Science & Literacy Activity

ACTIVITY OVERVIEW

This activity, which is aligned to the Common Core State Standards (CCSS) for English Language Arts, introduces students to scientific knowledge and language related to the evidence scientists use to understand the evolutionary relationships among living and extinct dinosaurs.

This activity has three components:

1. **BEFORE YOUR VISIT**, students will read a content-rich article about the evidence scientists use to understand the evolutionary relationships among living and extinct dinosaurs. This article will provide context for the visit, and also help them complete the post-visit writing task.
2. **AT THE MUSEUM**, students will read and engage with additional texts (including printed text, digital and physical/hands-on interactives, video, diagrams, models). This information will help them complete the post-visit writing task.
3. **BACK IN THE CLASSROOM**, students will draw on the first two components of the activity to complete a CCSS-aligned explanatory writing task about the evidence scientists use to understand the evolutionary relationships among living and extinct dinosaurs.

Materials in this packet include:

For Teachers

- Activity Overview (p. 1-2)
- Article (teacher version): "Shedding Light on the Dinosaur-Bird Connection" (p. 3-7)
- Answers to student worksheets (p. 8-9)
- Assessment rubric for student writing task (p. 10-11)

For Students

- Article (student version): "Shedding Light on the Dinosaur-Bird Connection" (p. 12-15)
- Student worksheet for the *Dinosaurs Among Us* exhibition visit (p. 16-17)
- Student writing task and rubric (p. 18-20)

Common Core State Standards

RST.9-10.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

RST.9-10.2 Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

WHST.9-10.2 Write informative/explanatory texts, including the narration of scientific procedures/experiments.

New York State Science Core Curriculum

LE3.1e

Next Generation Science Standards

DCI: LS4.A: Evidence of Common Ancestry and Diversity
Genetic information, like the fossil record, provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.

SEP 8: Obtaining, Evaluating and Communicating Information

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/ or to obtain scientific information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- Communicate scientific information or ideas in multiple formats (including orally, graphically, and textually).

1. BEFORE YOUR VISIT

Students will read a content-rich article about the evidence scientists use to understand the evolutionary relationships among living and extinct dinosaurs. This article will provide context for the visit, and help them complete the post-visit writing task.

Preparation

- Familiarize yourself with the student writing task and rubric (p. 18-20).
- Familiarize yourself with the teacher version of the article (p. 3-7), and plan how to facilitate the students' reading of the article.

Instructions

- Explain the goal: to complete a writing task about the evidence scientists use to understand the evolutionary relationships among living and extinct dinosaurs.

- Tell students that they will need to read an article before visiting the Museum, and read additional texts during the visit.
- Distribute the article, student writing task, and rubric to students.
- Review the rubric with students and tell them that it will be used to grade their writing.
- Read and discuss the article, using the teacher notes to facilitate.

2. DURING YOUR VISIT

At the Museum, students will read and engage with additional texts (including printed text, digital and physical/hands-on interactives, video, diagrams, models). The information they'll gather from these multiple sources will help them complete the post-visit writing task.

Preparation

- Review the educator's guide to see how themes in the exhibition connect to your curriculum and to get an advance look at what your students will encounter. (Guide is downloadable at **amnh.org/dinosaurs-among-us/educators**)
- Familiarize yourself with the student worksheet (p. 16-17) and the map of the exhibition.

Supports for Diverse Learners

This resource has been designed to engage all learners with the principles of Universal Design for Learning in mind. It represents information in multiple ways and offers multiple ways for your students to engage with content as they read about, discuss, view, and write about scientific concepts. Different parts of the experience (e.g. reading texts, or locating information in the Museum) may challenge individual students. However, the arc of learning is designed to offer varied opportunities to learn. We suggest that all learners experience each activity, even if challenging. If any students have an Individualized Education Program (IEP), consult it for additional accommodations or modifications.

Alternate Version of Article

Another version of the same article with a lower lexile level is available for download at amnh.org/dinosaurs-among-us/educators. You can use this same activity with that article.

Instructions

- Explain the goal of the Museum visit: to read and engage with texts (including printed text, digital and physical/hands-on interactives, video, diagrams, models), and to gather information to help them complete the post-visit writing task.
- Distribute and review the worksheet and map. Clarify what information students should collect, and where.

Additional Suggestions for Facilitating the Museum Visit

- Have students explore the exhibition in pairs, with each student completing his or her own student worksheet.
- Encourage student pairs to ask you or their peers for help locating information. Tell students they may not share answers with other pairs, but may point each other to places where answers can be found.

3. BACK IN THE CLASSROOM

Students will use what they have learned from the pre-visit article and at the Museum to complete a CCSS-aligned explanatory writing task about the evidence scientists use to understand the evolutionary relationships among living and extinct dinosaurs.

Preparation

- Plan how you will explain the student writing task and rubric (p. 18-20) to students.

Instructions

- Distribute the student writing task and rubric. Explain that they will use it while composing, and also to evaluate and revise what they have written.

Suggestions for Facilitating Writing Task

- Before they begin to write, have students use the writing task to frame a discussion around the information that they gathered at the Museum. They can work in pairs, small groups, or as a class, and can compare their findings.
- Referring to the writing task, have students underline or highlight all relevant passages and information from the article and from the notes taken at the Museum.
- Students should write their essays individually.

