UNIT STORYLINE

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

How students will engage with each of the phenomena

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

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

Phenomena or Design Problem

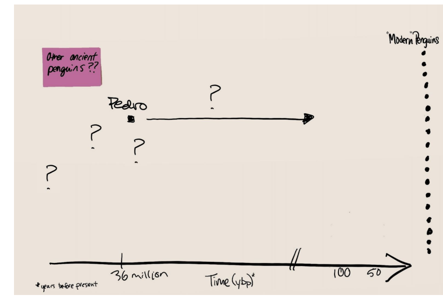
A giant fossil penguin, named Pedro, that lived 36 million years ago and was discovered in Peru has important anatomical similarities to and differences from penguins that are alive today.

What we do and figure out

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? and (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).

How we represent it



⇓ **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).

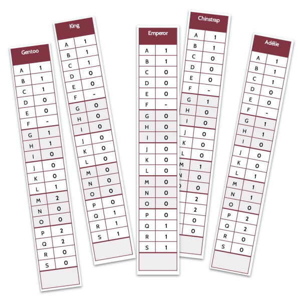
LESSON 2

2 days

How similar or different are different species of penguins?

Investigation

Phenomena or Design Problem



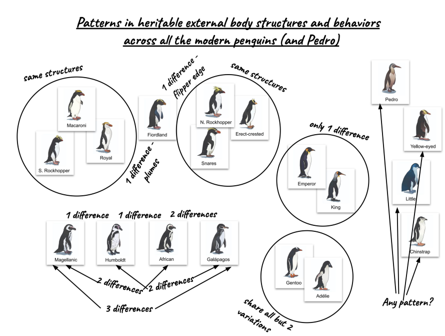
Heritable physical structure and behavior variations have been measured for different modern penguins, and some of these have been measured for Pedro.

What we do and figure out

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.

How we represent it



⇓ **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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it

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.

Updates to the Penguin Timeline for where the penguins of today came from

- All the species of ancient penguins that we know of, based on their fossils and when they lived, relative to one another
- What the penguins looked like
- The penguin body structures
- Where the penguins lived
- What the local and global environment was like when the penguins lived

⇓ **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 4

2 days

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

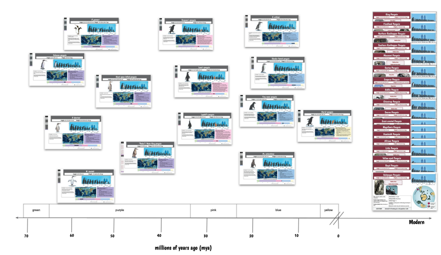
Putting Pieces Together, Problematizing

Ancient penguin	Number of fossils discovered so far	Percent of fossils discovered with the same variations 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

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

Phenomena or Design Problem:

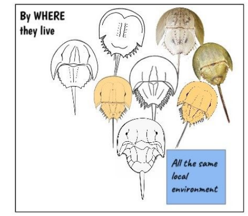
Body structure variation data have been collected from modern whales, horses, and horseshoe crabs, as well as from ancient fossils of these organisms. The specific locations where these fossils were found also provide information on how old they are and what their local and global environments were like at that time the fossils formed.

What we do and figure out:

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).

How we represent it:



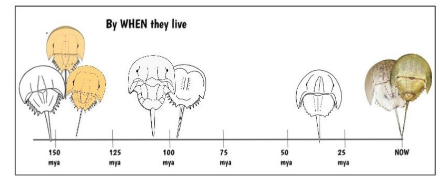


Image Credit: Darwini, Indopacific, American: Bicknell RDC, et al. (2020). Pictorial Atlas of Fossil... Earth Sci. 8:98. Syriacus, Walchi, Descheni: Reprinted from Journal of Paleontology, Vol 26(4), Størmer, L., Phylogeny and Taxonomy of Fossil Horseshoe Crabs/ pp. 630-640, 1952, with permission from SEPM Society for Sedimentary Geology Sibiricus: Kin, A., et al. (2014). The horseshoe crab of the genus... PloS one, 9(9), e108036.

⇓ **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?

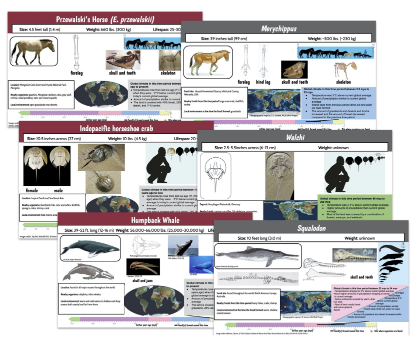
LESSON 6

2 days

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

Putting Pieces Together, Problematizing

Phenomena or Design Problem:



No new phenomena are introduced in this lesson. We put the pieces together for all phenomena we previously explored in Lessons 1 through 5.

