Uncover life’s connections through the lens of evolution. Topics include:

- Scientific evidence of common ancestry and the process of evolution.
- The use of Earth's fossil record to understand biogeography, extinction, and the rate of evolution.
- Analysis of phylogenetic trees to understand species relationships and trace common ancestry.

<table>
<thead>
<tr>
<th>TEKS standards</th>
<th>Example phenomena</th>
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<tbody>
<tr>
<td>SCIENCE.BIO.9.A</td>
<td>How do different sources of scientific evidence shed light on the common ancestry of various organisms, such as whales? Whales evolved from ancient four-legged land mammals that underwent a remarkable transformation and adaptation to ocean life, giving rise to the diverse cetaceans we see today. This transformation, as evidenced by fossil beds of ancient seas and in the genes of living species, is a fascinating case study of common ancestry and evolutionary change. Can also explore how ancestors of mammals evolved jaws into ears; early tetrapod jawbones evolved into modern mammals’ middle ear ossicles, enhancing hearing for survival and communication.</td>
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| SCIENCE.BIO.9.B | Prompts for students to consider:  
- Which characteristics of early whale fossils show their shift from land to sea and how?  
- How do whale fossils’ locations and global distribution suggest evolution from land mammals?  
- What whale features and vestigial structures reveal common ancestry with land mammals?  
- What do whale genetics and embryology reveal about their relation to other mammals? How does DNA analysis trace whale evolution?  
- Which pattern (gradualism, abrupt appearance, or stasis) do we tend to see in the fossil record of whales? How can we explain this apparent pattern in the fossil record?  

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How do different types of scientific evidence explain the evolutionary changes from dinosaurs to birds?

Journey back to the Mesozoic Era to uncover how birds evolved from their dinosaur ancestors, a process richly-documented in the fossil record with transitional fossils like Archaeopteryx. The link between modern birds and dinosaur ancestors is supported by genetic similarities with reptiles and comparative studies, such as shared bipedal posture with theropods, egg brooding behaviors, and the evolution of feathers for flight. These examples offer strong evidence for the evolutionary transition from theropod dinosaurs to the birds we see today. Check out the video, “Common Ancestry and Evolutionary Trees” to further connect birds as direct descendants of dinos.

Prompts for students to consider:

- How do fossils like Archaeopteryx illustrate common ancestry between dinosaurs and birds?
- How does the geographic spread of theropod dinosaur and early bird fossils highlight their evolutionary connection?
- How do shared anatomical features link birds and dinosaurs evolutionarily?
- Which pattern (gradualism, abrupt appearance, or stasis) do we tend to see in the fossil record of birds? How can we explain this apparent pattern in the fossil record?

How does evolutionary evidence provide insight into amphibians’ transition from water to land?

Over 350 million years ago, during the Devonian period, a monumental evolutionary event occurred: the emergence of amphibians from their lobe-finned fish ancestors. Key fossil discoveries show ancient amphibians’ adaptations for land, such as evolving limbs and respiratory systems. Today’s amphibians, with their specific anatomy and life cycles, clearly link back to these ancestors, illustrating the gradual evolution of these characteristics over time. Exploring amphibian evolution offers a unique glimpse into the adaptive processes of life during this critical juncture in Earth’s history.

Prompts for students to consider:

- How do fossils like Ichthyostega and Tiktaalik demonstrate the evolution of amphibians’ from ancient fish-like species?
- What does early amphibians’ geographic distribution indicate about their evolution?
- Which amphibian anatomical features suggest a common ancestry with lobe-finned fish (i.e., Eusthenopteron)?
- How does DNA analysis link amphibians to lobe-finned fish (specifically the Sarcopterygii group)?
- How does embryology show amphibians’ water-to-land transition?
- Which pattern (gradualism, abrupt appearance, or stasis) do we tend to see in the fossil record of amphibians? How can we explain this?
## Lesson overview