ARTICLE: TEACHER VERSION

About this Article

Lexile: 1130

Wordcount: 1108

Text Complexity: The Lexile level for this text falls towards the lower end of the grades 9-10 CCSS text complexity band. This text is suitable as an interactive read-aloud and is appropriate as an independently read text for high school students reading on grade level. Teachers should use their professional judgment and knowledge of students' independent reading levels regarding assigning this text for independent reading.

Key for Teacher Notes

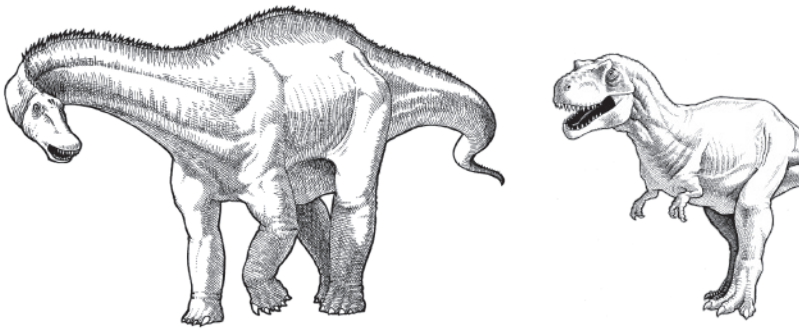
- Green text
  specific strategies
- Regular text
  instructions for teachers
- *Italicized text*
  teacher's instructions to students
- Underlined text
  important domain-specific words

Notes: Students should be sitting with partners for this interactive read-aloud. Whenever the teacher notes suggest Think/Pair/Share, it is generally followed by instructions to "listen in" to student conversations. This enables the teacher to select students to share out thinking that would benefit the whole group to hear. Additionally, it allows the teacher to informally assess student thinking about the text. The teacher can follow up with a think aloud to help clarify parts of the text as needed. At times, the teacher may want to facilitate whole class discussion after Think/Pair/Share.

These teacher notes allow for frequent stopping for partner talk and sharing out. Individual teachers should modify this interactive read-aloud in a way that suits the needs of their students. For instance, teachers may want to have students read parts of the text independently, depending on students' reading levels. A strategy that teachers might consider using throughout this text is annotating in the margins. After stopping to talk with a partner and/or have whole group discussion, students can jot a phrase that expresses the main idea ("gist statement") in the margin. Teachers can demonstrate this for the first few paragraphs and then ask students to jot gist statements in partners or independently as the read-aloud progresses.

Shedding Light on the Dinosaur-Bird Connection

When people think of dinosaurs, two types generally come to mind: the huge herbivores with their small heads and long tails and those fearsome carnivores that walked on two legs and had a mouthful of teeth like kitchen knives.



Living Dinosaurs

These large dinosaurs are no longer around, but dinosaurs still live among us today. They are the birds. It's difficult to imagine that a bird on your window sill and a *T. rex* have anything in common. One weighs less than a pound; the other was the size of a school bus, tipping the scales at eight tons. But for all their differences, the two are more closely related than you might think. Birds are living dinosaurs, and they are remarkably similar to their closest extinct relatives, the non-bird theropod dinosaurs.

Think Aloud: *Wow. It sounds like we just learned about the central idea of this article.*

Think/Pair/Share: *Can you turn and tell your partner what you think the central idea is so far? Go back to the text and reread if you'd like.* Listen in and select a pair to share out.

Think/Pair/Share: *With your partner, underline the sentences that support the idea that we just discussed (birds are actually dinosaurs).* Listen in and select a pair to share out.

Optional: Scribe notes on chart paper or smartboard throughout the read aloud. You might start by writing and underlining the central idea and adding bulleted points below, taken from the sentences that students underlined. You might choose to have students make notes as well. You can start off note-making together and then ask them to note-make in partners or independently.

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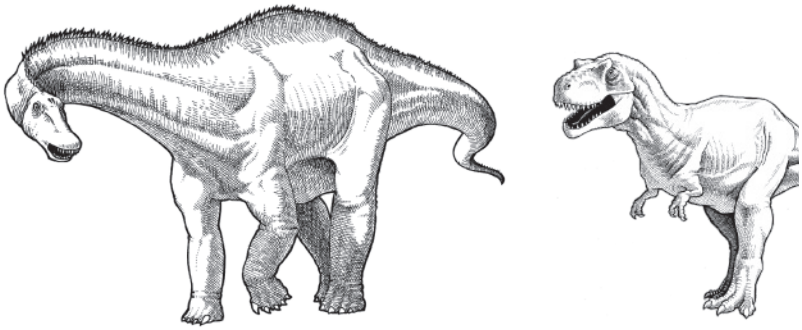

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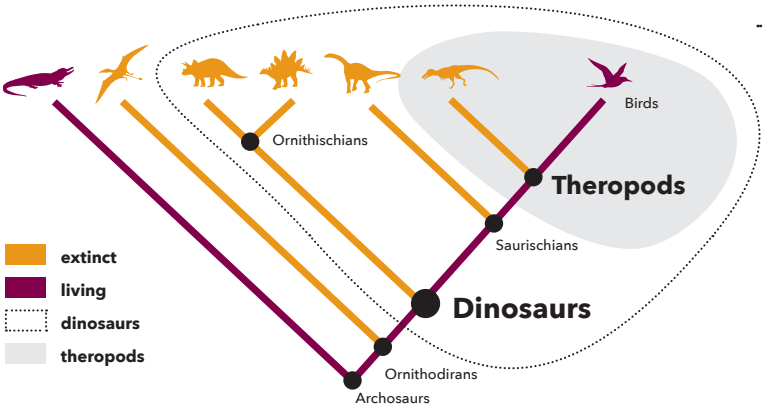
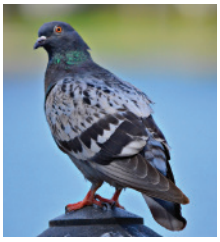


You are looking at just one branch of a cladogram, a "tree" showing the relationships among organisms. The group called dinosaurs includes the extinct dinosaurs and all their living descendants. All its members, including living birds, descended from the very first dinosaur–their common ancestor. That's why birds are a kind of dinosaur (just as humans are a kind of primate).

