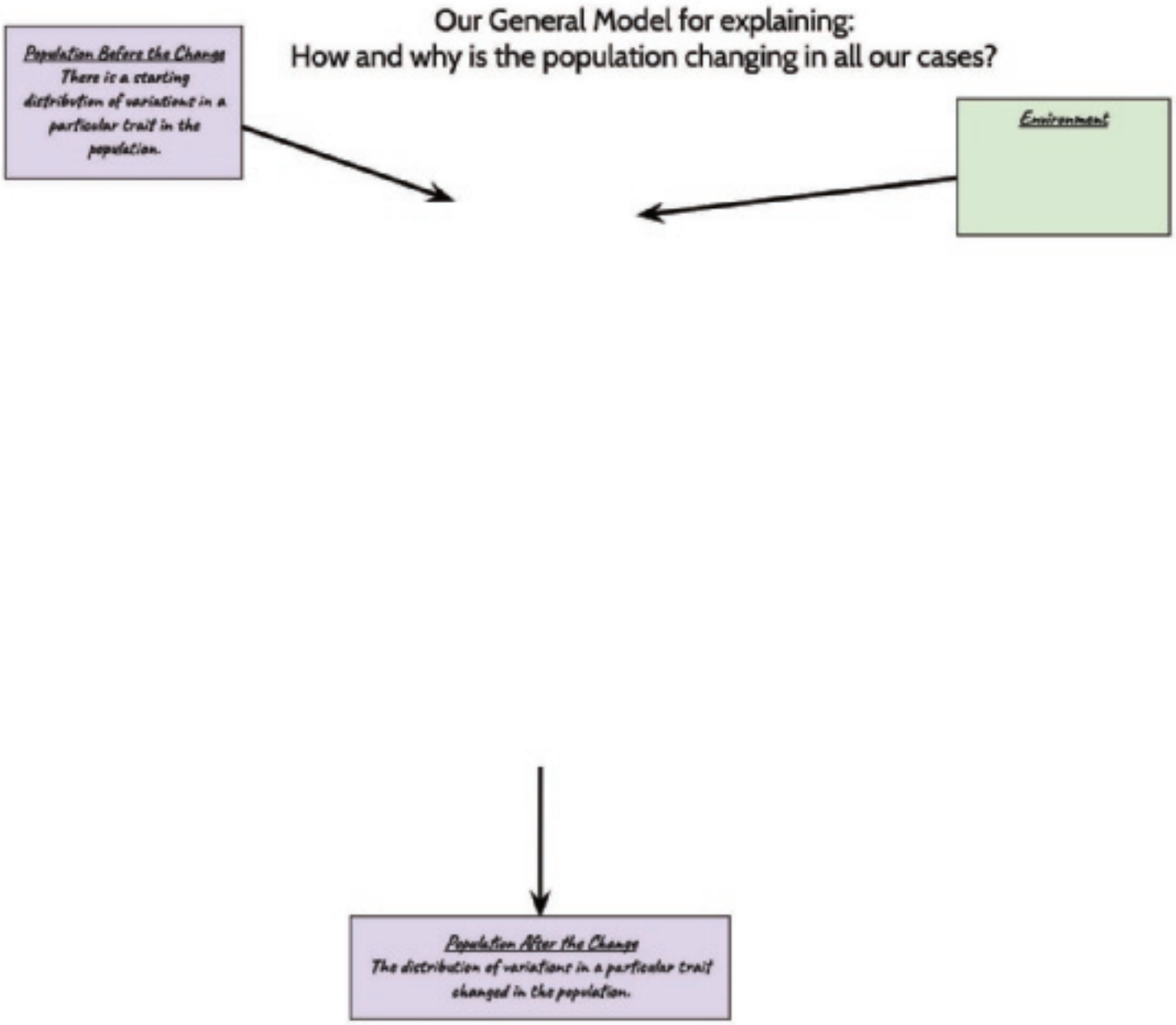
Lesson 8 Sample Images for General Model

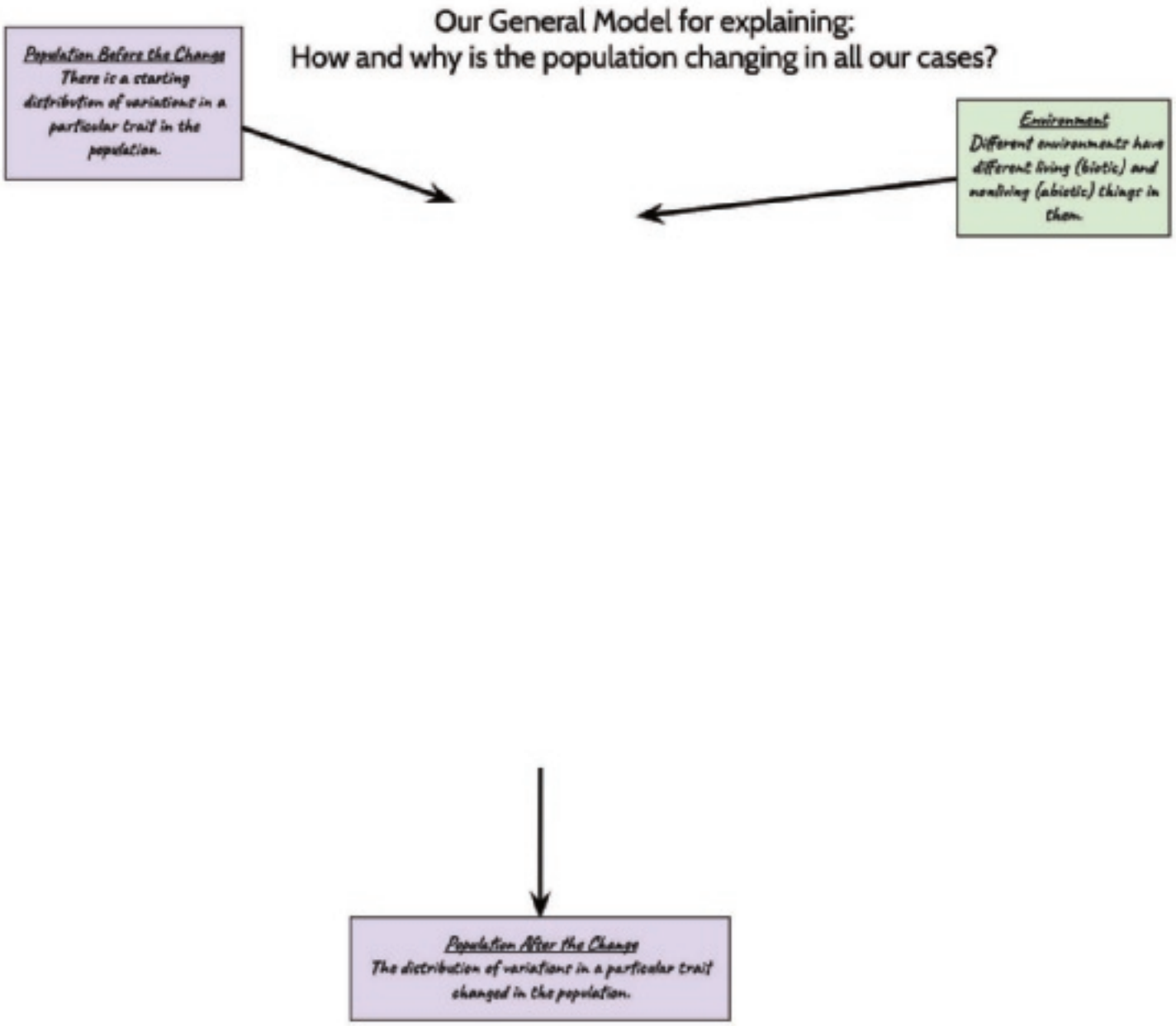
The following pages show the incremental building of the General Model for Natural Selection in Lesson 8. You will add a few more pieces in Lessons 9 and 10.

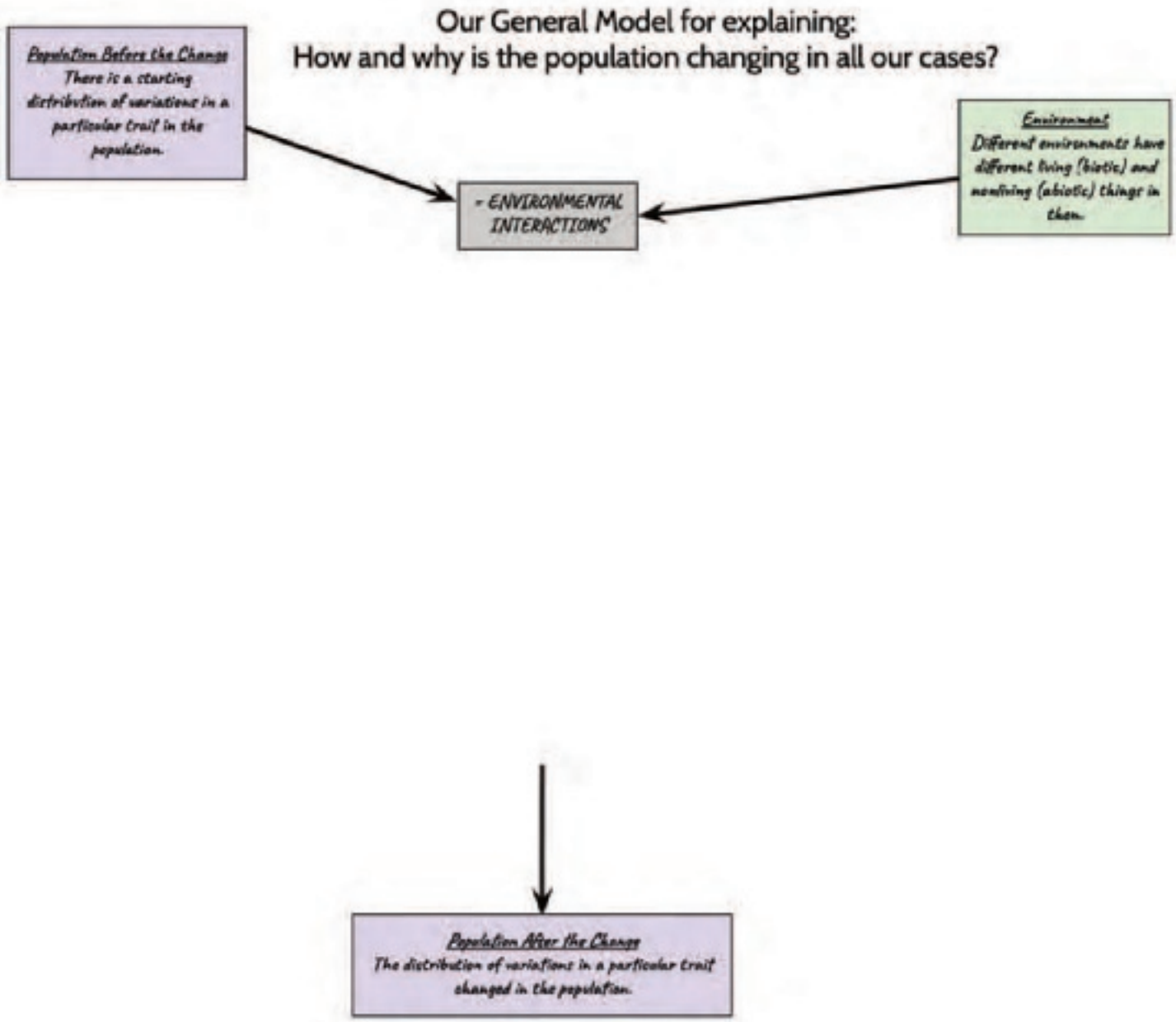


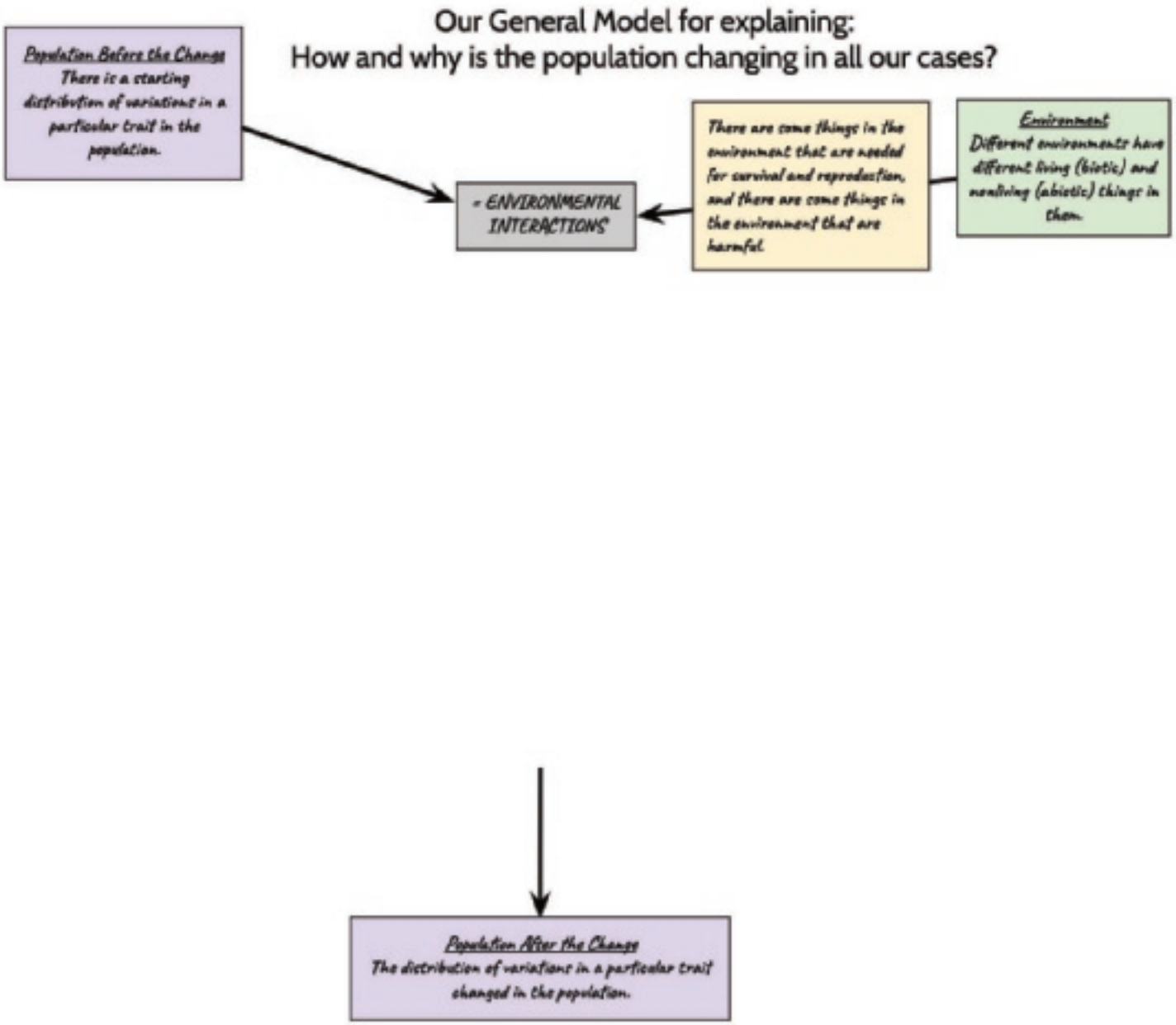


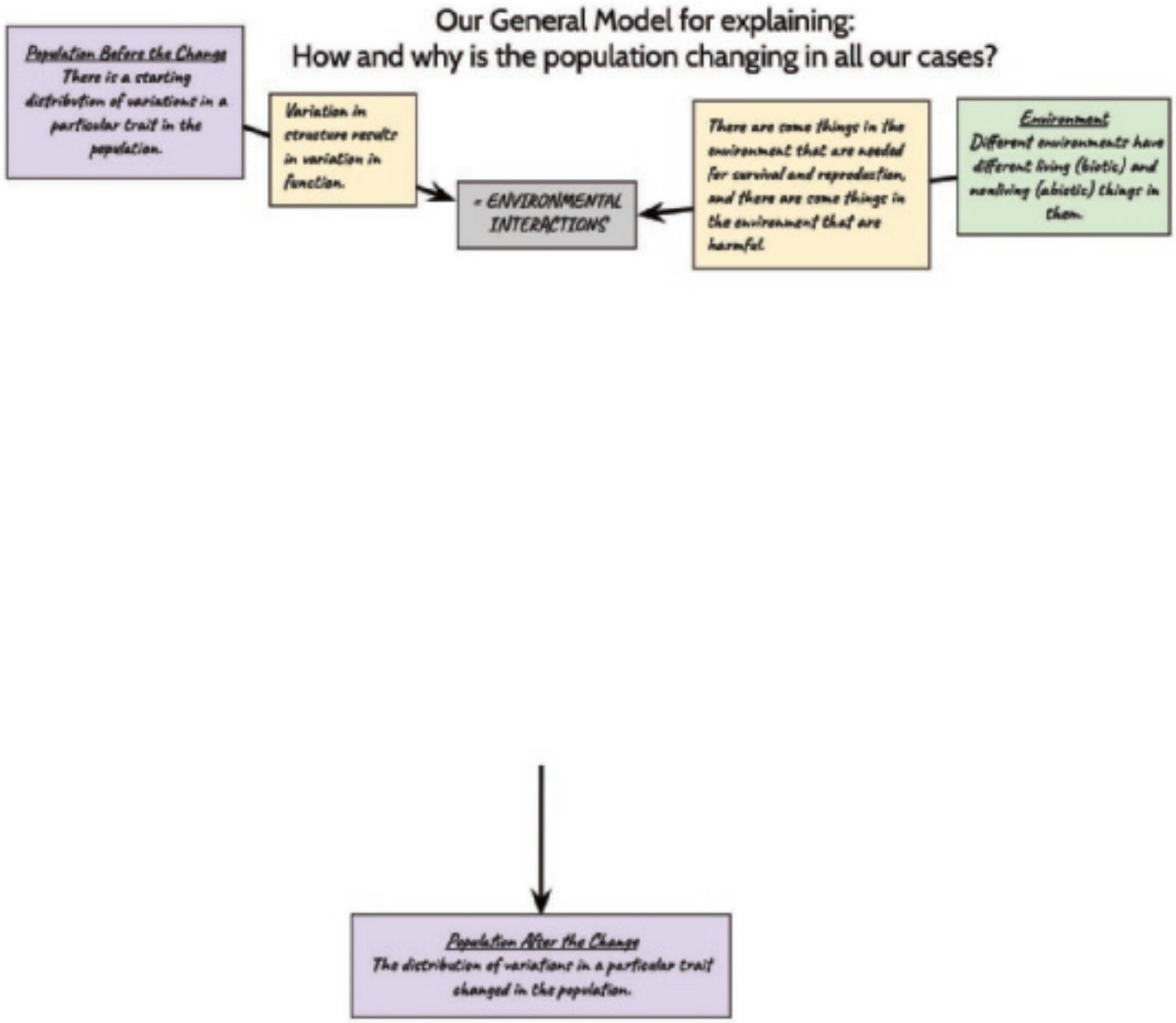

Our General Model for explaining:
How and why is the population changing in all our cases?
Population Before the Change
There is a starting distribution of variations in a particular trait in the population.
Environment
Population After the Change

