



Short Film  
***Great Transitions: The Origin of Birds***

## IN-DEPTH FILM GUIDE

### DESCRIPTION

In the short film *Great Transitions: The Origin of Birds* (<http://www.hhmi.org/biointeractive/great-transitions-origin-birds>), we join University of Texas paleontologist Dr. Julia Clarke on a journey to uncover the evidence that birds are a lineage of theropod dinosaurs. The film illustrates many of the practices of science, including asking important questions, formulating and testing hypotheses, analyzing and interpreting evidence, and revising explanations as new evidence becomes available.

### KEY CONCEPTS

- A. Species descend from other species. Any two species or groups of organisms, no matter how distantly related, can be traced back to a common ancestor.
- B. The fossil record provides a history of life on Earth. It includes organisms with features that are intermediate, or transitional, between major groups.
- C. One way scientists infer evolutionary relationships is by exploring patterns in the presence or absence of certain morphological traits in different species.
- D. Evidence that birds are descended from theropod dinosaurs includes shared anatomical features, as well as inferred physiological and behavioral similarities.
- E. The transition from dinosaurs on the ground to birds flying in the air did not happen in a sudden leap, nor did it happen in a linear, step-by-step progression.
- F. Feathers evolved before flight and therefore must have originally served other functions, such as insulation or communication. Traits that serve one function can be co-opted for a different function through evolution.
- G. Today, dinosaurs are classified into two groups: avian and non-avian. The non-avian dinosaurs are extinct, whereas the avian dinosaurs are still with us and are called birds.

### CURRICULUM AND TEXTBOOK CONNECTIONS

Curriculum	Standards
NGSS (2013)	MS-LS4-1, MS-LS4-2 HS-LS4-1, HS-LS4-4
AP Biology (2012–2013)	1.A.1, 1.A.4, 1.C.1, 4.B.4
IB Biology (2016)	5.1, 11.2
Textbook	Chapter Sections
Miller and Levine, <i>Biology</i> (2010 ed.)	16.3, 16.4, 18.2, 19.1, 19.2, 26.2
Reece et al., <i>Campbell Biology</i> (AP ed., 9th ed.)	22.1, 22.2, 22.3, 25.2, 25.4, 25.6, 26.3, 34.6

### PRIOR KNOWLEDGE

Students should

- be familiar with the tree of life and the general characteristics of tetrapods, reptiles, and birds;
- understand that groups are nested within the tree of life (e.g., dinosaurs are a group of reptiles, which are in turn a group of tetrapods, which are in turn a group of vertebrates, which are in turn a group of animals, and so on);



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- have a basic understanding of common descent and the evidence that supports common descent (i.e., homologies, which are shared characteristics that groups inherited from their ancestors); and
- be familiar with the concepts of speciation and extinction.

### PAUSE POINTS

The film may be viewed in its entirety or paused at specific points to review content with students. The table below lists suggested pause points, indicating the beginning and end times in minutes in the film.