Think/Pair/Share: *What do you notice about this image? Read the caption with your partner and discuss what this image is showing you.*

Finding the Evidence



When scientists study living animals, they can look at behavior, morphology, embryology, and DNA. It's a different story altogether when it comes to long-extinct animals. Behavior cannot be observed and their DNA has long since been destroyed. So understanding extinct animals and how they are related to living ones takes a special kind of detective work. Paleontologists use the clues found in ancient rocks: fossilized bones, teeth, eggs, footprints, teeth marks, and even dung.

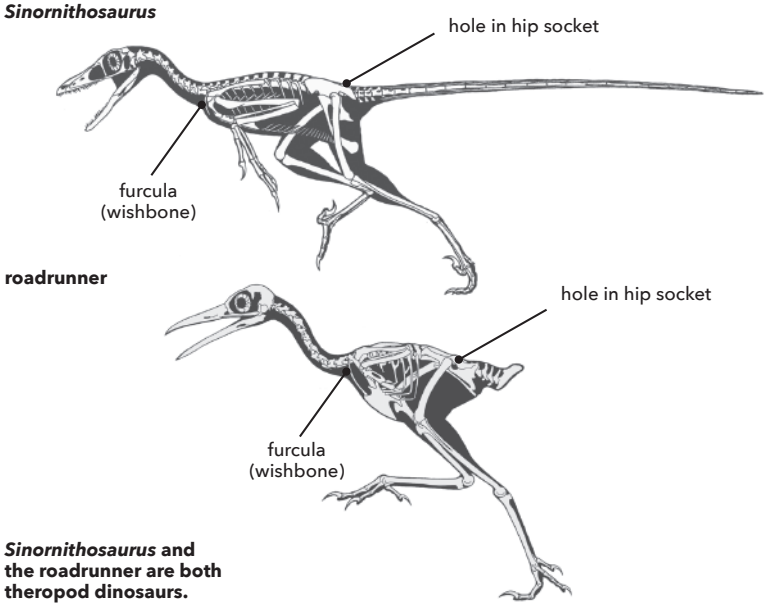
To better understand the link between non-bird theropod dinosaurs and birds, scientists look for the answers to questions such as: What features do they share? What behavioral similarities are there? Scientists use the process of comparative biology to answer these questions. It's a powerful approach to understanding how birds and non-bird dinosaurs are alike and how they evolved.

Think/Pair/Share: *How does studying extinct animals differ from studying living animals?* Listen in and select a pair to share out.

Think/Pair/Share: *Discuss what the second paragraph in this section is teaching you. What were scientists doing to "understand the link between non-bird theropod dinosaurs and birds?"*

Skeletal Evidence

Many similarities can be found when comparing a skeleton of a living bird to the fossilized skeleton of a non-bird theropod, like *Sinornithosaurus*. They both have a hole in the hipbone, a feature that distinguishes most dinosaurs from all other animals. This feature allows an animal to stand erect, with its legs directly beneath its body. All theropod dinosaurs, including birds, have a fused clavicle bone called a furcula, also known as a wishbone. Another shared characteristic is the presence of hollow bones. Hollow bones reduce the weight carried by an animal, resulting in the ability to run faster. This feature probably also played a role in the evolution of flight.



***Sinornithosaurus* and the roadrunner are both theropod dinosaurs.**

Think/Pair/Share: *Based on this paragraph and the illustrations, what are the similarities between* Sinornithosaurus *and the roadrunner?* Listen in and select a pair to share out.

Think/Pair/Share: *Explain the "skeletal evidence" linking theropod dinosaurs to birds.*

Optional: Add to notes.

Behavioral Evidence

When scientists look at non-bird theropod fossils they see evidence of behaviors that are common to living birds, such as nest-building, egg-laying, and brooding. These behaviors were first observed when, in 1993, an expedition to the Gobi Desert in Mongolia made an amazing discovery. Scientists unearthed a *Citipati* fossil brooding a cluster of eggs. Its limbs were folded back against its body. It is one of the few fossils ever found that demonstrates behavior—in this case, parental care. It shows that the behavior of brooding the nests that we see all around us today in living birds was already present in the non-bird ancestors of birds.

***Citipati* fossil nest**

Citipati, like many other non-bird dinosaurs, had feathers. Yet it could not fly. Feathers were once thought to have evolved for flight. The discovery of more and more non-flying dinosaurs with feathers disproved that explanation. For these dinosaurs, feathers may have served other functions, including gliding, insulation, protection, and display. Feathers play that same role in many bird species today.

Based on the evidence of shared characteristics, scientists have concluded that birds are a type of theropod dinosaur.