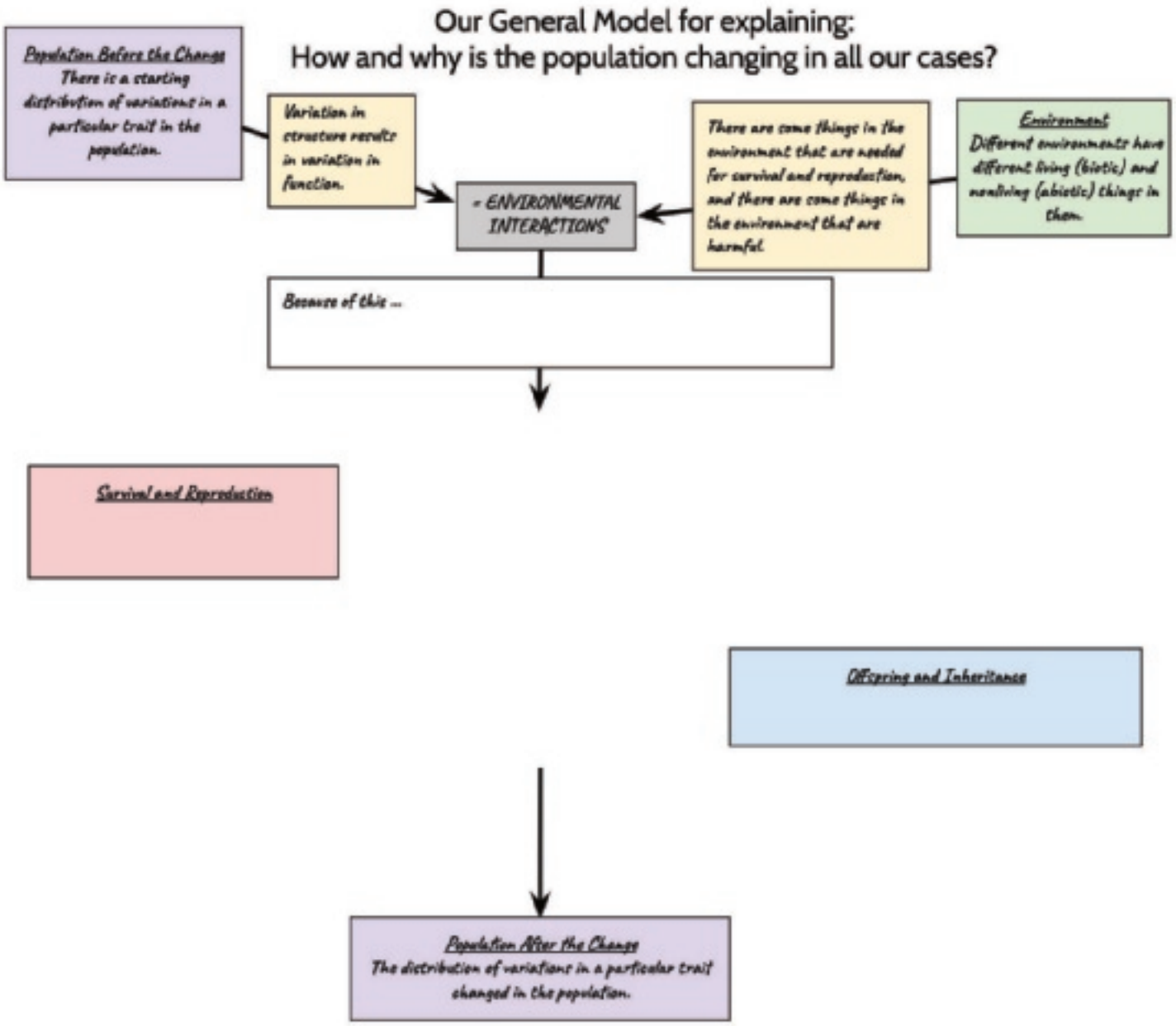

Our General Model for explaining:
How and why is the population changing in all our cases?
Population Before the Change
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Environment
Population After the Change
The distribution of variations in a particular trait changed in the population.

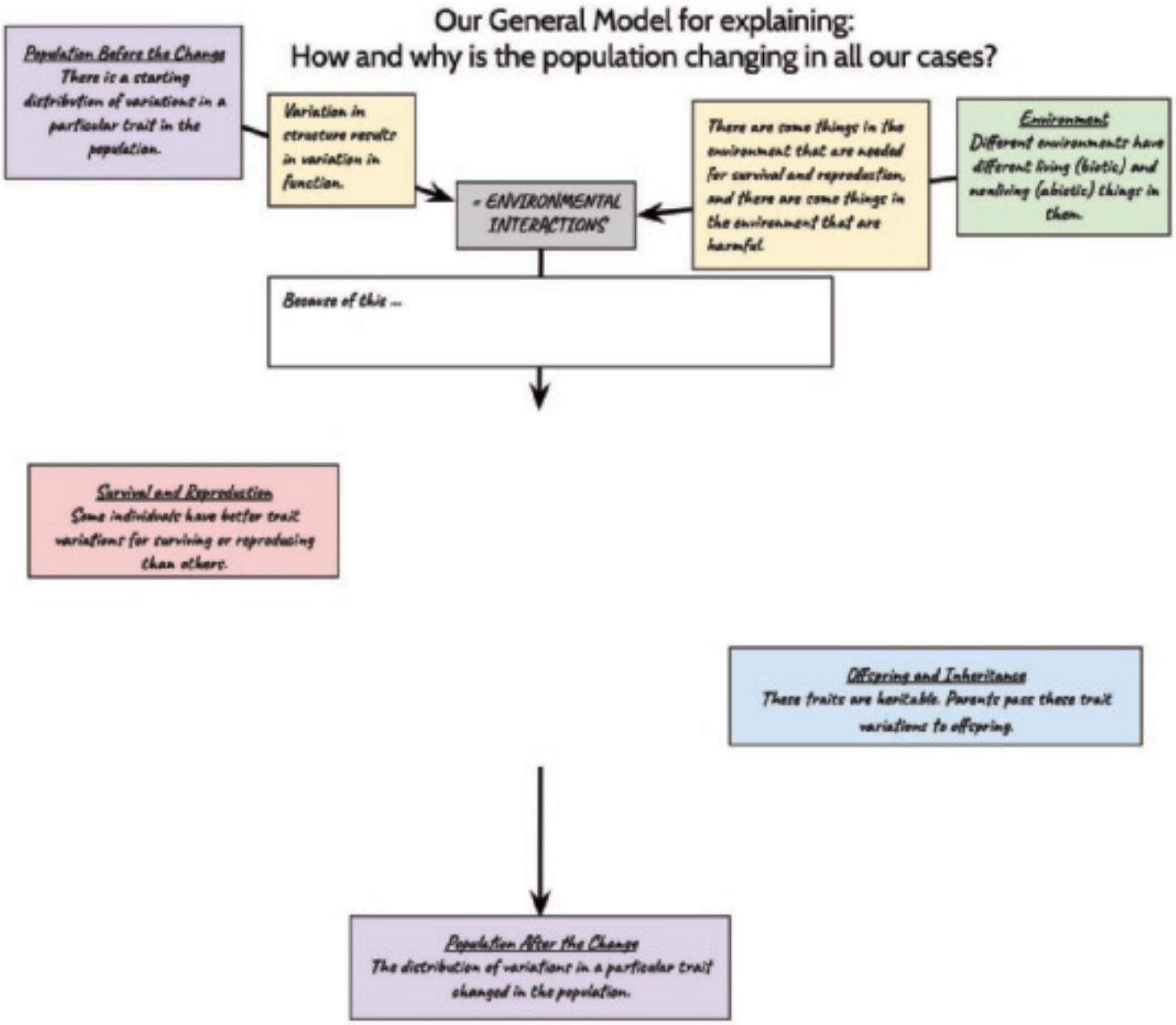

Our General Model for explaining:
How and why is the population changing in all our cases?
Population Before the Change
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Environment
Different environments have different living (biotic) and nonliving (abiotic) things in them.
Population After the Change
The distribution of variations in a particular trait changed in the population.

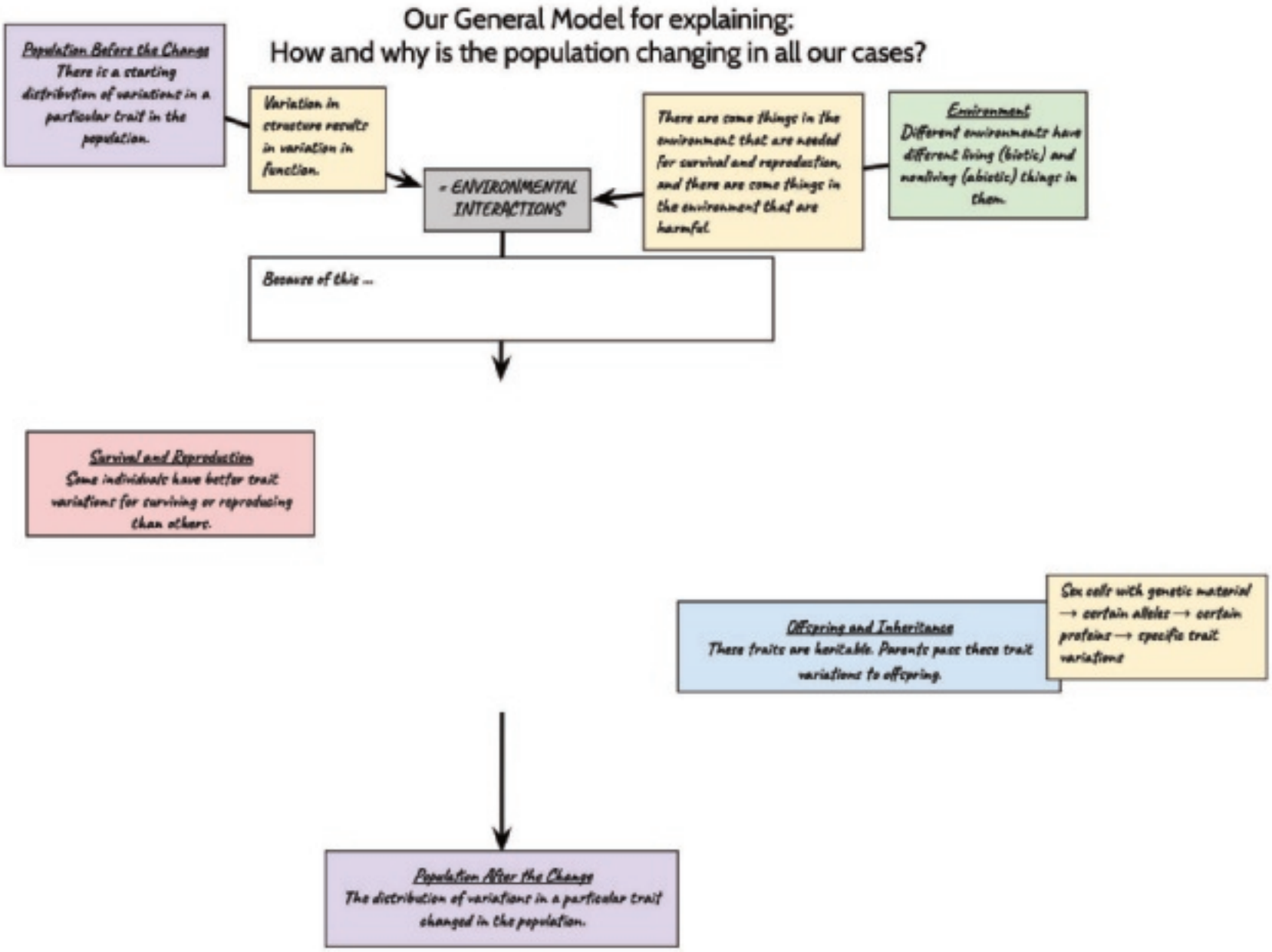

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Population After the Change
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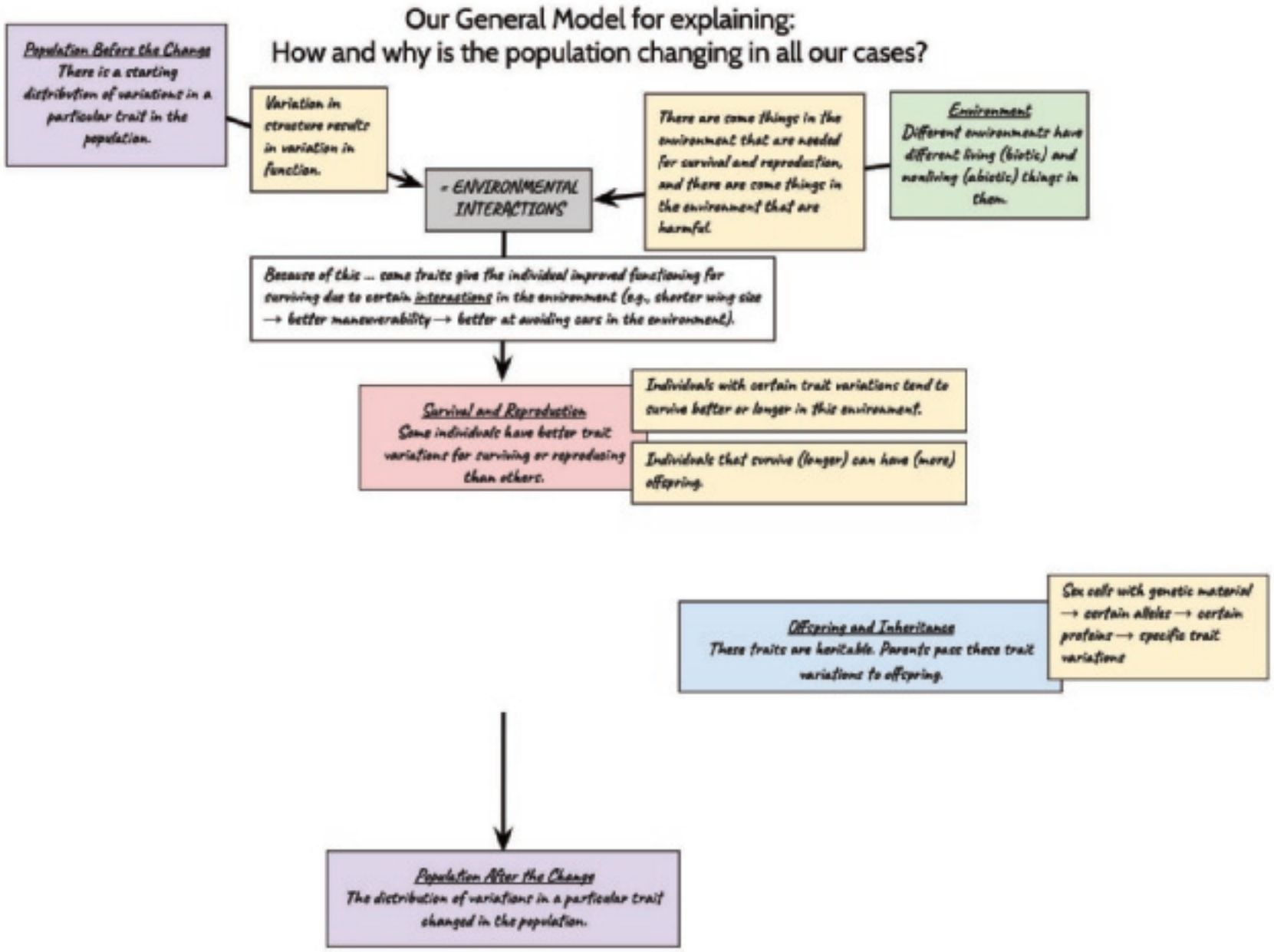