	Begin	End	Content Description	Review Questions	Standards
1	0:00	6:07	<ul style="list-style-type: none"> <li>• The first significant transitional fossil found was the 150-million-year-old <i>Archaeopteryx</i>, which has features characteristic of both living reptiles and living birds. Thus, the origin of birds was traced back to reptiles.</li> <li>• Pterosaurs, a group of reptiles, seemed like an obvious candidate to be close relatives of birds. However, the wings of birds and pterosaurs have very different structures, so scientists concluded that they are not closely related, and that flight evolved independently in both groups.</li> <li>• Thomas Huxley noticed similarities between a small fossil reptile called <i>Compsognathus</i> and <i>Archaeopteryx</i>. Because of these shared characteristics, Huxley proposed that birds evolved from the group of reptiles that included <i>Compsognathus</i>—the dinosaurs.</li> </ul>	<ul style="list-style-type: none"> <li>• What are transitional fossils, and why are they important?</li> <li>• What evidence suggests that <i>Archaeopteryx</i> evolved from dinosaurs rather than pterosaurs?</li> <li>• How does understanding the tree of life help scientists make inferences about the number of times that flight has evolved?</li> </ul>	<p>NGSS (2013) MS-LS4-1, MS-LS4-2, HS-LS4-1</p> <p>AP Biology (2012–13) 1.A.4</p> <p>IB Biology (2009) 5.4.2</p> <p>IB Biology (2016) 5.1</p>
2	6:08	13:13	<ul style="list-style-type: none"> <li>• At first, dinosaurs seemed unlikely ancestors to birds because most known dinosaurs were very large, were thought to have been slow moving and cold blooded, and lacked some key avian traits, such as the wishbone.</li> <li>• The discovery of <i>Deinonychus</i> convinced many that birds did descend from dinosaurs—from the dinosaur group called theropods, which includes <i>Deinonychus</i> and <i>Tyrannosaurus rex</i>.</li> <li>• The number of similarities between theropods and birds—including the presence of a wishbone, the structure of the hands and feet, and S-shaped necks—is best explained by common descent.</li> <li>• The most conclusive evidence of shared ancestry and transitional fossils comes from China, where many fossils of small theropods covered with primitive feathers have been discovered.</li> </ul>	<ul style="list-style-type: none"> <li>• How did the discovery of <i>Deinonychus</i> change scientists' view of dinosaurs?</li> <li>• In what ways are theropods and birds similar?</li> </ul>	<p>NGSS (2013) MS-LS4-1, MS-LS4-2, HS-LS4-1</p> <p>AP Biology (2012–13) 1.A.4</p> <p>IB Biology (2009) 5.4.2</p> <p>IB Biology (2016) 5.1</p>
3	13:14	15:12	<ul style="list-style-type: none"> <li>• The first feathers evolved before flight.</li> <li>• Existing structures can become modified, leading to the evolution of new features and abilities—a process called co-option.</li> <li>• Originally, feathers may have been involved in insulation or communication. Only later were some feathers modified in ways that enabled flight.</li> </ul>	<ul style="list-style-type: none"> <li>• Explain what Dr. Clarke means when she says that dinosaur feathers were co-opted for flight.</li> </ul>	<p>NGSS (2013) MS-LS4-2, HS-LS4-4</p> <p>AP Biology (2012–13) 1.A.1</p> <p>IB Biology (2016) 5.1, 11.2</p>



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4	15:13	End	<ul style="list-style-type: none"> <li>Fossils show that the characteristics of modern birds—such as a toothless beak, fused, clawless digits in the wing, a short tail, and a prominent breastbone—did not evolve in a simple, linear sequence.</li> <li>For tens of millions of years, scaled dinosaurs, feathered dinosaurs, and birds lived together.</li> <li>An asteroid impact led to a mass extinction that only one group of birds, among all dinosaurs, survived. All living birds are descended from this group.</li> <li>Dinosaurs are classified as being avian or non-avian. The non-avian dinosaurs went extinct 66 million years ago, while the avian dinosaurs live today as birds.</li> </ul>	<ul style="list-style-type: none"> <li>Is the evolution of birds from theropod dinosaurs more like a ladder or a bush? Explain.</li> <li>Why is it correct to assert that not all dinosaurs are extinct?</li> </ul>	<p><u>NGSS (2013)</u> MS-LS4-1, MS-LS4-2, HS-LS4-1</p> <p><u>AP Biology (2012–13)</u> 1.A.4, 1.C.1, 4.B.4</p> <p><u>IB Biology (2009)</u> 5.4.2, G.4.2</p> <p><u>IB Biology (2016)</u> 5.1</p>
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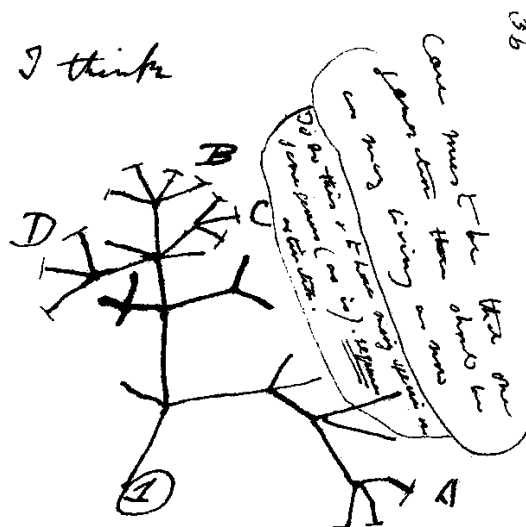
## BACKGROUND

The great naturalist Charles Darwin proposed that all species are descended with modification from other species (Figure 1). In *On the Origin of Species by Means of Natural Selection*, published in 1859, he wrote:

*By the theory of natural selection all living species have been connected with the parent-species of each genus, by differences not greater than we see between the varieties of the same species at the present day; and these parent-species, now generally extinct, have in their turn been similarly connected with more ancient species; and so on backwards, always converging to the common ancestor of each great class. So that the number of intermediate and transitional links, between all living and extinct species, must have been inconceivably great. But assuredly, if this theory be true, such have lived upon this earth.*

He then famously predicted that transitional fossils would be found:

*We ought not to expect at the present time to meet with numerous transitional varieties in each region, though they must have existed there, and may be embedded there in a fossil condition.*



**Figure 1. Darwin's tree of life.** Darwin used a tree-like diagram to illustrate his ideas on evolution. Today, both morphological and DNA sequence data provide evidence for shared ancestry among species. For species that lived millions of years ago, for which there is no usable DNA data, scientists rely on morphological structures preserved in the fossil record and make comparisons to structures in living organisms to determine evolutionary relationships.