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<th>Lesson</th>
<th>Objective</th>
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| **Lesson 1: Evidence for evolution**        | Analyze and interpret scientific evidence to understand and explain the concept of common ancestry among diverse species. | - Evidence for evolution encompasses fossils, anatomy (homologous structures, transitional features, embryos and development), biogeography, and molecular biology and genetics.  
- Map ancient fossil locations and explore links between biogeography and plate tectonics.  
- Investigate common ancestry with models, embryology, and DNA comparisons to identify shared genes among ancient and modern species. |
| **TEKS standard:** BIO.9.A.                  |                                                                           |                                                                                                                                             |
| Video | Article | Exercise | 2 | 1 | 1 |
| **Lesson 2: The fossil record**             | Describe how the fossil record provides evidence for common ancestry and the evolution of different species over time. | - The fossil record, a collection of plant and animal remains in sedimentary rocks, traces life's evolutionary history over millions of years.  
- Create a classroom timeline of geological eras, highlighting major fossils like *Archaeopteryx* and *Tiktaalik*, and mark significant extinctions.  
- Compare fossils with modern species, such as theropod dinosaurs to birds.  
- Show how CT scans, 3D imaging, VR, laser scanning, DNA analysis, electron microscopy, and radiometric dating aid in studying fossils. |
| **TEKS standard:** BIO.9.A; 9.B.              |                                                                           |                                                                                                                                             |
| Video | Article | Exercise | 4 | 1 | 1 |
| **Lesson 3: Phylogeny and evolutionary trees** | Interpret phylogenetic trees to analyze the evolutionary relationships among various species, using evidence from genetic, morphological, and fossil data to understand how these trees depict shared ancestries and divergences over time. | - Phylogenetic trees show species' evolutionary relationships, developed with molecular, morphological, or other data to trace ancestries and divergences.  
- Connect to previous units to show how molecular data is used in constructing phylogenetic trees.  
- Begin phylogenetic tree analysis with simple, well-known species like dog breeds, *Panthera* genus, or whales for students' initial projects.  
- Create a classroom "Tree of Life" display to illustrate relationships among various organisms, adding to it as students learn about new species.  
- Use online resources like OneZoom or Tree of Life for interactive phylogenetic tree exploration. |
| **TEKS standard:** BIO.9.A.                  |                                                                           |                                                                                                                                             |
| Video | Article | Exercise | 1 | 0 | 2 |
Best practices

COMMON MISCONCEPTIONS AND HOW TO ADDRESS THEM

“Evolution is a linear process leading to humans.”
Evolution is a branching, non-directed process with humans as one of many diverse outcomes.

How to address this misconception
Use a variety of activities that highlight the branching (and ongoing) nature of evolution. Constructing phylogenetic trees can show students that humans are merely one of many species branches. Creating timelines of Earth’s history helps students understand the long timescale of evolution, placing Homo sapiens as a recent addition, not the end goal. Research projects on various species, from plants to fungi, encourages the exploration of the extensive diversity shaped by evolution, reinforcing the idea that human evolution is just one part of a much larger ongoing process. Another angle of exploration to highlight is extinction! Lots of species have evolved over time in relation to specific conditions but a great majority of species that once existed have gone extinct. So, evolution can be examined from two perspectives; the diversity of life that has evolved but also the extinction of many different species.

"Gaps in the fossil record are a reflection of gaps in our understanding of evolution."
The rarity of the fossilization process often leads to perceived "missing links" or sudden appearances in the fossil record, not due to rapid evolution but the specific conditions required for fossil formation.

How to address this misconception
Explaining fossilization's rarity and the patterns of evolutionary change is crucial. Activities like analyzing the fossil record and simulating fossilization illuminate the commonality of gaps in the fossil record and the specific conditions needed for fossilization. Then, introduce apparent patterns in the fossil record, such as gradualism, abrupt appearance, and stasis. Evolution may appear rapid in the fossil record due to fast evolutionary events (which, in the fossil record still means taking millions of years) or due to irregular fossil preservation. The fossil record shows both slow, steady evolution and rapid changes. Scientists are investigating which pace is more common and how these evolutionary changes occur. Using activities like exploring the geologic time scale, constructing phylogenetic trees, and case studies like whale evolution help to clarify evolutionary patterns. These activities show students the value of the fossil record in supporting evolutionary theory.
CLASSROOM ACTIVITIES

**Fossil record analysis and simulating fossilization**

Discover why some organisms become part of history while others are lost in time. In this activity, students will analyze fossils and create their own replicas to understand fossilization and its role in evolutionary history. Like paleontologists, students will explore how organisms are preserved, connecting to concepts like fossilization, evolutionary patterns, and the fossil record's limitations.

**Part 1- Fossil analysis**

**Materials:** Assortment of fossil replicas (or high-quality images). Hand lenses or stereo microscope. World map for biogeographical analysis. Reference materials on geologic periods.

- Start with an overview of the fossil record's role in evolutionary history.
- Give student groups fossils or images to observe and describe focusing on features like size, shape, and function. If possible, students should map their fossils' origins.
- **Class discussion:** Lead a discussion on patterns observed in the fossil record, including major shifts in environmental conditions, the emergence of new species, and mass extinctions. Discuss the fossil record's limitations and the need for additional evidence in studying evolution.

**Extension:** give students different fossil images or descriptions to categorize in groups or as a class, such as into plant, animal, marine, or terrestrial groups.

**Part 2- Create your own fossil replicas**

**Materials:** Clay or plaster of Paris. Small organic materials (leaves, twigs, shells, small dead insects, chicken bones leftover from dinner, feathers, etc. having a variety of hard and soft organic materials is key. Shallow containers (aluminum foil tins work well). Water. Safety goggles and gloves. Plaster of Paris tips: watch YouTube tutorials and test the process on a small scale first. Have students make their own batches in groups—messy, but reinforces precision.