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Environment
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Population After the Change
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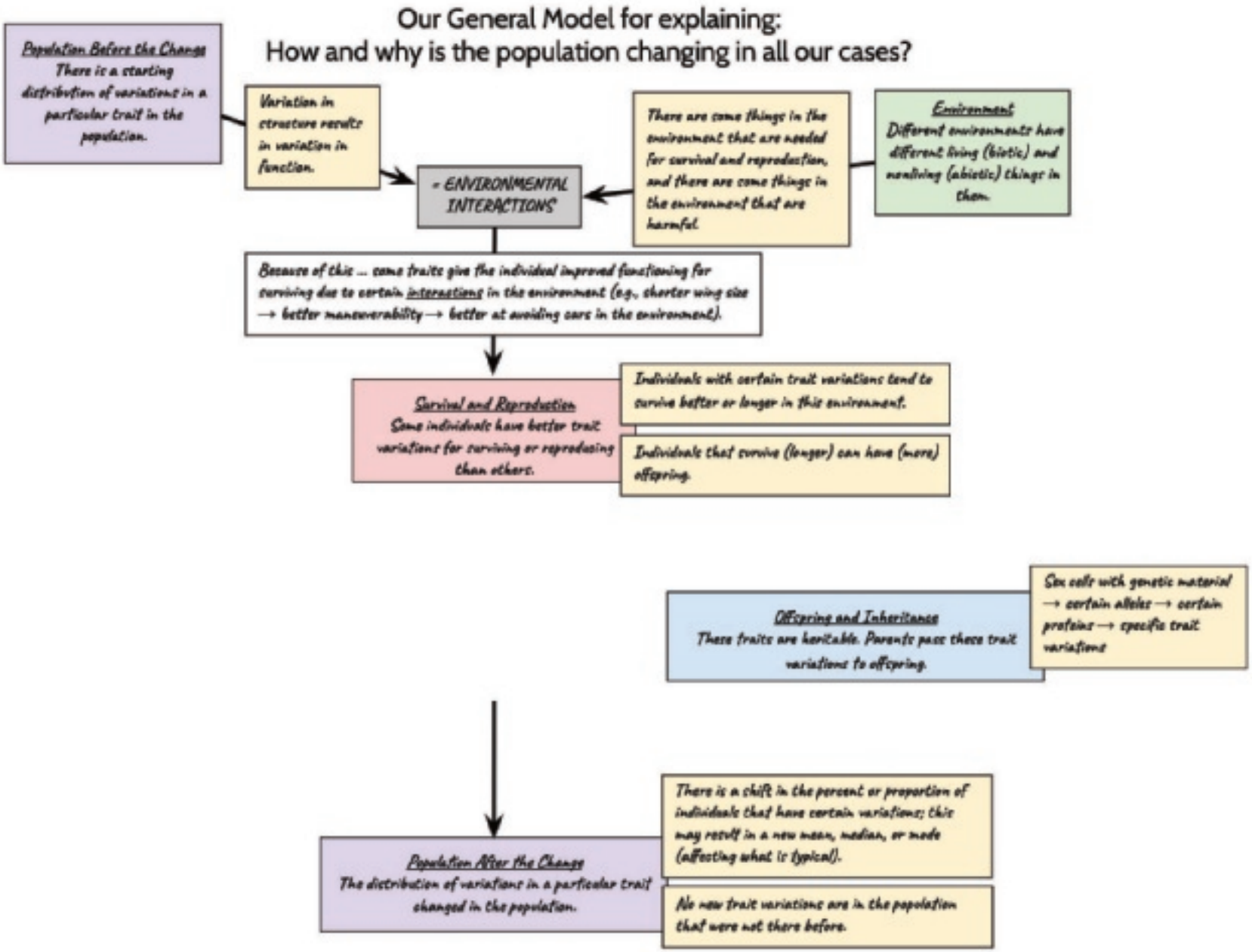

Our General Model for explaining:
How and why is the population changing in all our cases?
Population Before the Change
There is a starting distribution of variations in a particular trait in the population.
Variation in structure results in variation in function.
= ENVIRONMENTAL INTERACTIONS
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Population After the Change
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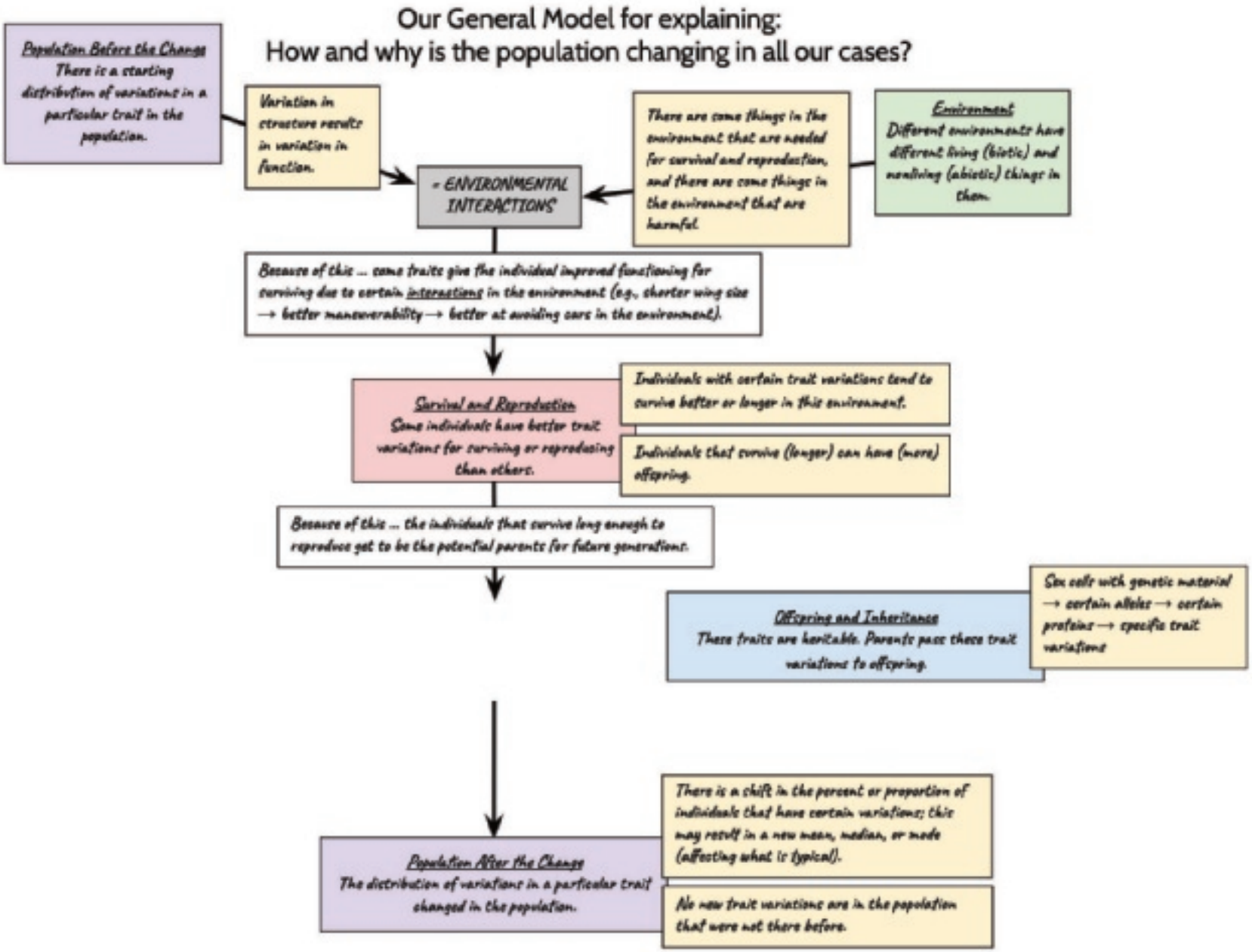

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Because of this ...
Survival and Reproduction
Offspring and Inheritance
Population After the Change
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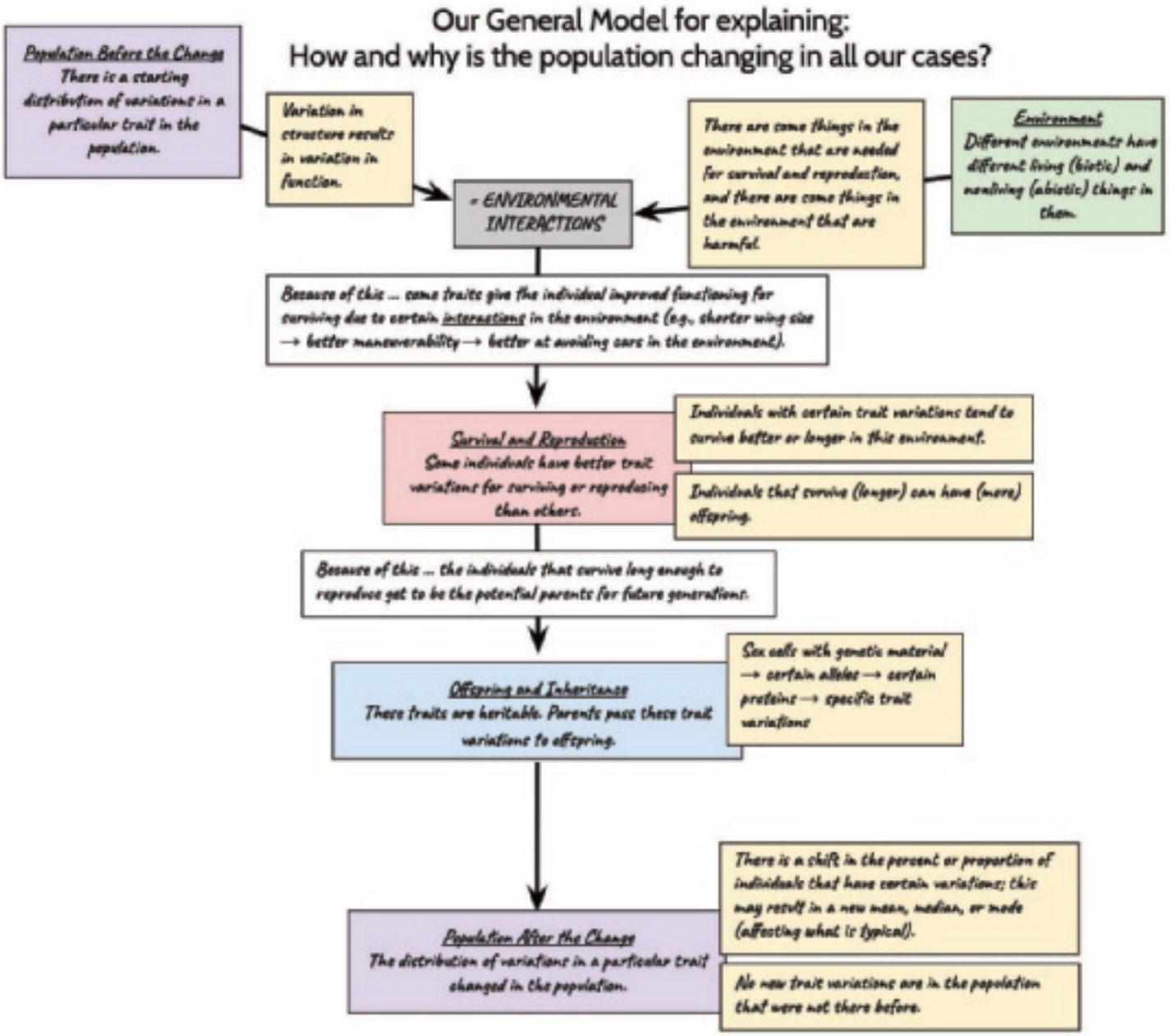

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Different environments have different living (biotic) and nonliving (abiotic) things in them.
Because of this ...
Survival and Reproduction
Some individuals have better trait variations for surviving or reproducing than others.
Offspring and Inheritance
These traits are heritable. Parents pass these trait variations to offspring.
Population After the Change
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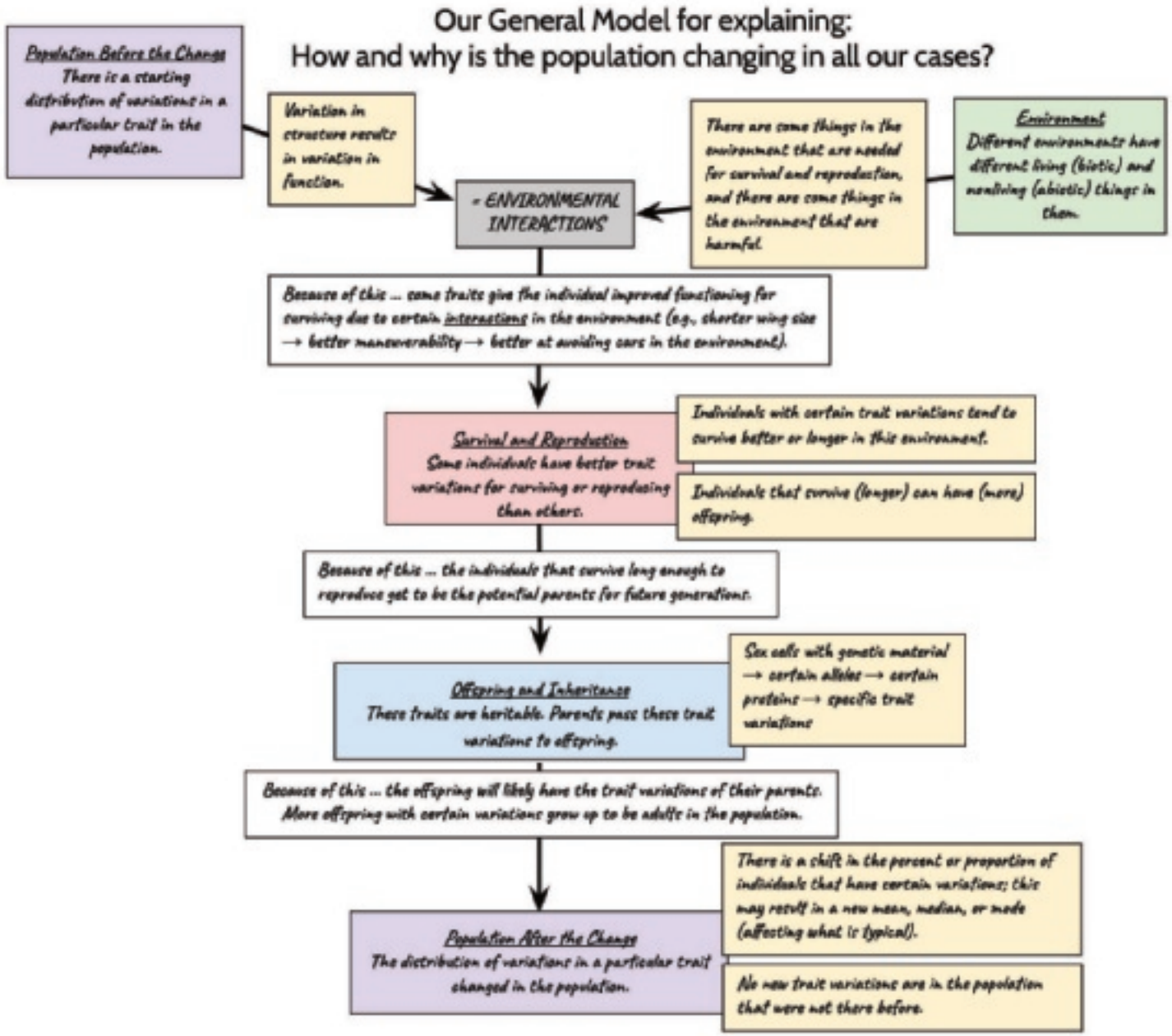

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Sex cells with genetic material → certain alleles → certain proteins → specific trait variations
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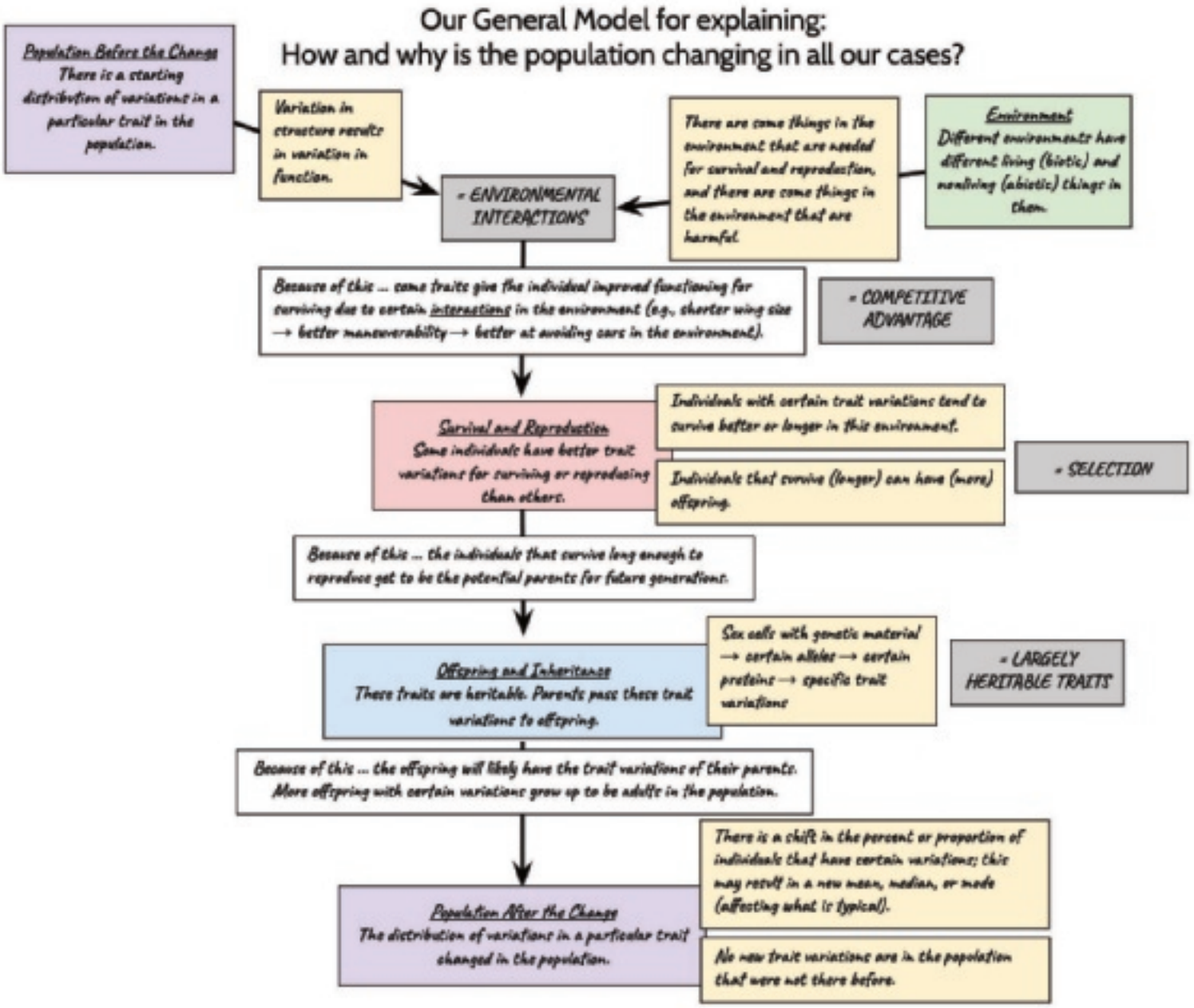