***Sinornithosaurus* had feathers similar to those of modern birds–even though it could not fly.**

Brain Evidence

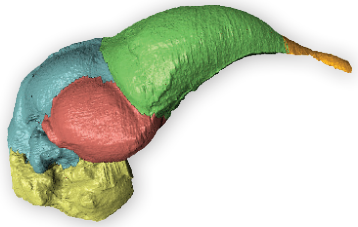
Birds are the only dinosaurs capable of flight. This is particularly interesting

Think/Pair/Share: *Discuss the two pieces of behavioral evidence that are explained in this section.* Listen in and select a pair to share out.

Optional: Add to notes.

to scientists who want to know when the capability of flight emerged. One promising new area of research is focused on the brains of bird and non-bird dinosaurs. Soft tissue, such as brains, is almost never preserved in the fossil record. What is preserved is the imprint the brain left on the inside of the skull. Now scientists are using computed tomography (CT) scanners to create digital endocranial casts—detailed, three-dimensional reconstructions of the interiors of fossilized skulls. In a recent study researchers were able to peer inside the braincases of more than two dozen specimens, including birds and closely related non-bird dinosaurs.

"Technology allows us to look inside these specimens without destroying them," says Dr. Amy Balanoff, a Museum research associate. "It's a non-destructive way to basically slice up a dinosaur brain and look inside and see what it can tell us about the evolution of the brain within dinosaurs. Most of us grew up thinking that dinosaurs had tiny brains, but actually some had really big brains."



Scientists use computed tomography (CT) scans of dinosaur skulls to create detailed, 3-D reconstructions of their interiors, like this one of *Archaeopteryx*.

The endocranial casts allow Balanoff and other researchers to explore the outer shape of the brain in more detail. In addition, the casts also provide new information about the total volume of each digital brain cast, as well as the volume and shape of different brain regions, including the olfactory bulbs, cerebrum, optic lobes, cerebellum, and brainstem. For example, the casts have provided scientists with a detailed view of the dinosaur cerebrum, a center for cognition and coordination in the brain. They found that this region was very large in non-bird dinosaurs closely related to birds. Dr. Balanoff's research suggests that these dinosaurs developed big brains long before flight, laying the cerebral foundation that made the eventual development of powered flight possible. Just as bigger brains in primates prepared the way for them to walk on two legs, bigger brains in dinosaurs prepared the way for flight.

One of the brains sampled by Dr. Balanoff was that of *Archaeopteryx,* a non-bird dinosaur that was thought to mark the transition from non-bird dinosaur to bird. "If *Archaeopteryx* had a flight-ready brain, which is almost certainly the case given its morphology, then so did at least some other non-bird dinosaurs," says Dr. Balanoff. She points out though, that there is no longer a clear boundary showing where the non-bird dinosaurs end and where birds begin. "That's how evolution works. It can be a slow and messy process, and eventually we end up with the amazing diversity of things flying around us today."

Think/Pair/Share: *How are scientists able to study the brains of long extinct dinosaurs?* Listen in and select a pair to share out.

Think/Pair/Share: *What did scientists discover when they looked at a detailed view of the dinosaur cerebrum?* Listen in and select a pair to share out. *Why was this important?* Listen in and select a pair to share out.

Think/Pair/Share: *Turn and talk to your partner about what you learned in this article.* Listen in and select one or two pairs to share out.

Think/Pair/Share: *What questions do you have after reading this article?*

Optional: Write a summary (no more than eight sentences) describing what you learned.

Image Credits

Apatosaurus, T. rex, and cladogram, © AMNH; pigeon, © Pamala Wilson; *Sinornithosaurus* and roadrunner, © AMNH / Sean Murtha; *Citipati* fossil nest and *Sinornithosaurus* fossil, © AMNH / Mick Ellison; *Archaeopteryx* skull, © AMNH / Amy Balanoff.

STUDENT WORKSHEET

Name **ANSWER KEY**

Welcome to the *Dinosaurs Among Us* exhibition! Today, you'll investigate how scientists use various forms of evidence to understand the evolutionary relationships among living and extinct dinosaurs.

Directions: In each section of the exhibition, find at least one example of evidence based on anatomy (the animal's body) or one example based on behavior. Record your observations in the data table below.

Location in exhibition	Fossil, specimen, or display	Type of evidence (behavioral or anatomical)	How does this help explain the evolutionary relationship among living and extinct dinosaurs?
Nests, Eggs, and Babies	*Sample answer (actual answers may vary):* Citipati osmolskae *("Big Mama") fossil found in Mongolia*	*Sample answer (actual answers may vary):* *behavioral*	*Sample answer (actual answers may vary):* *This fossil shows nesting behavior, specifically brooding where a parent protects the eggs.*
Brains, Lungs, and Hearts	*Sample answer (actual answers may vary):* Alligator mississippiensis *fossil cast*	*Sample answer (actual answers may vary):* *anatomical*	*Sample answer (actual answers may vary): This display shows that some reptiles like alligators and lizards have a one-way breathing system like birds. This means that the common ancestor of birds, other dinosaurs, and crocs was an energetic animal that had one-way lungs.*
Bones, Beaks, and Claws	*Sample answer (actual answers may vary):* *Sandhill Crane* (Grus canadensis) *humerus bone*	*Sample answer (actual answers may vary):* *anatomical*	*Sample answer (actual answers may vary): This hollow bone is next to a hollow dinosaur bone. This shows that birds are related to all other dinosaurs, like* Allosaurus. *Hollow bones appeared early in the dinosaur family tree, long before flying dinosaurs.*