What we do and figure out:

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:

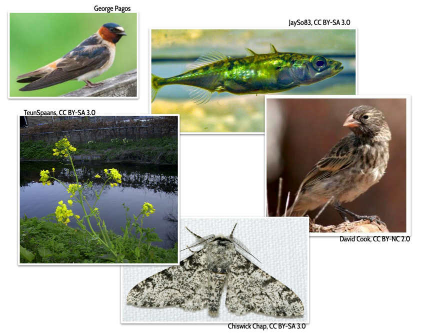
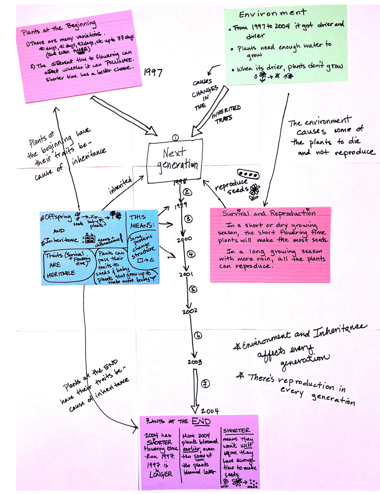
- There are clear patterns of differences in the body structures of some organisms over really long periods of time and across different environments.
- There must have been some population(s) of ancient organisms that had offspring that were lines of descendants that led to modern organisms.
- The body structure variations are somehow changing in a line of descendants from one of the ancient populations to one of the modern ones.

How we represent it:

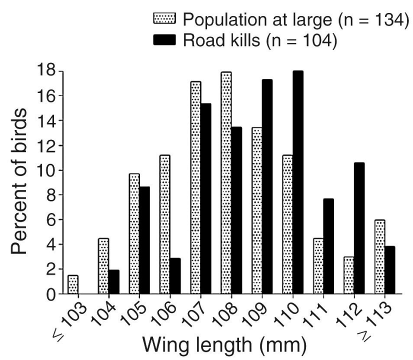
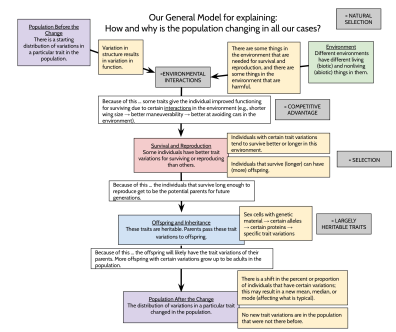
New Model Ideas

- *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).*

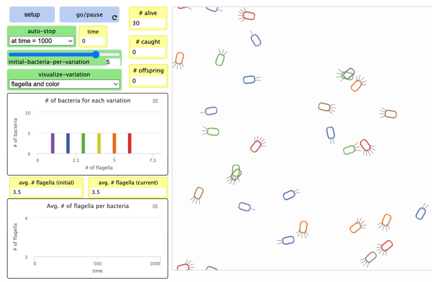
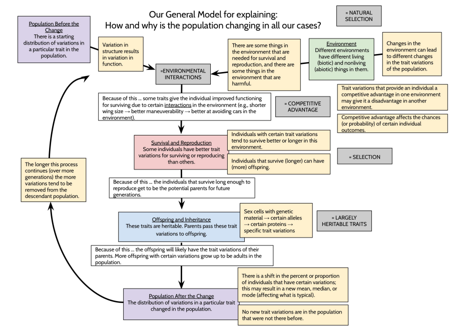
⇓ **Navigation to Next Lesson:** Since something was changing in these populations over time and we can't go back in time to observe it as it was happening to figure out how the change occurred, we need some cases with firsthand observations of a population-level trait change happening over a shorter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

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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.	

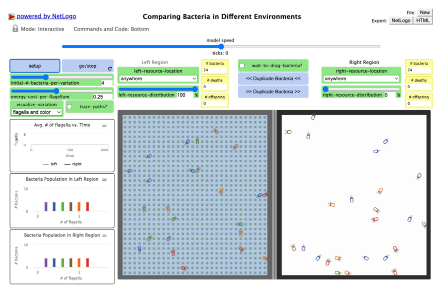
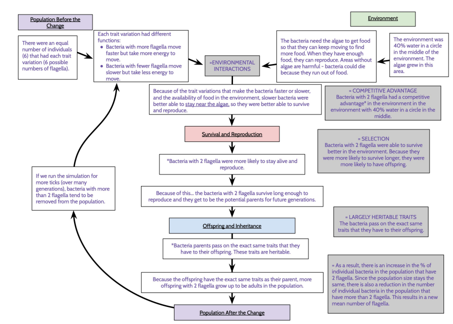
⇓ **Navigation to Next Lesson:** Though we have a case-specific set of causes and effects that explain the trait changes in a population in our system, we want to see whether there are any similar mechanisms that help explain the trait changes in the other populations across the rest of the case studies.