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Different environments have different living (biotic) and nonliving (abiotic) things in them.
Because of this ... some traits give the individual improved functioning for surviving due to certain interactions in the environment (e.g., shorter wing size → better maneuverability → better at avoiding cars in the environment).
Survival and Reproduction
Some individuals have better trait variations for surviving or reproducing than others.
Individuals with certain trait variations tend to survive better or longer in this environment.
Individuals that survive (longer) can have (more) offspring.
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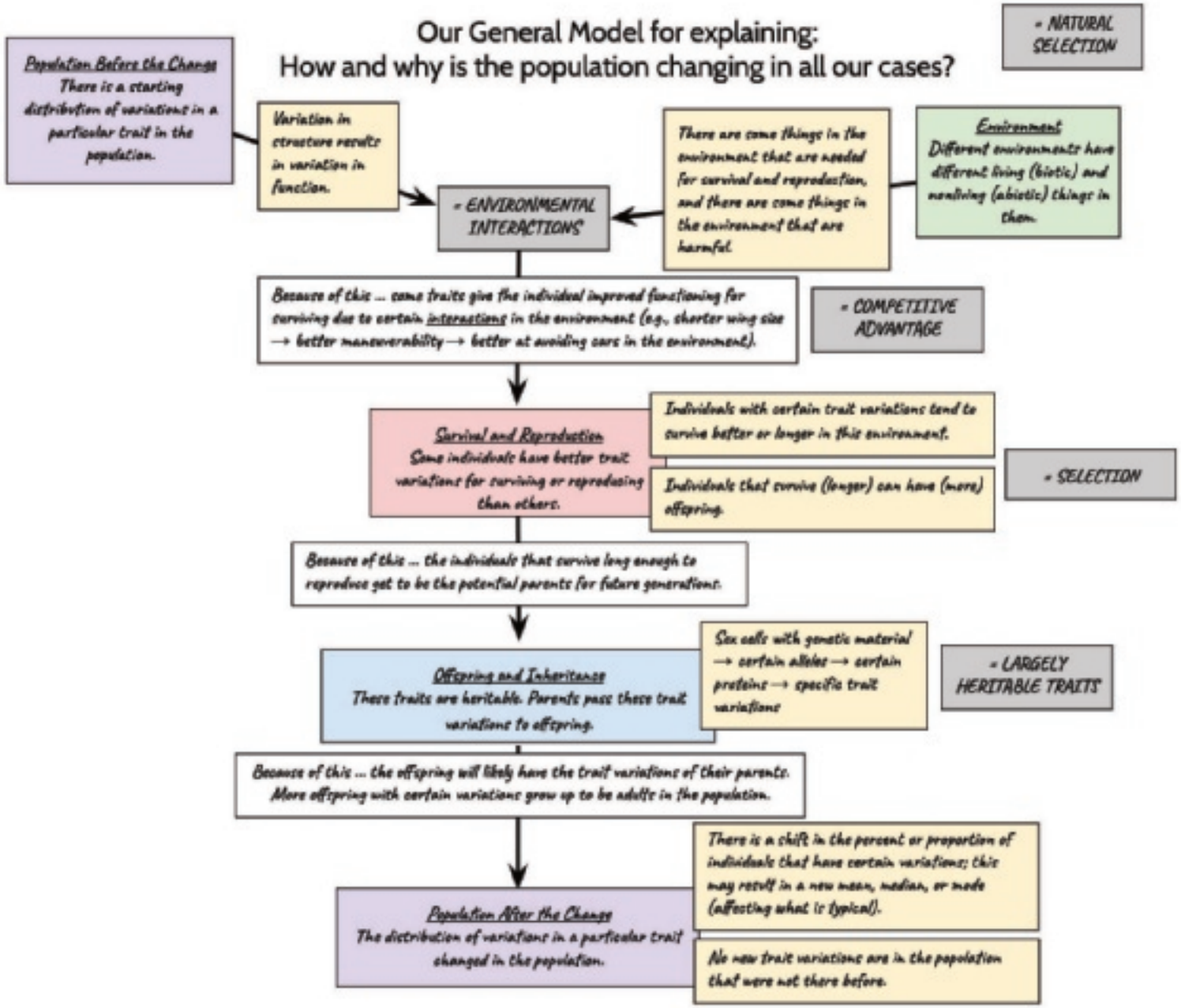

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The distribution of variations in a particular trait changed in the population.
There is a shift in the percent or proportion of individuals that have certain variations; this may result in a new mean, median, or mode (affecting what is typical).
No new trait variations are in the population that were not there before.


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Survival and Reproduction
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Individuals with certain trait variations tend to survive better or longer in this environment.
Individuals that survive (longer) can have (more) offspring.
Because of this ... the individuals that survive long enough to reproduce get to be the potential parents for future generations.
Offspring and Inheritance
These traits are heritable. Parents pass these trait variations to offspring.
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Because of this ... some traits give the individual improved functioning for surviving due to certain interactions in the environment (e.g., shorter wing size → better maneuverability → better at avoiding cars in the environment).
Survival and Reproduction
Some individuals have better trait variations for surviving or reproducing than others.
Individuals with certain trait variations tend to survive better or longer in this environment.
Individuals that survive (longer) can have (more) offspring.
Because of this ... the individuals that survive long enough to reproduce get to be the potential parents for future generations.
Offspring and Inheritance
These traits are heritable. Parents pass these trait variations to offspring.
Sex cells with genetic material → certain alleles → certain proteins → specific trait variations
Population After the Change
The distribution of variations in a particular trait changed in the population.
There is a shift in the percent or proportion of individuals that have certain variations; this may result in a new mean, median, or mode (affecting what is typical).
No new trait variations are in the population that were not there before.


Our General Model for explaining:
How and why is the population changing in all our cases?
Population Before the Change
There is a starting distribution of variations in a particular trait in the population.
Variation in structure results in variation in function.
= ENVIRONMENTAL INTERACTIONS
There are some things in the environment that are needed for survival and reproduction, and there are some things in the environment that are harmful.
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No new trait variations are in the population that were not there before.

LESSON 8: ANSWER KEY 1

How can we use our model to make predictions?

Scoring Guidance: The information in this key is intended to give you an idea of how students might respond to these prompts. This is intended to be a formative assessment opportunity to see how students are using the General Model of Natural Selection to make predictions.

We developed our General Model for Natural Selection by investigating 5 specific populations of organisms with different trait variations. Each population interacted with a particular environmental factor.

The populations we looked at were more-recent, modern examples. How does our model help us answer questions about what could be causing changes in populations of descendants from ancient to modern penguins, horses, whales, and horseshoe crabs over many, many generations and over millions of years?

Let's use our model to make predictions about what would happen

- to any population,
- in any environment, and
- over a different number of generations.

Complete each prompt below using words and/or pictures to share your thinking.

1. What does our model predict would happen in the next generation for any of the populations we investigated? What does our model predict would happen in the next generations after that?

The next generation	**The next generations after that**
This would happen again. *The offspring of those parents (survivors) have their traits.* *More offspring with certain traits grow up in the population, and the process repeats.* *Since they have that trait variation (or adaptation) that was passed to them by their parents, they will also survive and reproduce more than other individuals in the population without that trait.*	*The process would continue to repeat.* *More change could accumulate over time.* *At some point the amount of change in the population might become stable and change less or not at all.*

2. What does our model predict would happen if the environment changed gradually or suddenly so that the resources or risks in the environment changed?

The environment changed gradually	**The environment changed suddenly**
The model would start back at the beginning with the trait variations in the populations and the "new" resources and risks posed by the environmental change. *The population of organisms would have some traits that might give the individual improved functioning for survival due to interactions with this environmental change.* *Over time, the proportion of the traits in the population would change and we would see a higher percentage of traits that helped the organism survive and reproduce in the new environment.*	*The model would start back at the beginning with the trait variations in the populations and the "new" resources and risks posed by the environmental change.* *The population of organisms may have some traits that might give the individual improved functioning for survival due to interactions with this environmental change.* *Survival and reproduction would depend on how quickly the environmental change happened and how it impacted the population.*

3. What does our model predict would happen if a different population of organisms entered a new environment? Would we see changes in the distribution of the traits in the population in future generations of descendants?

If a different population of organisms entered a new environment, we'd predict to see something similar to what would happen if there was an environmental change.

The population of organisms would have some traits that might give the individual improved functioning for survival due to interactions with this environmental change. These traits might give them a competitive advantage over other similar organisms in the environment or they might experience more risk.

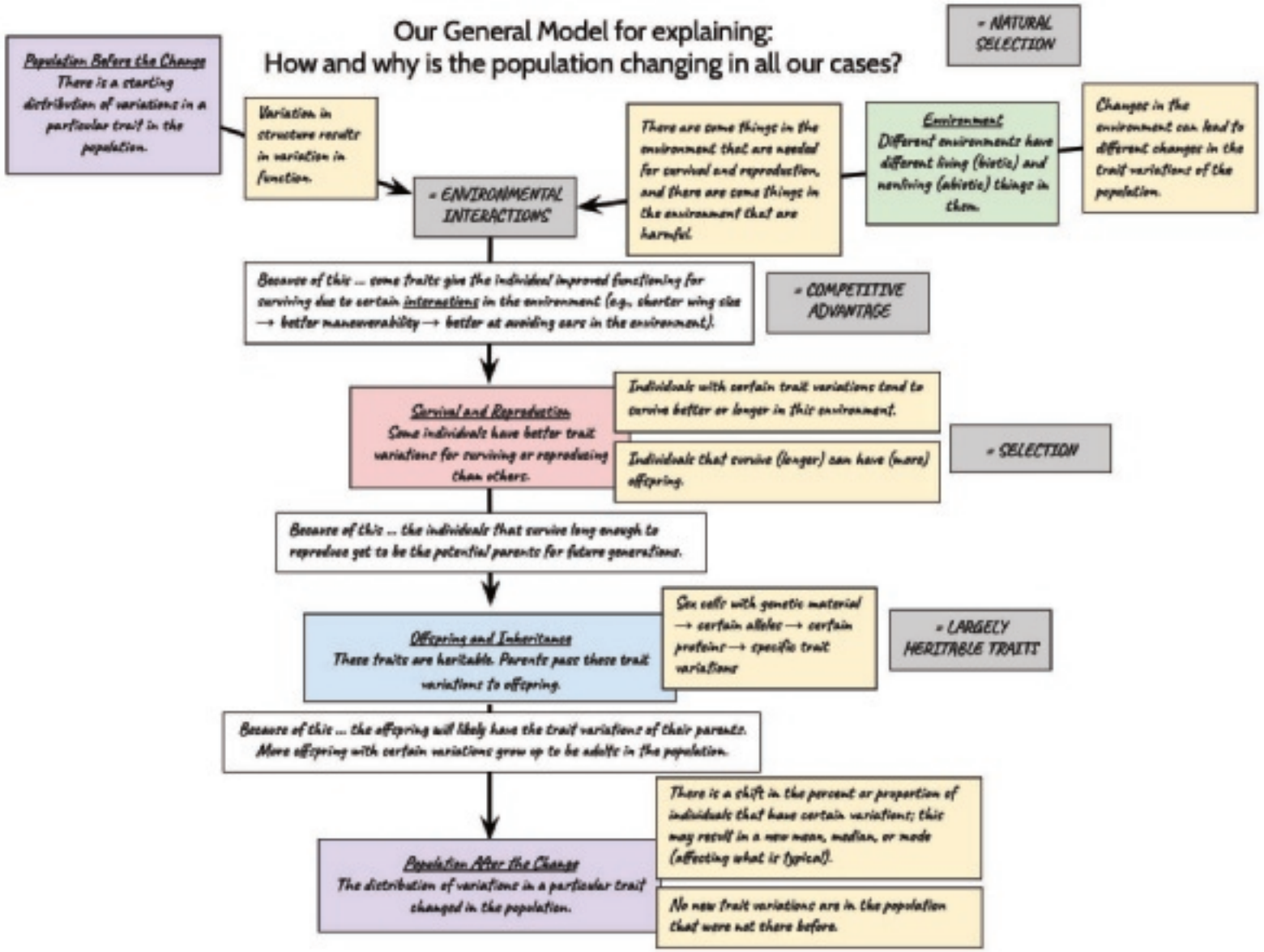
Over time, the proportion of the traits in the population would change and we would see a higher percentage of traits that helped the organism survive and reproduce in the new environment.

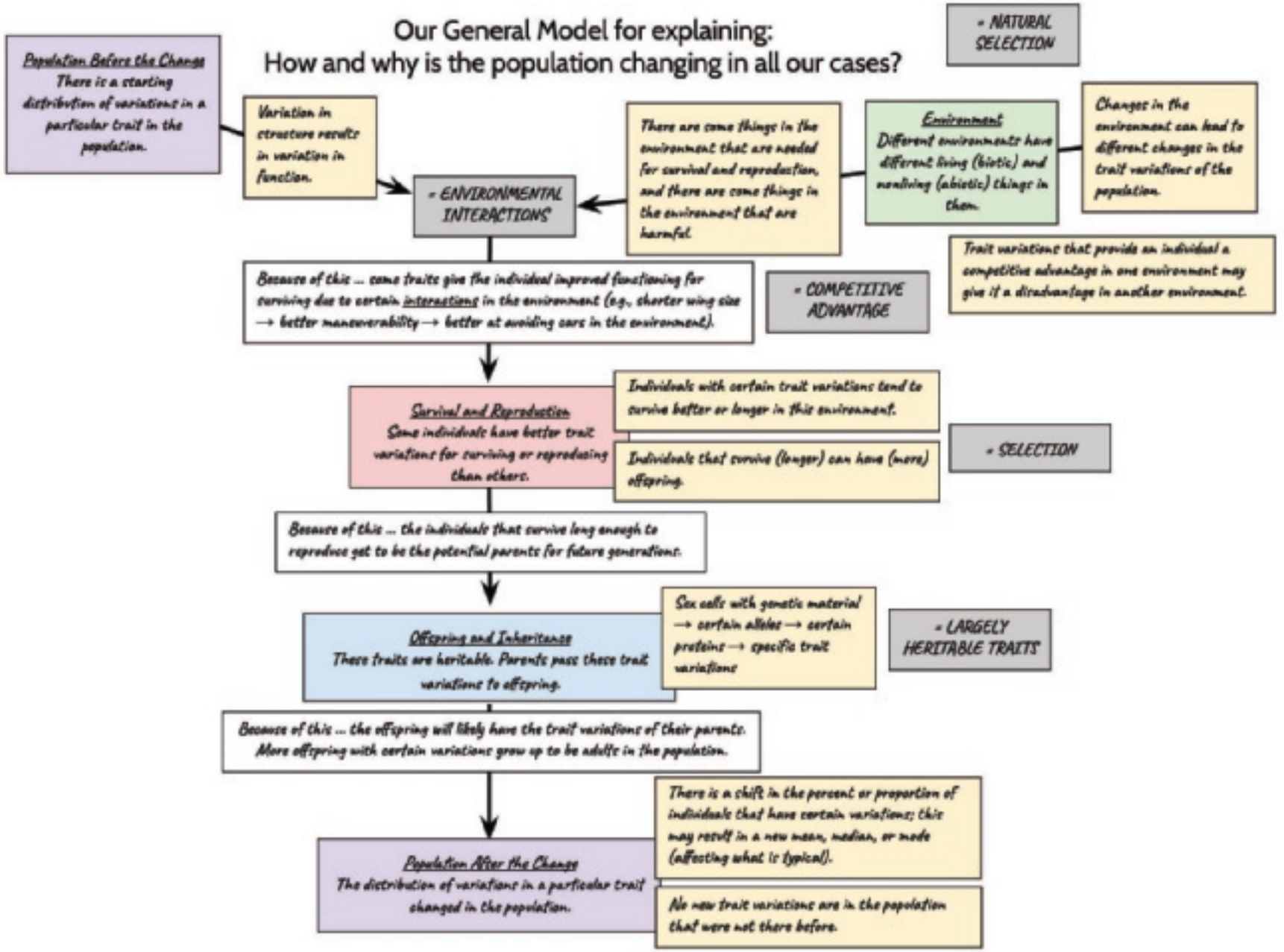
4. What ideas do you have about how we could test our model to see how good it is at predicting and explaining what would happen to other populations, in different environments, or over different lengths of time?