STUDENT WORKSHEET

Name **ANSWER KEY**

Location in exhibition	Fossil, specimen, or display	Type of evidence (behavioral or anatomical)	How does this help explain the evolutionary relationship among living and extinct dinosaurs?
Feathers	*Sample answer (actual answers may vary):* Yutyrannus huali *fossil from China*	*Sample answer (actual answers may vary):* *anatomical*	*Sample answer (actual answers may vary): This large dinosaur was probably covered in feathers. Many different kinds of dinosaurs had feathers, including those that could not fly. Today birds are the only animals with feathers.*
Flight	*Sample answer (actual answers may vary):* Anchiornis huxleyi *model*	*Sample answer (actual answers may vary):* *behavioral*	*Sample answer (actual answers may vary):* Anchiornis *had wings and feathers, but could not fly. It may have used its wings to glide down from trees, jump on prey, or run up steep slopes. These are behaviors found in some birds today.*
Additional fossil of student's choice			
Additional fossil of student's choice			

ESSAY SCORING RUBRIC: TEACHER VERSION - page 1

	Exceeds	Meets	Approaches	Needs Additonal Support
	4	3	2	1
Research: "Shedding Light on the Dinosaur-Bird Connection" Article	Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the article	Presents paraphrased information from the article relevant to the prompt with sufficient accuracy and detail	Presents information from the article mostly relevant to the purpose of the prompt with some lapses in accuracy or completeness AND/OR information is copied from the text	Attempts to present information in response to the prompt, but lacks connections to the article or relevance to the purpose of the prompt
Research: *Dinosaurs Among Us* Museum Exhibition	Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the exhibition	Presents paraphrased information from the exhibition relevant to the prompt with sufficient accuracy and detail	Presents information from the exhibition mostly relevant to the purpose of the prompt with some lapses in accuracy or completeness AND/OR information is copied from the text	Attempts to present information in response to the prompt, but lacks connections to the exhibition content or relevance to the purpose of the prompt
Science Explanations	Develops the topic thoroughly by selecting the most significant and relevant facts and details to extensively describe the evidence that links birds to extinct dinosaurs	Develops the topic by selecting the relevant facts and details to sufficiently describe the evidence that links birds to extinct dinosaurs	Choice of facts and details is ineffective or lacking. Descriptions of the evidence that links the birds to extinct dinosaurs are incomplete	Does not describe the evidence that links birds to extinct dinosaurs, OR the descriptions are minimal
	Provides thorough explanations that demonstrate in-depth understanding of evidence that scientists use to understand the evolutionary relationship between living and extinct dinosaurs	Provides sufficient explanations that demonstrate understanding of evidence that scientists use to understand the evolutionary relationship between living and extinct dinosaurs	Provides some explanations of the evidence that scientists use to understand the evolutionary relationships between living and extinct dinosarus. Explanations are incomplete or contain minor errors.	Does not provide any explanations of the evidence that scientists use to understand the evolutionary relationships between living and extinct dinosaurs OR explanations are mostly innaccurate.
	Consistent and effective use of precise and domain-specific language	Some or ineffective use of precise and domain-specific language	Little use of precise and domain-specific language	No use of precise and domain-specific language

ESSAY SCORING RUBRIC: TEACHER VERSION - page 2

	Exceeds	Meets	Approaches	Needs Additonal Support
	4	3	2	1
Development	Includes an opening paragraph that clearly introduces the topic and previews what is to follow	Introduces an opening paragraph that clearly introduces the topic	Includes an opening section that sufficiently introduces the topic	Includes an opening section that is insufficiant or irrelevant OR does not include an introduction
	Includes more than sufficient highly detailed examples of the evidence that links birds to extinct dinosaurs to address the writing prompt	Includes sufficient examples of the evidence that links birds to extinct dinosaurs to address the writing prompt	Includes examples of the evidence that links birds to extinct dinosaurs, but not sufficient to fully address the prompt	Does not include any examples
	Provides a concluding section that follows from and effectively supports the information or explanation presented	Provides a concluding section that follows from and sufficently supports the information or explanation presented	Provides a concluding section that mostly supports the information or explanation presented	Provides a concluding section that does not support the information or explanation presented OR provides no concluding section
Conventions	Demonstrates and maintains a well-developed command of standard English conventions and cohesion, with few errors.; response includes language and tone consistently appropriate to the purpose and specific requirements of the prompt	Demonstrates a command of standard English conventions and cohesion, with few errors; response includes language and tone appropriate to the purpose and specific requirements of the prompt	Demonstrates an uneven command of standard English conventions and cohesion; uses language and tone with some inaccurate, inappropriate, or uneven features	Attempts to demonstrate standard English conventions, but lacks cohesion and control of grammar, usage, and mechanics