- Start the lab with a discussion on the process of fossil formation, highlighting its rarity and the specific conditions needed.
- Distribute clay or Plaster of Paris along with various organic materials to students or groups.
- Instruct them to press various organic materials into their chosen medium, simulating the burial of organisms in sediment.
- Have students record which materials they used.
- Allow time for the medium to set, representing the prolonged process of fossilization.
- Once set, students will carefully extract the material to reveal an impression, akin to a real fossil.
- They should observe and document their "fossil" creations, noting any alterations or gaps.
- **Class discussion:** Lead a discussion to connect their simulations with actual fossilization, addressing the conditions necessary for fossil preservation and the reasons behind the fossil record's incompleteness. Encourage students to consider how their hands-on experience and new knowledge shed light on the nature of the fossil record.

**Extension:** assign or let students choose a fossil species to research in-depth, including its discovery, paleoecology, significance, and what it tells us about Earth's past.
Tracing evolution with DNA barcoding
Unlock the secrets of life with DNA barcoding! Compare genetic sequences to reveal evolutionary relationships and common ancestry, linking to concepts like genetic similarities and species evolution.

**Materials:** Computer access for online DNA databases. Sample DNA sequences of different species (can be provided digitally from Barcode of Life Data Systems and GenBank).

- Begin with a brief overview of DNA barcoding, explaining how it involves comparing genetic sequences to identify species and understand evolutionary relationships.
- Divide students into small groups and distribute sample DNA sequences from different species.
- Instruct students to visually compare sequences, identifying genetic similarities and differences, and record their observations, with a focus on how genetic similarities suggest common ancestry.
- Allow students time to explore and familiarize themselves with databases such as BOLD (Barcode of Life Data System) and the International Barcode of Life project.

**Questions to guide exploration:**
- How do genetic similarities in databases like BOLD support common ancestry theories?
- What biodiversity patterns in DNA barcoding data reveal about species evolution?
- How does DNA barcoding trace evolutionary histories and identify new species?
- What challenges do DNA barcoding data pose for studying evolutionary biology?

**Class discussion:** lead a discussion on the objectives, challenges, and significance of using DNA barcoding in studying common ancestry.

**Extension:** discuss the role of DNA barcoding in conservation, highlighting its use in identifying and monitoring endangered species and monitoring illegal wildlife trade.

**Extension:** discuss DNA barcoding for identifying mislabeled seafood, such as imitation crab, especially for those with seafood allergies. For deeper analysis, check out BioRad Comparative Proteomics Kit.

Fossil record detectives
Become a detective of the past! Investigate the pace of evolution through case studies, identifying patterns of gradualism, abrupt changes, and stasis in the fossil record. Determine which evolutionary pattern is most common among various species and explore explanations for these patterns.

**Materials:** Case study materials (texts or articles on specific evolutionary examples). Access to research resources (library, internet). Whiteboards or chart paper for group work.

- **Case study exploration:** dive into selected case studies showcasing species that have undergone gradualism, experienced abrupt appearances, or remained in stasis.
  - Gradualism: horses (gradual size increase and toe reduction), elephants (ancestor Moeritherium), sharks, and whales.
  - Abrupt appearance: species from the Cambrian explosion, for example: trilobites, Anomalocaris, Opabinia, Marella, and Wiwaxia.
  - Stasis: coelacanth, horseshoe crab, velvet worms; often considered “living fossils,” have shown little morphological change over millions of years.

- **Detective work:** as fossil record detectives, examine evidence from the case studies to identify which evolutionary pattern each species exemplifies.

- **Pattern analysis:** discuss as a class which pattern appears most frequently in the fossil record and why certain species might exhibit one pattern over others.

- **Detectives at it again:** investigate and hypothesize reasons behind the observed patterns. Consider factors like environmental changes, survival advantages, and the nature of fossilization itself.
PRO TIPS

Building and understanding phylogenetic trees
Phylogenetic trees can often be a stumbling block for students in understanding evolutionary relationships. Begin with simple tree diagrams of species students are familiar with (local species, pets, or Panthera) before moving onto more complex ones. Color-coded trees and those with pictures of species can help students better visualize and understand relationships. Encourage students to reflect on and apply what they've learned in previous units to new scenarios, fostering deeper understanding and critical thinking. Check out the Khan and PBS NOVA collaboration “Evolution 101” for support in constructing and interpreting phylogenetic trees!

Unit resources

- For the videos in this unit, use the Learning summary video notetaking guide
- For the articles in this unit, use the Article notetaking guide
- For the exercises in this unit, use the Blank workspace template
- Vocabulary and notation notetaker

GENERAL CLASSROOM IMPLEMENTATION RESOURCES:

- Weekly Khan Academy Quick Planning Guide: Use this template to easily plan your week using Khan Academy.
- Student Learning Templates: Choose a template for students to record their learning. There are templates for watching videos, reading articles, and doing exercises.
- Using Khan Academy in the Classroom: Learn about teaching strategies and structures to support your students in their learning with Khan Academy.
- Differentiation Strategies for the Classroom: Read about strategies to support the learning of all students.