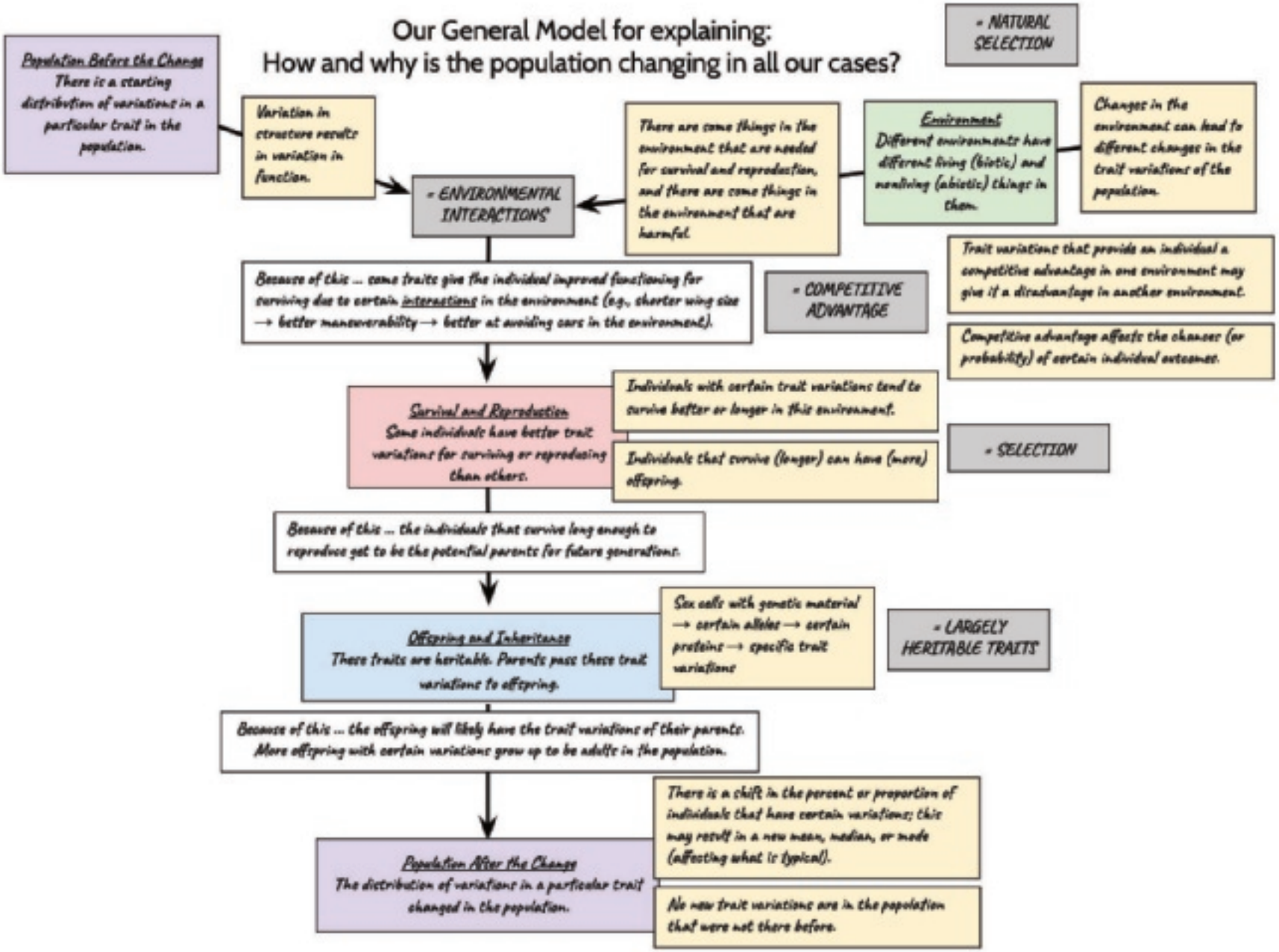
Accept all answers from students. This conversation will continue in the beginning of Lesson 9.

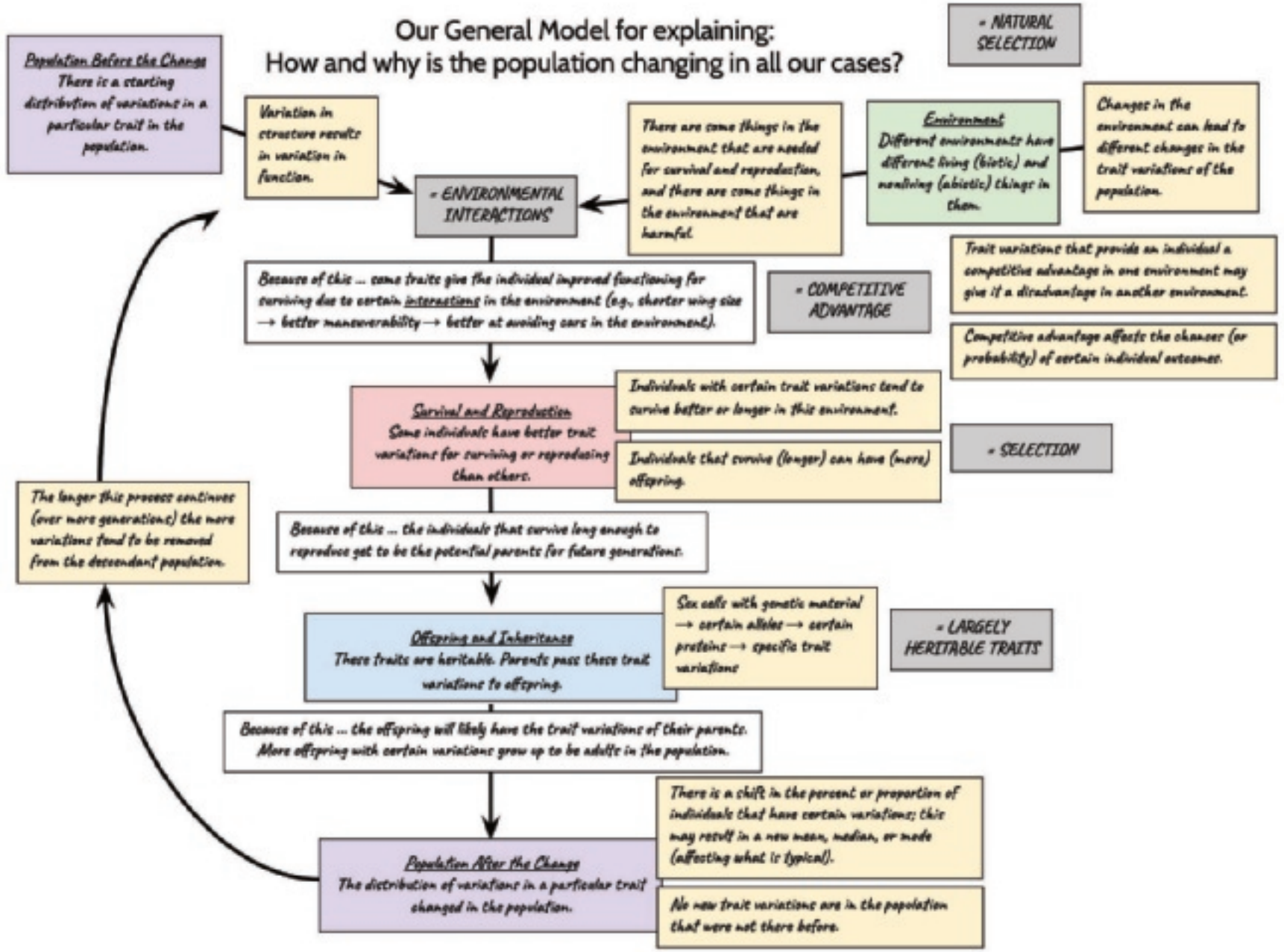
Lesson 9 Sample Images for General Model

The following pages show the incremental additions you will make to the General Model for Natural Selection in Lesson 9. You will add one final idea in Lesson 10.




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Different environments have different living (biotic) and nonliving (abiotic) things in them.
Changes in the environment can lead to different changes in the trait variations of the population.
Trait variations that provide an individual a competitive advantage in one environment may give it a disadvantage in another environment.
Because of this ... some traits give the individual improved functioning for surviving due to certain interactions in the environment (e.g., shorter wing size → better maneuverability → better at avoiding cars in the environment).
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Survival and Reproduction
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Competitive advantage affects the chances (or probability) of certain individual outcomes.
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Individuals with certain trait variations tend to survive better or longer in this environment.
Individuals that survive (longer) can have (more) offspring.
= SELECTION
The longer this process continues (over more generations) the more variations tend to be removed from the descendant population.
Because of this ... the individuals that survive long enough to reproduce get to be the potential parents for future generations.
Offspring and Inheritance
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Key: Refining and Applying Our General Model for Natural Selection

Part A

1. How did using a simulation help us refine our General Model for Natural Selection?

   We figured out some new ideas that we couldn't see before when we looked at the five different cases. We saw how the same trait variations could be advantageous or not in different environmental interactions. We also saw that what happens to individuals is mostly due to chance. Not everyone with a disadvantageous trait variation dies off. Not everyone with an advantageous trait variation survives.

2. We explored what happened to a bacterial population over time when we recreated the interactions with different types of white blood cells. Those white blood cells were a risk to be avoided for this type of organism.

   Let's consider other things in the environment that affect bacteria survival and reproduction.

List some resources that bacteria would need from their environment in order to survive and reproduce.	List the things that would need to be changed in the simulation to mimic bacteria interacting with some of these resources.
Food	How much food there is
Shelter	Where the food is
A safe place to divide (reproduce)	Safe areas for them to shelter
Warmth	The shape of the space they are in
Water	Temperature
	Amount of water
	Where the water is

3. Do you think bacteria with a different number of flagella might have a competitive advantage for surviving or reproducing in environments that have different amounts or distributions of these sorts of resources in them? Why?

   Yes. Flagella help them move. They need to move to get to food and to get to shelter. So more flagella might be better if that stuff is far away. Then they need to not move if they're in a safe place with a lot of the resources they need. So fewer flagella might be better in that environment.

Part B (optional)

4. Now consider whether our General Model could be used to explain some things about penguins. Penguins spend about 75% of their lives in the water. Most penguins can swim much faster in the water than the fastest human swimmer (4.7 mph). On land however, all penguins move much slower than humans.

List some of the heritable traits that penguins have that you think contribute to being able to swim so fast in the water.	List some of the heritable traits that penguins have that limit their ability to move fast on land.
Their overall body shape	Short legs
Being longer rather than rounder	Webbed feet
Smooth feathers	Only two legs
Webbed feet	Wings that can't fly
Strong wings	They're fat
Paddle-shaped wings	They're tall, not close to the ground
Big muscles for wings and feet	Uncoordinated muscles for walking
Sharp beaks	
Pointy heads	
Pointy tails	
Lighter bones?	

5. How could variations in some of these (or other) heritable traits give some individuals a competitive advantage over others in the water? How might that affect their chances of surviving or reproducing?

   Trait variations that help them swim fast will help them avoid predators and also catch their prey. If one swims faster than the other, it will be more likely to avoid predators and it will catch more food, so it will survive better. If it survives better, it can reproduce more. Also, if it catches more food it can feed its babies better.

6. How could variations in some of these (or other) heritable traits give some individuals a competitive advantage over others on the land? How might that affect their chances of surviving or reproducing?

   The variations make them move more slowly on land. This is OK because they don't have predators on the land and also they don't catch their food on the land. If they move more slowly, they might stick together more with other penguins and stay warmer or be able to find more mates. If they move slower on land they can rest more on land and store up energy for going back into the water.

Key for Different Environmental Conditions and Results

The following table includes only one set of sample responses. Depending on the ways students set up the simulation parameters, results and responses will vary from those shown here.

Part 1:

	Environment #1 (left)	Environment #2 (right)
The initial distribution of traits in both populations	I started each time with 4 bacteria per variation (4 of each of the 6 numbers of flagella).	
The environment	There was 40% water in a circle in the middle of the environment. This is where algae grew.	There was 90% water in a strip on the right side of the environment. This is where algae grew.
Length of time you simulated	300 ticks	
# of deaths that occurred over this time	trial #1: 49, trial #2: 57, trial #3: 39, trial #4: 47	trial #1: 58, trial #2: 63, trial #3: 63, trial #4: 56
# of offspring that were produced over this time	trial #1: 37, trial #2: 50, trial #3: 39, trial #4: 41	trial #1: 85, trial #2: 90, trial #3: 87, trial #4: 79
The final distribution of trait variations in each population	trial #1: most had 1, trial #2: most had 5, trial #3: most had 2, trial #4: most had 1	trial #1: most had 5, trial #2: most had 4, trial #3: most had 5, trial #4: most had 5

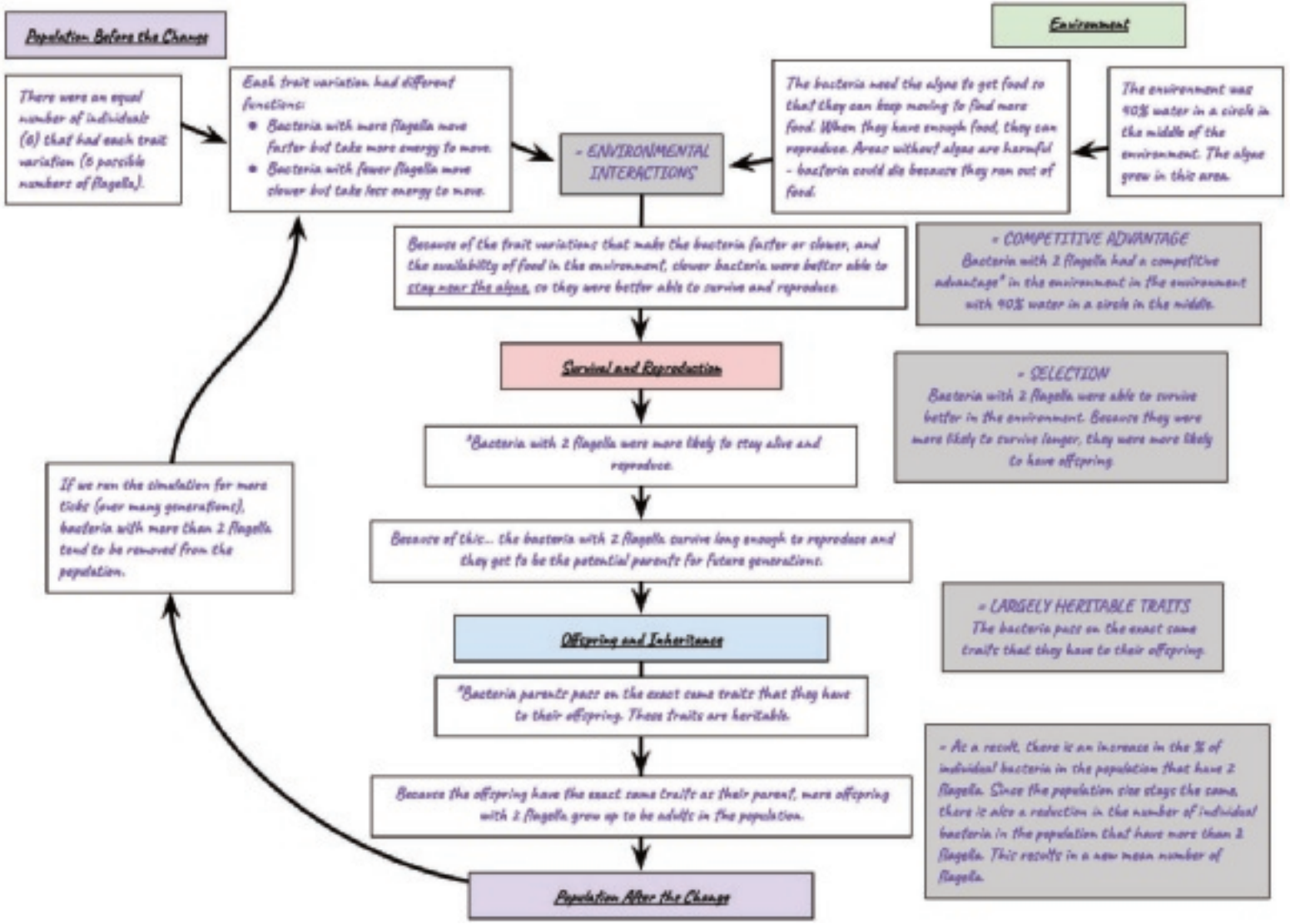
Part 2:

	Environment #1 (left)	Environment #2 (right)
How do you know the shift in the distribution of variations was a typical outcome over time in this environment?	I ran the model 4 times and 3 out of those 4 times the most common bacteria at the end had only 1 or 2 flagella. (You might encourage students to run more trials and calculate the mean or other data landmarks to justify their conclusions.)	I ran the model 4 times and 3 of those times the most common bacteria at the end had 5 flagella, and the other time the most common had 4 flagella. (You might encourage students to run more trials and calculate the mean or other data landmarks to justify their conclusions.)
Describe what you saw happening to the population in between the start and the end of the model run.	At the beginning, there was an equal distribution of all the numbers of flagella. Soon after the start of the simulation, there were more bacteria with 5 or 6 flagella and fewer of the others, but as time went on, they usually sort of evened out again and by the end the population had the highest percentage of bacteria with 2 flagella.	At first, there was an equal distribution of all the numbers of flagella. Pretty quickly after starting the simulation, a pattern emerged: the histogram looked like stairsteps going up, There were usually fewer of the bacteria with fewer flagella, and more bacteria with more flagella. As time went on, though, the number of bacteria with 6 flagella would start to decrease till we were left with most of the population having 4 or 5 flagella.