STUDENT READING

Shedding Light on the Dinosaur-Bird Connection

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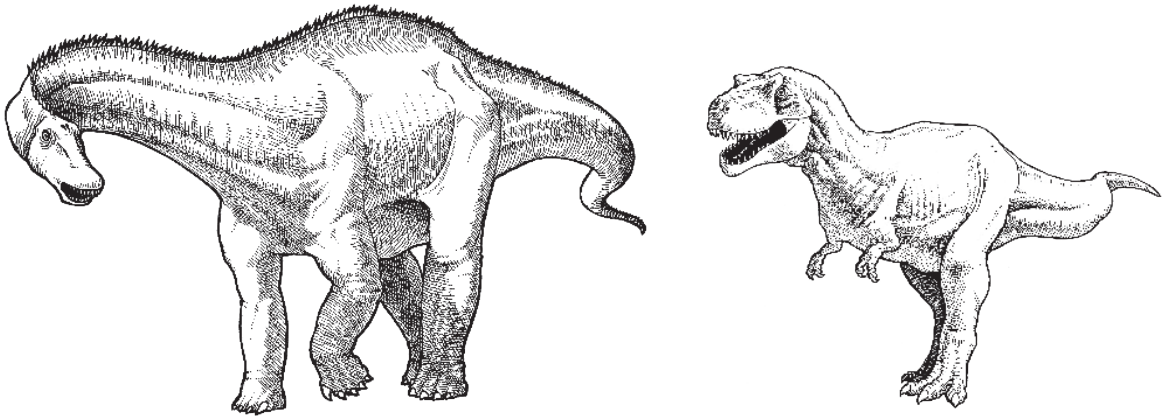
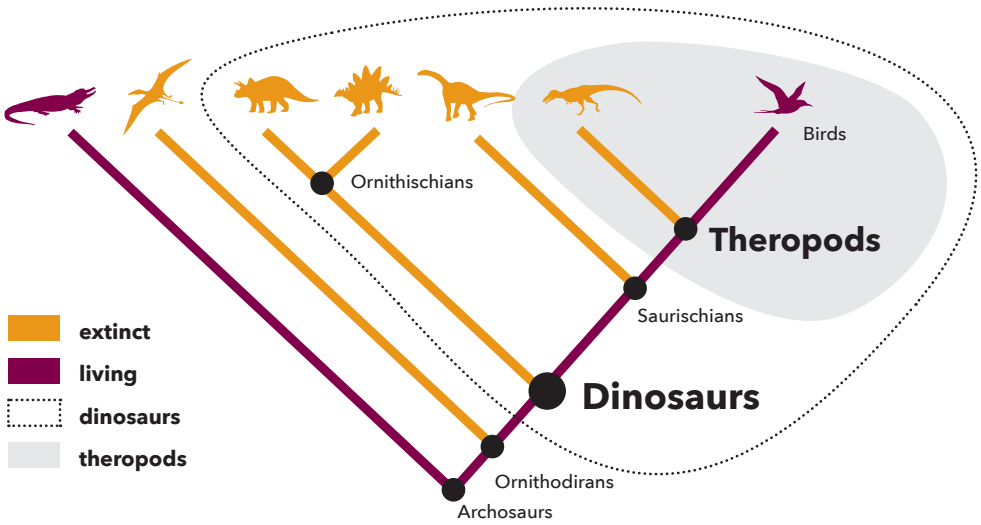


Living Dinosaurs

These large dinosaurs are no longer around, but dinosaurs still live among us today. They are the birds. It's difficult to imagine that a bird on your window sill and a *T. rex* have anything in common. One weighs less than a pound; the other was the size of a school bus, tipping the scales at eight tons. But for all their differences, the two are more closely related than you might think. Birds are living dinosaurs, and they are remarkably similar to their closest extinct relatives, the non-bird theropod dinosaurs.



You are looking at just one branch of a cladogram, a "tree" showing the relationships among organisms. The group called dinosaurs includes the extinct dinosaurs and all their living descendants. All its members, including living birds, descended from the very first dinosaur–their common ancestor. That's why birds are a kind of dinosaur (just as humans are a kind of primate).