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	 *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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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.

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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

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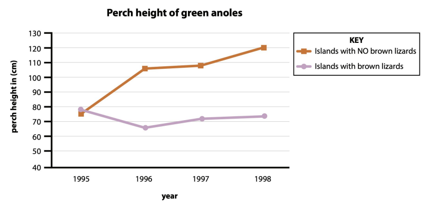

On islands with green and brown anole lizards, the green lizards now live higher (than in the past) in the trees than on islands without brown anole lizards.

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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.

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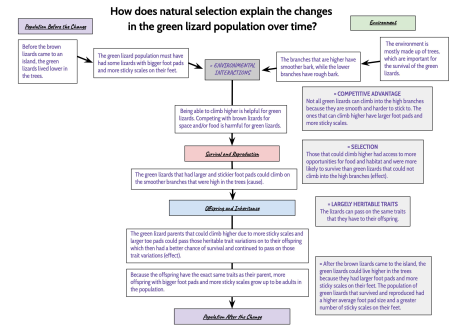

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⇓ **Navigation to Next Lesson:** We tested our General Model for Natural Selection on a new phenomenon. Next, we want to see if we can use our model to explain the types of changes we think are happening over millions of generations.

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LESSON 12

2 days

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

Putting Pieces Together, Problematizing

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Ancient and modern horses and horseshoe crabs have body structures that help(ed) them survive in their specific environments.

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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.

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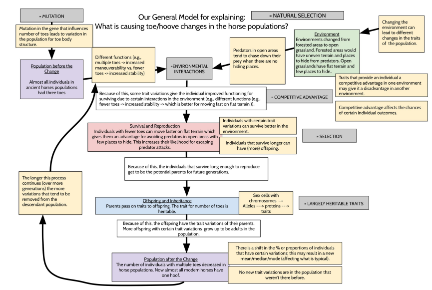

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⇓ **Navigation to Next Lesson:** We wonder if the General Model for Natural Selection can explain cases where there are several different modern species with many different body structures.

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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

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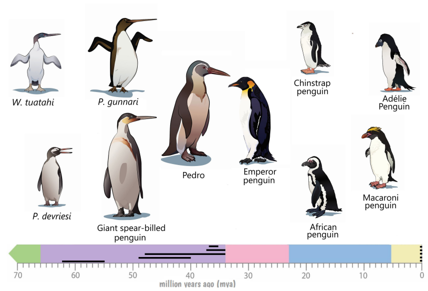

No new phenomena are introduced in this lesson. We put the pieces together for penguin phenomena we explored throughout the unit.

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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.

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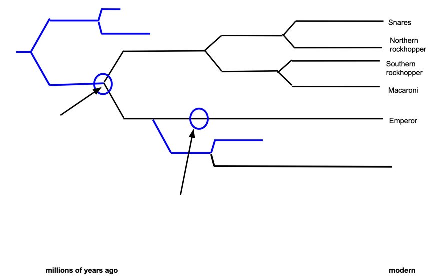

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⇓ Navigation to Next Lesson: What other kinds of evidence would you want to help you figure out how all species trace back to their ancestors?

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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

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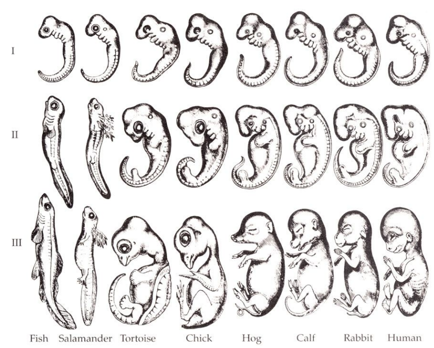

Similarities exist between the physical structures of embryos for different animal species that are not evident in the fully formed anatomy.

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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.

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What new questions did your analysis of the embryo sketches raise?

- *What is the common ancestor for egg-layers vs. non-egg-layers?*
- *What do the embryos for other animals on our Related Phenomena list look like? How do they compare to these we saw today?*
- *How can organisms look so similar as embryos and have such varied structures when they are born?*
- *What additional fossil evidence do we have for these other living things?*
- *What additional evidence related to genetic information do we have for these other living things?*

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⇓ 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.

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LESSON 15

1 day

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

Putting Pieces Together

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Asking questions about phenomena gives us a mission for our science learning.

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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.

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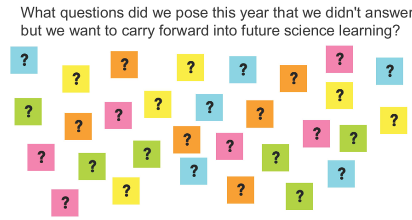

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⇓ **Navigation to Next Lesson:** This is the last lesson in the unit.

LESSONS 1-15

31 days total