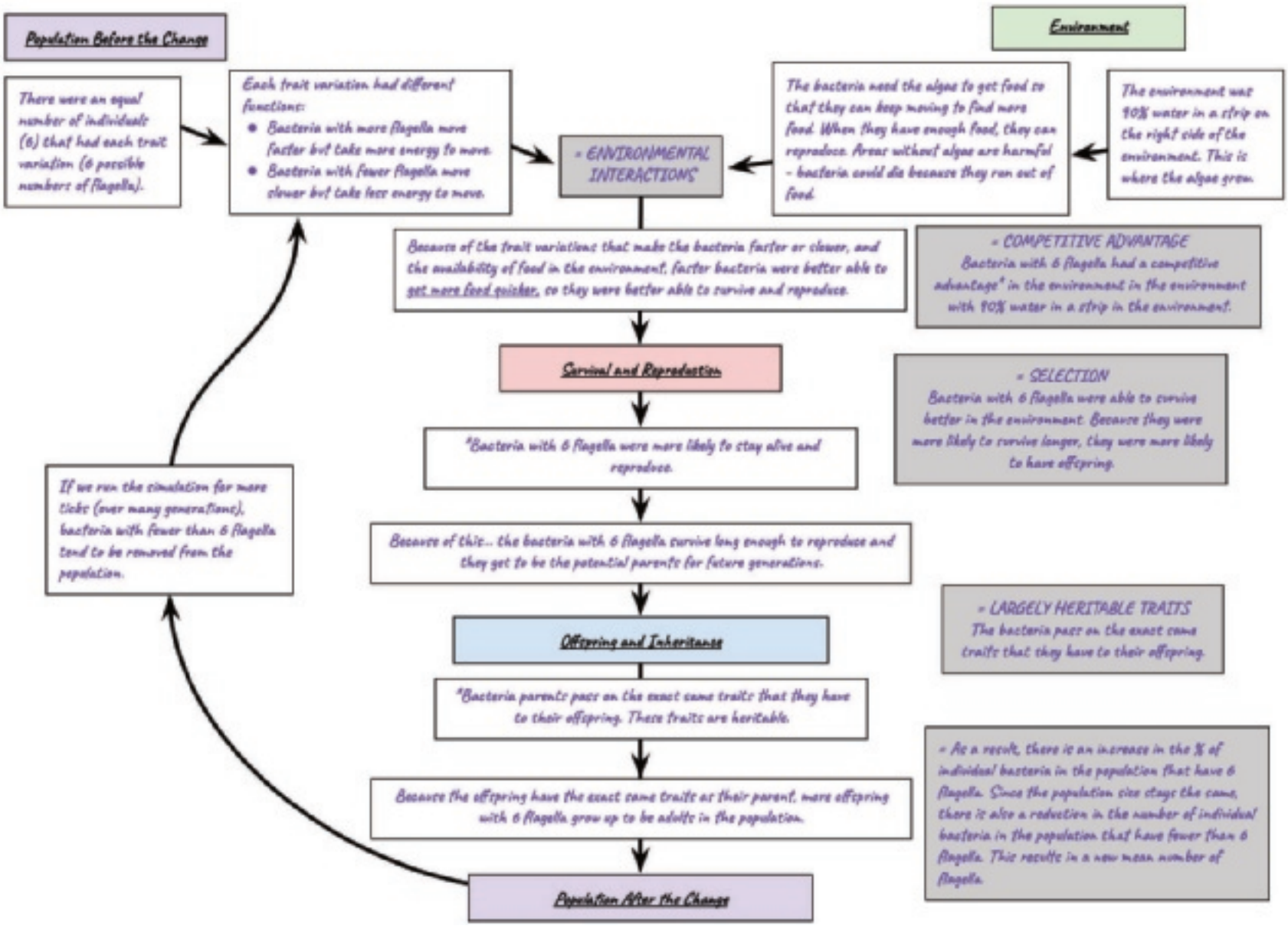
My Model for Changes in Bacteria Populations

The following sample responses represent only one way a student could use the model to explain changes in the two environments. Depending on the ways your students set up the simulation parameters, results and responses will vary from those shown here.

My explanation for what is causing changes in the population for Environment 1 (left) using our model:



My explanation for what is causing changes in the population for Environment 2 (right) using our model:



Name: _____ Date: _____

Green Anole Lizard Explanation

Green anole lizards are from Florida. Brown anole lizards are from Cuba. Brown lizards have recently been found on islands in Florida where only green lizards lived before. These green and brown lizards are different species, but they have very similar behaviors—they eat similar food and live in similar habitats.

Green anole lizard (*Anolis carolinesis*)



Brown anole lizard (*Anolis sagrei*)



The islands where the lizards live are covered with plants. Some of the plants on the islands where they live are pictured here:

Juniperus virginianus



Sabal palmetto

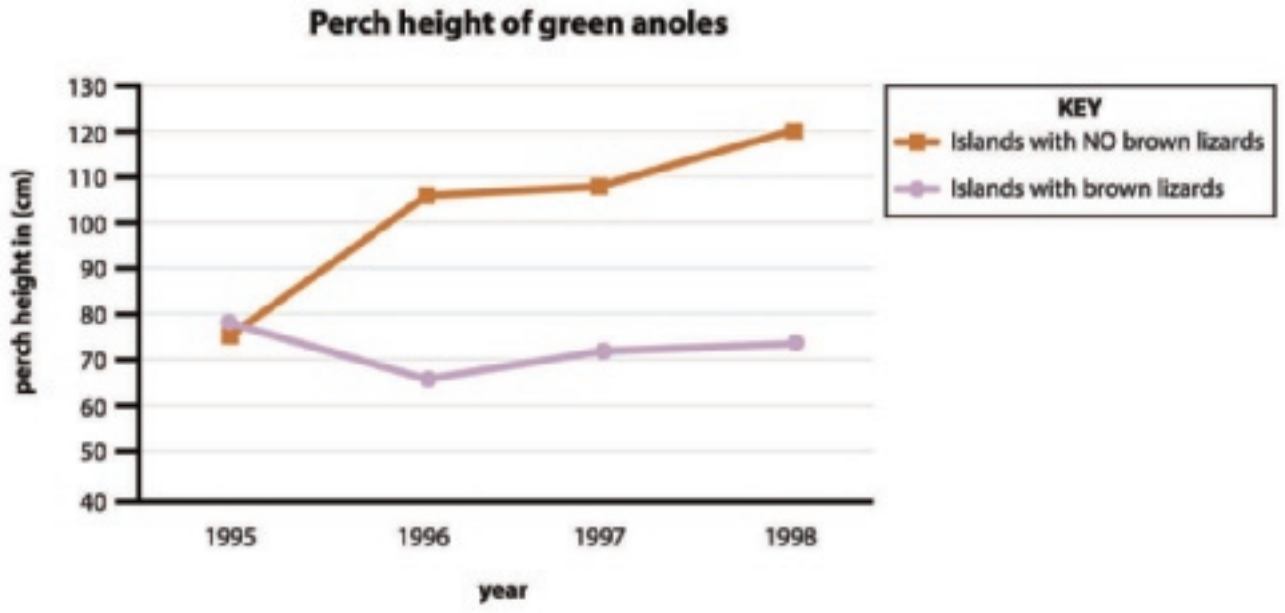


Schinus terebinthefolius



On some of these plants, the branches farther off the ground are thinner and smoother compared to the branches closer to the ground.

Green lizards tend to hang out higher in trees than the brown lizards. When the lizards both live on the same island, the green lizards perch even farther above the ground where the branches can be harder to hang on to. This change happens very quickly—within months of the introduction of brown lizards to an island, the green lizards move to higher branches. From 1995 to 1998, scientists studied these lizards on islands where both green and brown lizards lived and on islands where only green lizards lived. The graph that follows is from a study showing how high in the trees the green lizards are found on islands with brown lizards and on islands without brown lizards.



Data source: Stuart, Y. E., et al (2014). Rapid evolution of a native species following invasion. . . Science, 346(6208).

During the same study, scientists collected data on the foot structures—the toe pads and the sticky scales—of the green lizards. Both the size of the toe pad and the number of sticky scales can help the green lizards climb higher. Below are the data for green lizards on the islands with brown lizards and on the islands with no brown lizards. In this study, the islands with no brown anoles represent what we would expect the green lizard population to be like before the brown lizards arrived on the islands.

Data for Green Lizards		
	Green lizards on an island with **no** brown lizards	Green lizards on an island **with** brown lizards
Average perch height in trees (cm)	75	120
Average size of the toe pads (cm)	1.27	1.33*
Average number of sticky scales on the feet	51	54*

*Even though the differences in these numbers may seem small, they are significant for such a small lizard.

1. What do you notice about the behavior and body structures of the green lizards who live on islands with brown lizards versus the green lizards who live on islands with no brown lizards?

2. Construct an explanation: How does natural selection explain the changes in the green lizard population over time?

- Take out your *Progress Tracker Copy of Our General Model* (updated in Lesson 10) and reference examples in your notebook of organisms changing over time.
- Use words or pictures (or a combination) for your explanation.
- Use the key parts of the General Model to explain the cause and effect of the changes in the green lizard population over time.
  - In your explanation make sure to include the following:
    - the key parts of the model
    - cause and effect to describe how the population changed over time
    - the data about the green and brown lizard populations that support your explanation

Data adapted from: Stuart, Y. E., Campbell, T. S., Hohenlohe, P. A., Reynolds, R. G., Revell, L. J., & Losos, J. B. (2014). Rapid evolution of a native species following invasion by a congener. *Science, 346*(6208), 463–466. https://doi.org/10.1126/science.1257008

LESSON 11: ANSWER KEY

Key: Green Anole Lizard Explanation

Allow your students to choose the modality for communicating their thinking. They can explain the phenomenon through written explanation, orally, or using a diagrammatic or pictorial explanatory model. Guidance in this document is provided for a written response, which you may also use to guide the feedback you give for an oral or pictorial response.

This assessment can be used to assess student progress on the lesson level performance expectation. This lesson level PE is an integration of elements from the three dimensions.

11.A Construct and revise an explanation using a model to explain why a change to the environment (cause) leads to a predominance of certain genetic variations of traits in a green lizard population that increase some individuals' probability of surviving and reproducing (effect).

SEPs	DCIs	CCCs
Construct an explanation using models or representations. Students use the General Model for Natural Selection from previous lessons to construct an explanation. Look for how students bring in the key parts of the General Model to support a specific explanation for why the green lizard population is changing over time. Students should bring in data from the task to support their explanations as well as ideas from the General Model.	Natural selection leads to the predominance of certain traits in a population and the suppression of others. (MS-LS4-4) Students should use their understanding of natural selection to explain how a trait variation in a population changes over time as a result of an environmental change. To explain this, students should bring in the ideas that trait variations exist in a population before the change in the environment and individuals with trait variations that increase their probability of surviving and reproducing are likely to pass those variations on to the next generation. This can lead to certain traits increasing in prevalence in a population and other, less-advantageous traits decreasing in the population.	Cause and effect relationships may be used to predict phenomena in natural or designed systems. Students use their understanding of cause-and-effect relationships to explain the green lizard perch height phenomenon. Specifically, they use their understanding of the population before and after the change, changes in the environment (cause), and the effect on survival, reproduction, offspring, and inheritance.

Scoring Guidance: The scoring guidance provided below uses a + notation that can help you identify different ideas that students should (or could) include in their responses.

If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether they are struggling with a science practice, a science idea, or both.

If all or almost all of the ideas marked with a + are present in a student's response, this may indicate the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

Your students may have constructed their explanation through written words, in pictures, or orally. Guidance in this document is provided for a written response, which you may also use to guide the feedback you give for an oral or pictorial response.

Green anole lizards are from Florida. Brown anole lizards are from Cuba. Brown lizards have recently been found on islands in Florida where only green lizards lived before. These green and brown lizards are different species, but they have very similar behaviors—they eat similar food and live in similar habitats.

Green anole lizard (*Anolis carolinesis*)

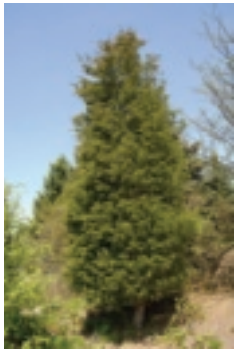


Brown anole lizard (*Anolis sagrei*)

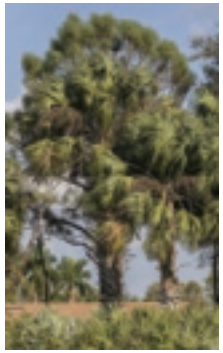


The islands where the lizards live are covered with plants. Some of the plants on the islands where they live are pictured here:

Juniperus virginianus



Sabal palmetto

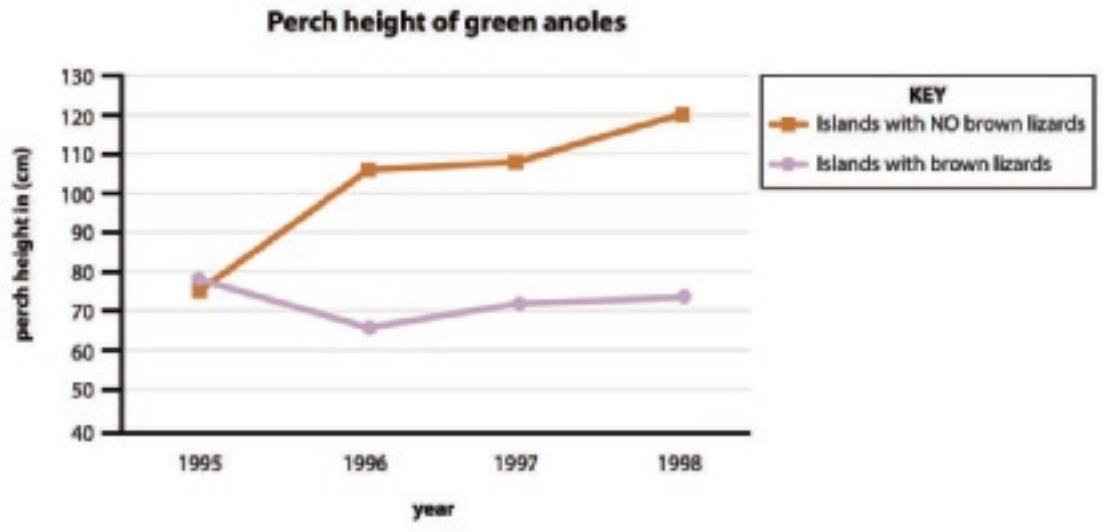


Schinus terebinthefolius



On some of these plants, the branches farther off the ground are thinner and smoother compared to the branches closer to the ground.

Green lizards tend to hang out higher in trees than the brown lizards. When the lizards both live on the same island, the green lizards perch even farther above the ground where the branches can be harder to hang on to. This change happens very quickly—within months of the introduction of brown lizards to an island, the green lizards move to higher branches. From 1995 to 1998, scientists studied these lizards on islands where both green and brown lizards lived and on islands where only green lizards lived. The graph here is from a study showing how high in the trees the green lizards are found on islands with brown lizards and on islands without brown lizards.



Data source: Stuart, Y. E., et al (2014). Rapid evolution of a native species following invasion... Science, 346(6208).

During the same study, scientists collected data on the foot structures—the toe pads and the sticky scales—of the green lizards. Both the size of the toe pad and the number of sticky scales can help the green lizards climb higher. Below are the data for green lizards on the islands with brown lizards and on the islands with no brown lizards. In this study, the islands with no brown anoles represent what we would expect the green lizard population to be like before the brown lizards arrived on the islands.

Data for Green Lizards		
	Green lizards on an island **without** brown lizards	Green lizards on an island **with** brown lizards
Average perch height in trees (cm)	75	120
Average size of the toe pads (cm)	1.27	1.33*
Average number of sticky scales on the feet	51	54*

*Even though the differences in these numbers may seem small, they are significant for such a small lizard.

1. What do you notice about the behavior and body structures of the green lizards who live on islands with brown lizards versus the green lizards who live on islands with no brown lizards?

+ These data show that something about the brown lizards being on the island with the green lizards has caused the size and structure of the green lizards' toe pads to change.

+ Green lizards live higher in the trees on islands with brown lizards than they do on islands with no brown lizards.

+ Green lizards have larger toe pads and more sticky feet scales on islands with brown lizards than they do on islands with no brown lizards.

2. Construct an explanation: How does natural selection explain the changes in the green lizard population over time?

- Take out your *Progress Tracker Copy of Our General Model* (updated in Lesson 10) and reference examples in your notebook of organisms changing over time.
- Use words or pictures (or a combination) for your explanation.
- Use the key parts of the General Model to explain the cause and effect of the changes in the green lizard population over time.
    - In your explanation make sure to include the following:
        - the key parts of the model
        - cause and effect to describe how the population changed over time
        - the data about the green and brown lizard populations that support your explanation

Students may choose to respond with a written description or a diagrammatic representation or a combination of the two. In any type of responses look for students to engage in explanation using writing or an explanatory model.

Look for the following ideas represented in written or pictorial form. Encourage students to use a key if pictorial form is chosen.

Population before the Change

+ Before the brown lizards came to an island, the green lizards lived lower in the trees.

+ The green lizard population must have had some lizards with bigger foot pads and more sticky scales on their feet.

Environment

+ The environment is mostly made up of trees, which are important for the survival of the green lizards.

+ The branches that are higher have smoother bark, while the lower branches have rough bark.

Environmental Interactions

+ Being able to climb higher is helpful for green lizards.

+ Competing with brown lizards for space and/or food is harmful for green lizards.

+ Not all green lizards can climb into the high branches because they are smooth and harder to stick to. The ones that can climb higher have larger foot pads and more sticky scales.

Survival and Reproduction

+ When the brown lizards were introduced to the islands with green lizards, they competed for food and habitat, therefore impacting the survival of the green anoles. The green lizards that had larger and stickier foot pads could climb on the smoother branches that were high in the trees (cause). Those that could climb higher had access to more opportunities for food and habitat and were more likely to survive than green lizards that could not climb into the high branches (effect).