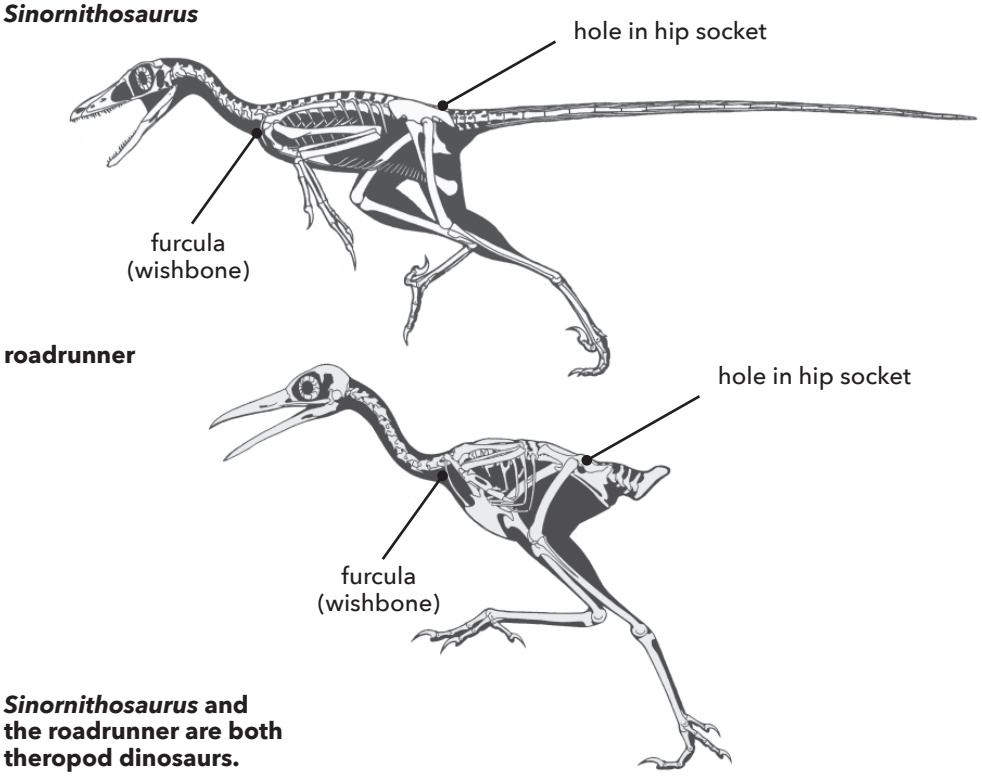
Finding the Evidence

When scientists study living animals, they can look at behavior, morphology, embryology, and DNA. It's a different story altogether when it comes to long-extinct animals. Behavior cannot be observed and their DNA has long since been destroyed. So understanding extinct animals and how they are related to living ones takes a special kind of detective work. Paleontologists use the clues found in ancient rocks: fossilized bones, teeth, eggs, footprints, teeth marks, and even dung.

To better understand the link between non-bird theropod dinosaurs and birds, scientists look for the answers to questions such as: What features do they share? What behavioral similarities are there? Scientists use the process of comparative biology to answer these questions. It's a powerful approach to understanding how birds and non-bird dinosaurs are alike and how they evolved.

Skeletal Evidence

Many similarities can be found when comparing a skeleton of a living bird to the fossilized skeleton of a non-bird theropod, like *Sinornithosaurus*. They both have a hole in the hipbone, a feature that distinguishes most dinosaurs from all other animals. This feature allows an animal to stand erect, with its legs directly beneath its body. All theropod dinosaurs, including birds, have a fused clavicle bone called a furcula, also known as a wishbone. Another shared characteristic is the presence of hollow bones. Hollow bones reduce the weight carried by an animal, resulting in the ability to run faster. This feature probably also played a role in the evolution of flight.



***Sinornithosaurus* and the roadrunner are both theropod dinosaurs.**

Behavioral Evidence

When scientists look at non-bird theropod fossils they see evidence of behaviors that are common to living birds, such as nest-building, egg-laying, and brooding. These behaviors were first observed when, in 1993, an expedition to the Gobi Desert in Mongolia made an amazing discovery. Scientists unearthed a *Citipati* fossil brooding a cluster of eggs. Its limbs were folded back against its body. It is one of the few fossils ever found that demonstrates behavior—in this case, parental care. It shows that the behavior of brooding the nests that we see all around us today in living birds was already present in the non-bird ancestors of birds.

***Citipati* fossil nest**

Citipati, like many other non-bird dinosaurs, had feathers. Yet it could not fly. Feathers were once thought to have evolved for flight. The discovery of more and more non-flying dinosaurs with feathers disproved that explanation. For these dinosaurs, feathers may have served other functions, including gliding, insulation, protection, and display. Feathers play that same role in many bird species today.

Based on the evidence of shared characteristics, scientists have concluded that birds are a type of theropod dinosaur.

***Sinornithosaurus* had feathers similar to those of modern birds–even though it could not fly.**

Brain Evidence

Birds are the only dinosaurs capable of flight. This is particularly interesting

to scientists who want to know when the capability of flight emerged. One promising new area of research is focused on the brains of bird and non-bird dinosaurs. Soft tissue, such as brains, is almost never preserved in the fossil record. What is preserved is the imprint the brain left on the inside of the skull. Now scientists are using computed tomography (CT) scanners to create digital endocranial casts—detailed, three-dimensional reconstructions of the interiors of fossilized skulls. In a recent study researchers were able to peer inside the braincases of more than two dozen specimens, including birds and closely related non-bird dinosaurs.

"Technology allows us to look inside these specimens without destroying them," says Dr. Amy Balanoff, a Museum research associate. "It's a non-destructive way to basically slice up a dinosaur brain and look inside and see what it can tell us about the evolution of the brain within dinosaurs. Most of us grew up thinking that dinosaurs had tiny brains, but actually some had really big brains."

Scientists use computed tomography (CT) scans of dinosaur skulls to create detailed, 3-D reconstructions of their interiors, like this one of *Archaeopteryx*.

The endocranial casts allow Balanoff and other researchers to explore the outer shape of the brain in more detail. In addition, the casts also provide new information about the total volume of each digital brain cast, as well as the volume and shape of different brain regions, including the olfactory bulbs, cerebrum, optic lobes, cerebellum, and brainstem. For example, the casts have provided scientists with a detailed view of the dinosaur cerebrum, a center for cognition and coordination in the brain. They found that this region was very large in non-bird dinosaurs closely related to birds. Dr. Balanoff's research suggests that these dinosaurs developed big brains long before flight, laying the cerebral foundation that made the eventual development of powered flight possible. Just as bigger brains in primates prepared the way for them to walk on two legs, bigger brains in dinosaurs prepared the way for flight.

One of the brains sampled by Dr. Balanoff was that of *Archaeopteryx,* a non-bird dinosaur that was thought to mark the transition from non-bird dinosaur to bird. "If *Archaeopteryx* had a flight-ready brain, which is almost certainly the case given its morphology, then so did at least some other non-bird dinosaurs," says Dr. Balanoff. She points out though, that there is no longer a clear boundary showing where the non-bird dinosaurs end and where birds begin. "That's how evolution works. It can be a slow and messy process, and eventually we end up with the amazing diversity of things flying around us today."