Offspring and Inheritance

+ The green lizard parents that could climb higher due to more sticky scales and larger toe pads could pass those heritable trait variations on to their offspring which then had a better chance of survival and continued to pass on those trait variations (effect).

Population after the Change

+ After the brown lizards came to the island, the green lizards could live higher in the trees because they had larger foot pads and more sticky scales on their feet.

+ The population of green lizards that survived and reproduced had a higher average foot pad size and a greater number of sticky scales on their feet.

Data adapted from: Stuart, Y. E., Campbell, T. S., Hohenlohe, P. A., Reynolds, R. G., Revell, L. J., & Losos, J. B. (2014). Rapid evolution of a native species following invasion by a Congener. *Science, 346*(6208), 463–466. https://doi.org/10.1126/science.1257008

Mutation Story from 8.5, the Muscles Unit

Discuss as a whole class the origin of the different alleles. Display **slide B** (from the Penguins *Unit* Lesson 12). Say, *We know that these extra-big muscles in the offspring are caused by the presence of a specific allele, indicated by the star symbol. And we know that this star-symbol allele is something that was inherited from that individual's parents. So then it would seem reasonable to argue that any star-symbol allele that is inherited from a set of parents is also one that they inherited from their parents. In this line of reasoning, we should be able to find that any allele can be traced back in time across many generations. Do you think that in our case of typical and extra-big muscles that there were always these two kinds of alleles?* Allow a few minutes for students to respond.

Say, *It is interesting that we actually know this part of the story. The historical records indicate that in the 1800s in a small town in Italy called Guarene d'Alba a mutation for heavy musculture appeared in a cow that wasn't in the local population of cattle before that point. Once this mutation occurred, that individual was able to pass it on to its offspring and thus to all its descendants.*

Point out that all cattle used to have two copies of just the circle-symbol allele, but when this mutation occurred, it was the first time any cattle had the star-symbol allele. That individual continued to pass that different allele on to its offspring.

Say, *By the start of the 1900s, there were already 680,000 of its descendants with the different allele living in Italy alone. Each of them had inherited the allele, which had originally appeared as a single mutation in that one ancestor many generations earlier. When an event occurs in which an allele appears in a genotype of an offspring that wasn't there in the parents' genotypes, it is referred to as a* ***mutation****. A mutation is a small change that happens to the structure of a chromosome that can be passed on to future offspring, but it wasn't there before. These small structural changes can sometimes happen randomly when sex cells are being produced. And each mutation can result in there being a new allele of a gene.*

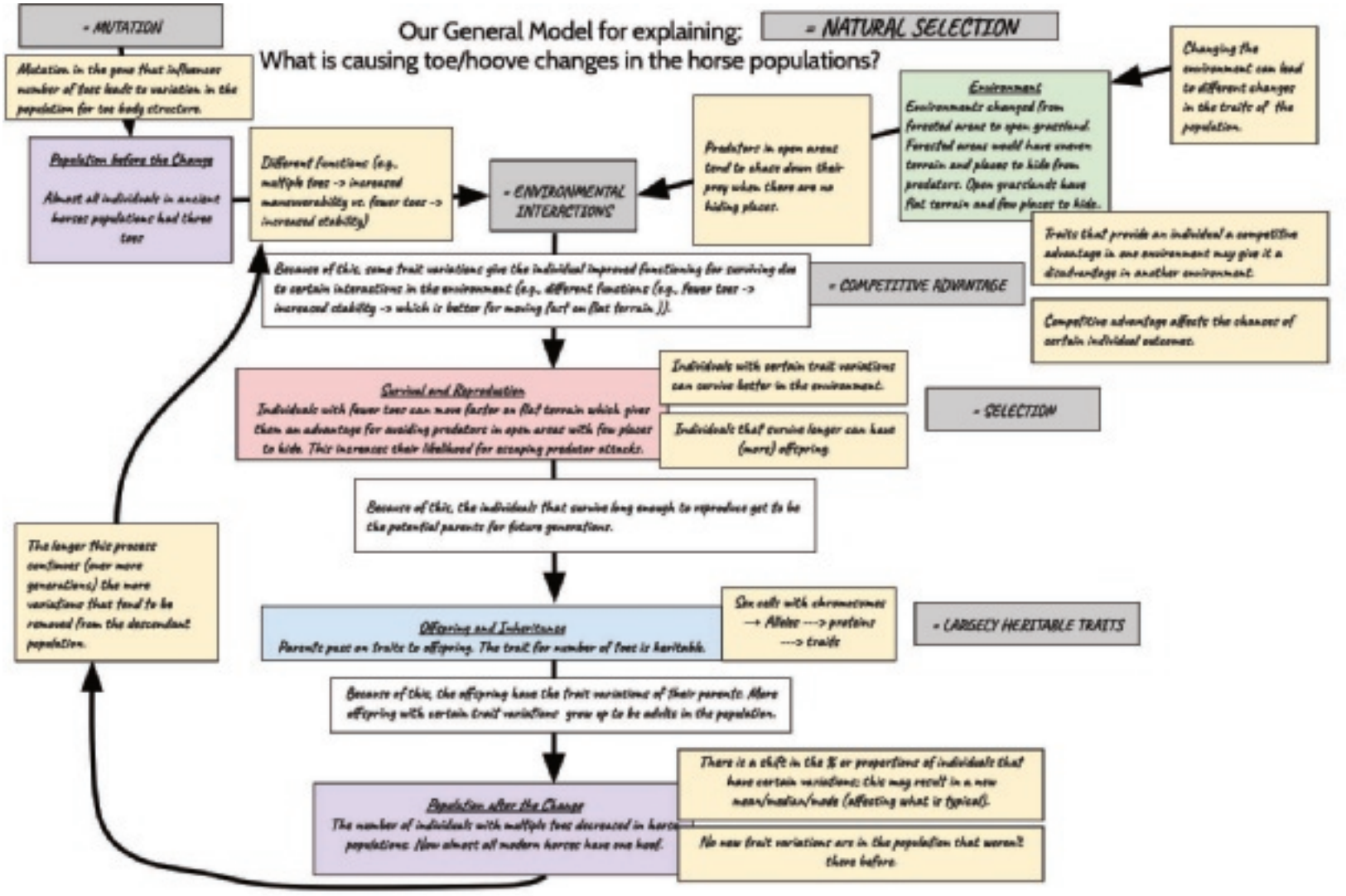
Ask, *If a mutation changes a gene, what do you think it does to the protein that gene makes?*

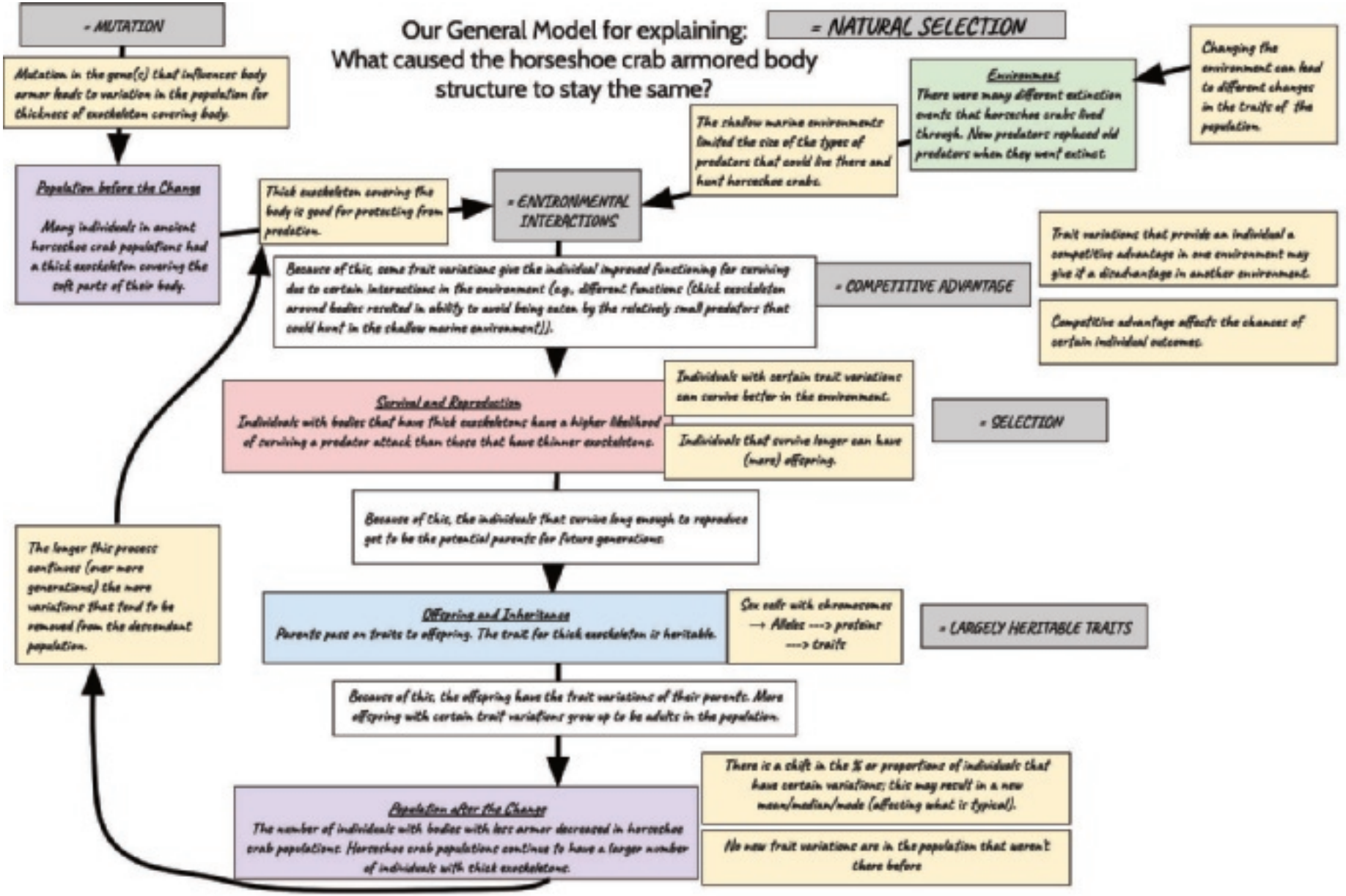
Sample student response: It changes the protein so it's different, like the two different myostatin proteins.

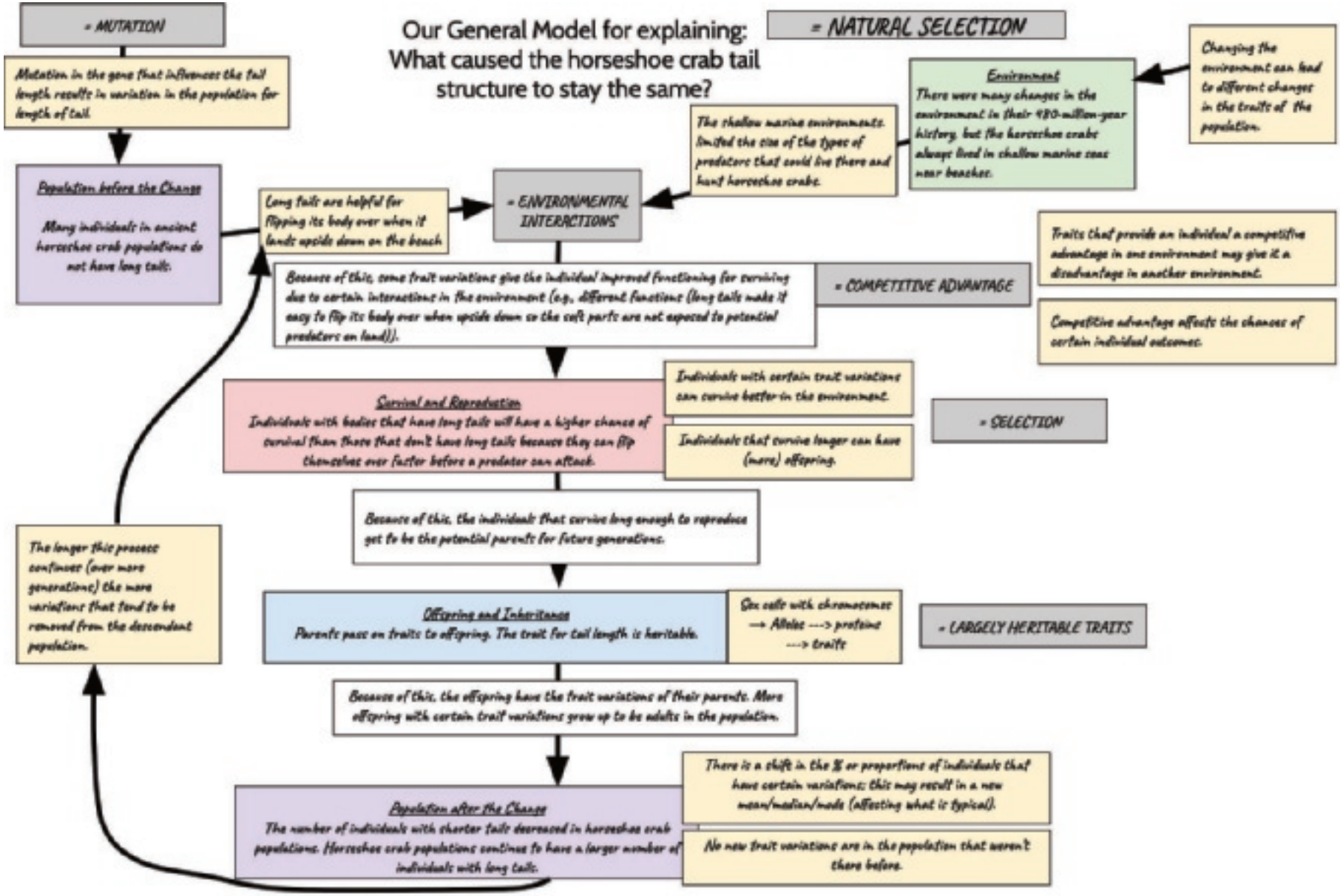
Note that if your students have not experienced the *Muscles Unit*, you may need to explain the model on the slide showing how the two different myostatin proteins influence the trait of musculature differently.

Student Examples of Using General Model to Explain Body Structures

These examples show only one possible way to use our model to explain these phenomena. Keep in mind that student language will vary from what is shown in these examples. Using specific information is important, but the precise words used to describe connections are not.




= MUTATION
Mutation in the gene(s) that influences body armor leads to variation in the population for thickness of exoskeleton covering body.
Our General Model for explaining:
What caused the horseshoe crab armored body structure to stay the same?
= NATURAL SELECTION
Environment
There were many different extinction events that horseshoe crabs lived through. New predators replaced old predators when they went extinct.
Changing the environment can lead to different changes in the traits of the population.
The shallow marine environments limited the size of the types of predators that could live there and hunt horseshoe crabs.
Population before the Change
Many individuals in ancient horseshoe crab populations had a thick exoskeleton covering the soft parts of their body.
Thick exoskeleton covering the body is good for protecting from predation.
= ENVIRONMENTAL INTERACTIONS
Because of this, some trait variations give the individual improved functioning for surviving due to certain interactions in the environment (e.g., different functions (thick exoskeleton around bodies resulted in ability to avoid being eaten by the relatively small predators that could hunt in the shallow marine environment)).
= COMPETITIVE ADVANTAGE
Trait variations that provide an individual a competitive advantage in one environment may give it a disadvantage in another environment.
Competitive advantage affects the chances of certain individual outcomes.
Survival and Reproduction
Individuals with bodies that have thick exoskeletons have a higher likelihood of surviving a predator attack than those that have thinner exoskeletons.
Individuals with certain trait variations can survive better in the environment.
Individuals that survive longer can have (more) offspring.
= SELECTION
Because of this, the individuals that survive long enough to reproduce get to be the potential parents for future generations.
The longer this process continues (over more generations) the more variations that tend to be removed from the descendant population.
Offspring and Inheritance
Parents pass on traits to offspring. The trait for thick exoskeleton is heritable.
Sex cells with chromosomes → Alleles ---> proteins ---> traits
= LARGELY HERITABLE TRAITS
Because of this, the offspring have the trait variations of their parents. More offspring with certain trait variations grow up to be adults in the population.
Population after the Change
The number of individuals with bodies with less armor decreased in horseshoe crab populations. Horseshoe crab populations continue to have a larger number of individuals with thick exoskeletons.
There is a shift in the % or proportions of individuals that have certain variations; this may result in a new mean/median/mode (affecting what is typical).
No new trait variations are in the population that weren't there before


Our General Model for explaining:
What caused the horseshoe crab tail structure to stay the same?
= MUTATION
Mutation in the gene that influences the tail length results in variation in the population for length of tail.
= NATURAL SELECTION
Environment
There were many changes in the environment in their 480-million-year history, but the horseshoe crabs always lived in shallow marine seas near beaches.
Changing the environment can lead to different changes in the traits of the population.
The shallow marine environments limited the size of the types of predators that could live there and hunt horseshoe crabs.
Population before the Change
Many individuals in ancient horseshoe crab populations do not have long tails.
Long tails are helpful for flipping its body over when it lands upside down on the beach
= ENVIRONMENTAL INTERACTIONS
Traits that provide an individual a competitive advantage in one environment may give it a disadvantage in another environment.
Because of this, some trait variations give the individual improved functioning for surviving due to certain interactions in the environment (e.g., different functions (long tails make it easy to flip its body over when upside down so the soft parts are not exposed to potential predators on land)).
= COMPETITIVE ADVANTAGE
Competitive advantage affects the chances of certain individual outcomes.
Survival and Reproduction
Individuals with bodies that have long tails will have a higher chance of survival than those that don't have long tails because they can flip themselves over faster before a predator can attack.
Individuals with certain trait variations can survive better in the environment.
Individuals that survive longer can have (more) offspring.
= SELECTION
Because of this, the individuals that survive long enough to reproduce get to be the potential parents for future generations.
The longer this process continues (over more generations) the more variations that tend to be removed from the descendant population.
Offspring and Inheritance
Parents pass on traits to offspring. The trait for tail length is heritable.
Sex cells with chromosomes --> Alleles ---> proteins ---> traits
= LARGELY HERITABLE TRAITS
Because of this, the offspring have the trait variations of their parents. More offspring with certain trait variations grow up to be adults in the population.
Population after the Change
The number of individuals with shorter tails decreased in horseshoe crab populations. Horseshoe crab populations continue to have a larger number of individuals with long tails.
There is a shift in the % or proportions of individuals that have certain variations; this may result in a new mean/median/mode (affecting what is typical).
No new trait variations are in the population that weren't there before.

Body Structure Similarities and Differences between Modern Penguin Species

Numbers of similarities are listed in blue, and numbers of differences are shown in red.

	Emp	King	Chin	Gento	Adele	Yello	Snock	Macar	Nrock	Fiord	Snare	Royal	Ecres	Littl	Afric	Magel	Humb	Galap
Emperor		35	27	24	23	20	16	18	16	18	16	18	16	23	20	20	20	19
King	1		26	25	24	19	17	19	16	19	16	19	16	24	21	20	21	20
Chinstrap	9	10		31	31	27	22	23	22	23	22	23	22	28	23	24	23	22
Gentoo	12	11	5		34	25	23	24	22	24	22	24	22	28	23	22	23	23
Adelie	13	12	5	2		26	25	26	24	26	24	26	24	27	22	21	22	22
Yellow-eyed	16	17	9	11	10		26	29	27	29	27	29	27	29	25	27	26	27
Southern Rockhop	17	16	11	10	8	7		33	31	32	31	33	31	25	22	21	22	22
Macaroni	18	17	13	12	10	7	0		31	35	31	36	31	27	23	21	23	23
Northern Rockhop	17	17	11	11	9	6	2	2		32	33	32	33	24	21	21	21	21
Fiordland	18	17	13	12	10	7	1	1	1		31	35	32	27	23	22	23	23
Snares	17	17	11	11	9	6	2	2	0	2		31	33	24	21	21	21	21
Royal	18	17	13	12	10	7	0	0	1	1	2		31	27	23	22	23	23
Erect crested	17	17	11	11	9	6	2	2	0	1	0	2		24	21	21	21	21
Little	13	12	8	8	9	7	8	9	9	9	9	9	9		27	29	30	29
African	16	15	13	13	14	11	11	13	12	13	12	13	12	9		34	35	34
Magellanic	16	16	12	14	15	9	12	15	12	14	12	14	12	7	2		35	33
Humboldt	16	15	13	13	14	10	11	13	12	13	12	13	12	6	1	1		34
Galapagos	17	16	14	13	14	9	11	13	12	13	12	13	12	7	2	3	2	

Name: _____ Date: _____

Version 1: Ancient and Modern Penguin Explanation

Consider the Penguin Ancestry Model your small group created as well as the General Model for Natural Selection we have developed as a class. What do these models show in terms of answering the following questions? For each claim you make, be sure to provide any patterns in the data that you have examined that serve as evidence to support your claim. Explain the process or mechanism that helps justify why those data serve as evidence to support your claim.

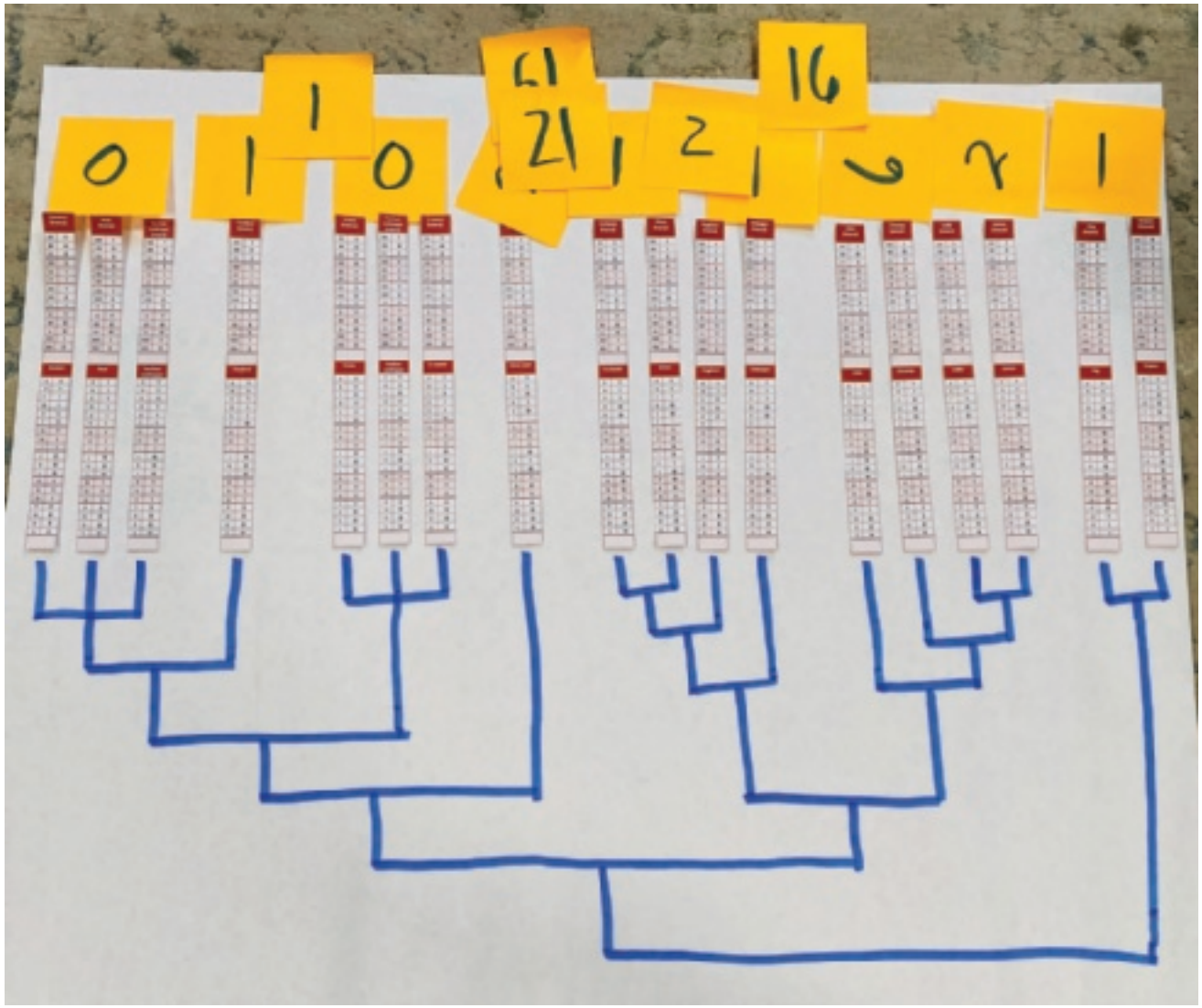
1. Where did all the different species of modern penguins come from?

2. Where did all the ancient penguins go?

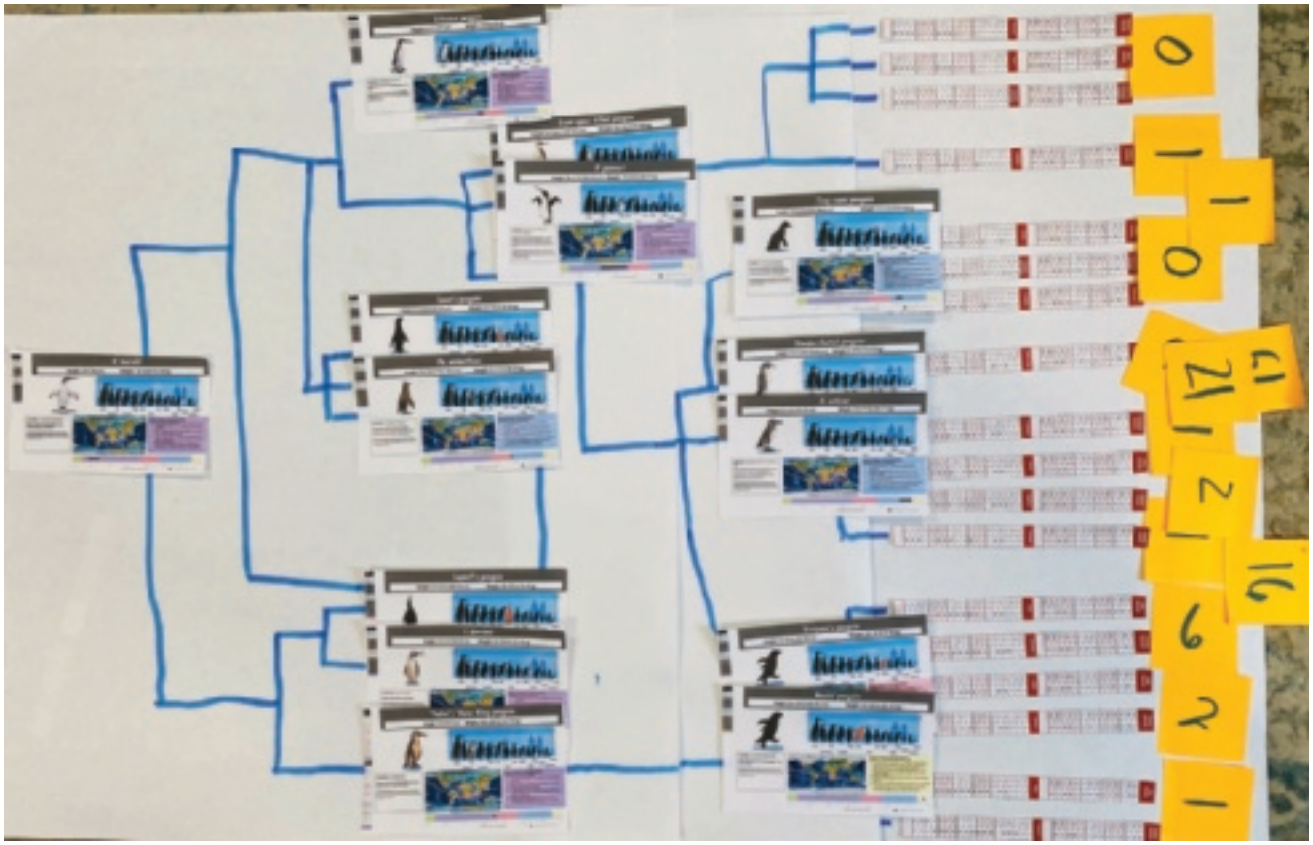
3. How could things living today be connected to the things that lived long ago?

Student Examples of Penguin Ancestry Model

These examples of student small-group Penguin Ancestry Models show one possible way that modern penguins are connected to each other and to ancient penguins. Note that students may organize these penguins in many different ways other than what is shown here.



With modern penguins only



Including ancient penguins

Name: _____ Date: _____

Version 2: Ancient and Modern Penguin Explanation

Consider the Penguin Ancestry Model your small group created as well as the General Model for Natural Selection we have developed as a class. What do these models show in terms of answering the following questions?

1. Where did all the different species of modern penguins come from?

What patterns in data have you examined that serve as evidence to support your claim?

Explain the process or mechanism that helps justify why those data serve as evidence to support your claim.

2. Where did all the ancient penguins go?

What patterns in data have you examined that serve as evidence to support your claim?

Explain the process or mechanism that helps justify why those data serve as evidence to support your claim.

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

What patterns in data have you examined that serve as evidence to support your claim?

Explain the process or mechanism that helps justify why those data serve as evidence to support your claim.

Key for Ancient and Modern Penguin Explanation

This assessment can be used to evaluate student progress on the following lesson level PE. The lesson level PEs are an integration of elements from the three dimensions, so look for these three aspects working together across the students' responses to the three prompts.

13.B Construct a scientific explanation proposing relationships between all modern penguins and ancient penguins using the similarities and differences in accumulated body structure changes over time to estimate how relatively long ago they shared a recent ancestor.

SEPs	DCIs	CCCs
Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. Evidence that demonstrates students are using this practice in their written response includes the following: • Using natural selection in differing environments as well as the accumulation of mutations to explain the differences in body structures they observe • Using the relationship between differences in body structure and lengths of time to justify which penguin species share recent ancestors • Using the relationship between differences in body structure and lengths of time to claim a species of penguin was either a direct ancestor of a certain modern penguin or group of penguins or that a species of ancient penguin went extinct	In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. Natural selection leads to the predominance of certain traits in a population and the suppression of others. Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common and those that do not become less common. Thus, the distribution of traits in a population changes. Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. Evidence that demonstrates students are using these science ideas in their written response includes the following: • Natural selection requires trait variation; the origin of new variation is random mutation. • Some mutations result in a trait that allows for an individual to survive and reproduce better than others. Individuals with those heritage traits have more offspring who also have the advantageous trait. Over time the population changes so the frequency of that trait greatly increases. • Depending on the effect of the mutation and the environment, new traits may either disappear from the population or increase in frequency.	Stability might be disturbed either by sudden events or gradual changes that accumulate over time. Evidence that demonstrates students are using these concepts in their written response includes the following: • Students acknowledge that changes in the environment lead to change in species. This could be adaptation by natural selection, or the species also could go extinct. • Student explanations may include either or both of these ideas: that penguins of long ago may have gone extinct, or they may have accumulated differences over time so the modern species they became is no longer recognized as the same species from long ago.

	• Over time, if populations have been separated, mutations and the effects of natural selection result in an accumulation of differences in populations. By analyzing how different organisms are from each other, one can estimate when the populations diverged. • Using the number of trait differences one can predict which of the modern penguins shared a more-recent common ancestor (are more closely related). • By examining traits in fossils one can use the same strategy to make some hypotheses about how the ancient penguins are connected to the modern penguins.	• When responding to "Where did all the different species of modern penguins come from?" students also need to acknowledge some change in the environment, for the whole population and/or that part of the population split off into a different environment in order for these changes over time to happen.

Consider the Penguin Ancestry Model your small group created as well as the General Model for Natural Selection we have developed as a class. What do these models show in terms of answering the following questions? For each claim you make, be sure to provide any patterns in the data that you have examined that serve as evidence to support your claim. Explain the process or mechanism that helps justify why those data serve as evidence to support your claim.

1. Where did all the different species of modern penguins come from?

+Penguins of today came from ancestors.

+Species that have fewer differences between them share a more-recent common ancestor.

+We can connect all living penguins back to a common ancestor.

+Populations of penguins in the past were split into different environments.

+When they were separated, random mutations happened as well as natural selection; as time passed the separate populations became more different.

2. Where did all the ancient penguins go?

+Penguins of long ago may have gone extinct, or they may have accumulated differences over time so the modern species they became is no longer recognized as the same species from long ago.

+When changes happen in the environment, individuals with body structure variations that help them survive and reproduce will do so, and their offspring will also have those trait variations that help them survive and reproduce. Over time, the frequency of the trait variations of those individuals will increase in the population.

+If a population does not have the trait variations necessary to survive in the environment, they could go extinct.

+Mutation can provide new variation, but it is random and not common.

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

+All living things today are connected to an ancestor that lived long ago.

+Species that are similar share a common ancestor more recently than species that are very different from one another.

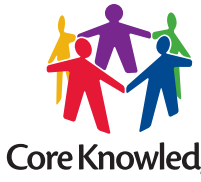
+We can connect all living things back to a common ancestor.

+When a population of any organism is separated, random mutations happen as well as natural selection. As time passes the separated populations become more different.

LESSON 14: ANSWER KEY

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

A) What new ideas do you have about how to answer our lesson question?	B) What new questions did your analysis of the embryo sketches raise?
Accept all answers. Also look for application of ideas from the unit that were not raised in Lesson 1 but connect to work in recent lessons, such as the following: • Natural selection and mutation might help explain the similarities in traits across different types of organisms. • All living things may share common ancestors. Also look for development of new model ideas that lay the foundation for future HS-level exploration of concepts related to these ideas: • Shared (common) aspects of cellular processes (e.g., differentiation) across different species • Cell and tissue development being triggered or cued by some process (differentiation) • Shared (common) portions of genetic information across species related to macroevolution, DNA, and cellular processes	Accept all answers. Look for questions around these ideas: • Which organisms are more closely related than others? • The common ancestor for egg-layers vs. non-egg-layers • Connections to how the organisms on the Related Phenomena poster (e.g., dinosaurs, wooly mammoths) may be related to all the organisms alive today. • The origin of all species • The origin of all life • The structure of the tree of life • What common ancestors humans have with other living things • How such similar processes (in embryo development) can produce such varied structures • What is happening at a cellular and tissue level to produce different tissues and structures. • What additional fossil evidence we have for these other living things • What additional evidence related to genetic information do we have for these other living things?
C) What patterns in the data you analyzed in this lesson led you to consider these new ideas and/or questions?	
Referencing specific patterns in the data linked to a specific idea or question above	



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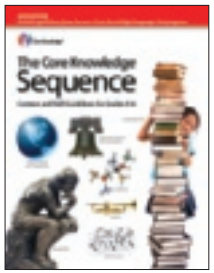
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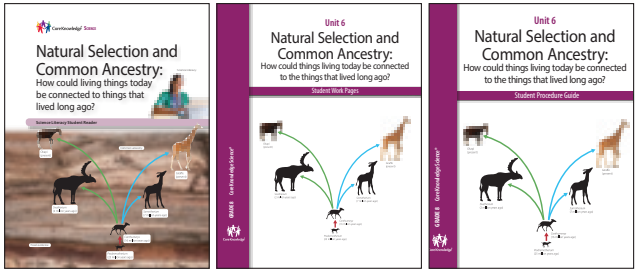
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