Image Credits

Apatosaurus, T. rex, and cladogram, © AMNH; pigeon, © Pamala Wilson; *Sinornithosaurus* and roadrunner, © AMNH / Sean Murtha; *Citipati* fossil nest and *Sinornithosaurus* fossil, © AMNH / Mick Ellison; *Archaeopteryx* skull, © AMNH / Amy Balanoff.

STUDENT WORKSHEET

Name _____

Welcome to the *Dinosaurs Among Us* exhibition! Today, you'll investigate how scientists use various forms of evidence to understand the evolutionary relationships among living and extinct dinosaurs.

Directions: In each section of the exhibition, find at least one example of evidence based on anatomy (the animal's body) or one example based on behavior. Record your observations in the data table below.

Location in exhibition	Fossil, specimen, or display	Type of evidence (behavioral or anatomical)	How does this help explain the evolutionary relationship among living and extinct dinosaurs?
Nests, Eggs, and Babies			
Brains, Lungs, and Hearts			
Bones, Beaks, and Claws			

STUDENT WORKSHEET

Name _____

Location in exhibition	Fossil, specimen, or display	Type of evidence (behavioral or anatomical)	How does this help explain the evolutionary relationship among living and extinct dinosaurs?
Feathers			
Flight			

STUDENT WRITING TASK

What evidence do scientists use to understand the evolutionary relationships among living and extinct dinosaurs?

After reading "Shedding Light on the Dinosaur-Bird Connection" and taking notes in the *Dinosaurs Among Us* exhibition, write an essay in which you:

- describe the evidence
- explain how it supports the current understanding of the relationships among living birds and extinct dinosaurs.

ESSAY SCORING RUBRIC: STUDENT VERSION

	Exceeds	Meets	Approaches	Needs Additonal Support
	4	3	2	1
Research: "Shedding Light on the Dinosaur-Bird Connection" Article	Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the article	Presents paraphrased information from the article relevant to the prompt with sufficient accuracy and detail	Presents information from the article mostly relevant to the purpose of the prompt with some lapses in accuracy or completeness AND/OR information is copied from the text	Attempts to present information in response to the prompt, but lacks connections to the article or relevance to the purpose of the prompt
Research: *Dinosaurs Among Us* Museum Exhibition	Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the exhibition	Presents paraphrased information from the exhibition relevant to the prompt with sufficient accuracy and detail	Presents information from the exhibition mostly relevant to the purpose of the prompt with some lapses in accuracy or completeness AND/OR information is copied from the text	Attempts to present information in response to the prompt, but lacks connections to the exhibition content or relevance to the purpose of the prompt
Science Explanations	Develops the topic throughly by selecting the most significant and relevant facts and details to extensively describe the evidence that links birds to extinct dinosaurs	Develops the topic by selecting the relevant facts and details to sufficiently describe the evidence that links birds to extinct dinosaurs	Choice of facts and details is ineffective or lacking; descriptions of the evidence that links the birds to extinct dinosaurs are incomplete	Does not describe the evidence that links birds to extinct dinosaurs, OR the descriptions are minimal
	Provides thorough explanations that demonstrate in-depth understanding of evidence that scientists use to understand the evolutionary relationship between living and extinct dinosaurs	Provides sufficient explanations that demonstrate understanding of evidence that scientists use to understand the evolutionary relationship between living and extinct dinosaurs	Provides some explanations of the evidence that scientists use to understand the evolutionary relationships between living and extinct dinosaurs; explanations are incomplete or contain minor errors	Does not provide any explanations of the evidence that scientists use to understand the evolutionary relationships between living and extinct dinosaurs OR explainations are mostly innaccurate
	Consistent and effective use of precise and domain-specific language	Some or ineffective use of precise and domain-specific language	Little use of precise and domain-specific language	No use of precise and domain-specific language

ESSAY SCORING RUBRIC: STUDENT VERSION

	Exceeds	Meets	Approaches	Needs Additonal Support
	4	3	2	1
Development	Includes an opening paragraph that clearly introduces the topic and previews what is to follow	Introduces an opening paragraph that clearly introduces the topic	Includes an opening section that sufficiently introduces the topic	Includes an opening section that is insufficiant or irrelevant OR does not include an introduction
	Includes more than sufficient highly detailed examples of the evidence that links birds to extinct dinosaurs to address the writing prompt	Includes sufficient examples of the evidence that links birds to extinct dinosaurs to address the writing prompt	Includes examples of the evidence that links birds to extinct dinosaurs, but not sufficient to fully address the prompt	Does not include any examples
	Provides a concluding section that follows from and effectively supports the information or explanation presented	Provides a concluding section that follwos from and sufficently supports the information or explanation presented	Provides a concluding section that mostly supports the information or explanation presented	Provides a concluding section that does not support the information or explanation presented OR provides no concluding section
Conventions	Demonstrates and maintains a well-developed command of standard English conventions and cohesion, with few errors; response includes language and tone consistently appropriate to the purpose and specific requirements of the prompt	Demonstrates a command of standard English conventions and cohesion, with few errors; response includes language and tone appropriate to the purpose and specific requirements of the prompt	Demonstrates an uneven command of standard English conventions and cohesion; uses language and tone with some inaccurate, inappropriate, or uneven features	Attempts to demonstrate standard English conventions, but lacks cohesion and control of grammar, usage, and mechanics