Transitional fossils represent forms with features that are intermediate between those of an ancestral form and its descendants. The mix of ancestral and new, or distinct, characters in these transitional fossils helps us understand how different groups of organisms alive today are related. Just two years after Darwin published *Origin*, paleontologist Christian Erich Hermann von Meyer obtained a single feather from the Solnhofen limestone deposit in southern Germany. Shortly thereafter, a nearly complete skeleton of the feathered animal, which was given the name *Archaeopteryx*, was found in the same limestone formation. It was clearly the kind of transitional organism that Darwin had predicted.

As many as 12 fossil skeletons of *Archaeopteryx* have been discovered to date, all about 150 million years old. *Archaeopteryx* fossils show features in common with both living birds and living reptiles (Figure 2). Its reptilian features include a full set of teeth, a long, bony tail, gastralia (belly ribs), and claws. These features are also seen in land-dwelling vertebrates that existed before *Archaeopteryx*. Its most remarkable avian features are its feathered wings, furcula (wishbone), and reduced number of fingers. *Archaeopteryx* provides evidence that living birds are close relatives to reptiles. But which reptiles?

The film *Great Transitions: The Origin of Birds* takes us on a journey to uncover the evidence for birds' evolutionary relationships. That evidence consists primarily of shared anatomical features, which are evidence of common ancestry, but it also includes similarities in behavior (i.e., nesting behavior) and physiology (i.e., thermoregulation). We'll see that while many bird traits are shared with all reptiles, some of their most striking features are shared only with dinosaurs.



**Figure 2.** *Archaeopteryx* is considered the first true transitional fossil discovered. Although many fossils had been found in Darwin's time, none had features that were so obviously intermediate between two major groups of living animals.

### Anatomical Evidence

Darwin's friend Thomas Huxley noticed similarities between *Archaeopteryx* and a fossil dinosaur called *Compsognathus*. Based on these similarities, he proposed that birds were related to dinosaurs. Dinosaurs are a distinct group of prehistoric reptiles that share common anatomical features, such as reduced fourth and fifth digits on each hand (corresponding to our ring finger and pinky) and a hip socket that forms a hole in the pelvis rather than just an indentation as in other four-legged animals.



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Pterosaurs, mentioned in the film as possible ancestors of birds, are *not* dinosaurs, though they are a closely related group.

Dinosaurs are divided into two large groups, saurischians and ornithischians. We recognize these groups by using hip structure and many other characteristics. The saurischians include the large, “lumbering” sauropods seen in the film as well as bipedal predators such as *Tyrannosaurus rex* and *Velociraptor*. Ornithischians include a variety of herbivorous dinosaurs, such as the duck-billed dinosaurs, horned dinosaurs, and armored dinosaurs.

As discussed in the film, the prevailing public image of dinosaurs in the century or so after the discovery of *Archaeopteryx* was that of large, slow, lumbering beasts. As a result, Huxley’s hypothesis that birds were related to dinosaurs was controversial and slow to catch on within the scientific community.

Dr. John Ostrom’s discovery of *Deinonychus* in 1963, however, began to change the image of dinosaurs, and Huxley’s idea suddenly seemed more plausible. *Deinonychus* is a saurischian dinosaur that belongs to a group called theropods. It has lightly built bones and a large, sickle-shaped claw on one toe of each foot, strongly suggesting that it was an active predator, chasing down and capturing prey. Dr. Ostrom spent five years constructing and analyzing a complete *Deinonychus* skeleton. In announcing the results of his work, Ostrom wrote that the *Deinonychus* foot is “perhaps the most revealing bit of anatomical evidence” about how dinosaurs really behaved. In contrast to the view of dinosaurs as slow, lumbering beasts, *Deinonychus* “must have been a fleet-footed, highly predaceous, extremely agile, and very active animal, sensitive to many stimuli and quick in its responses,” wrote Dr. Ostrom. (The quotations are from page 139 of Ostrom’s 1969 monograph on *Deinonychus*; see the references.)

Theropods like *Deinonychus* and *Tyrannosaurus rex* share many characteristics of living birds, such as a furcula, running upright on two legs, and lightly constructed bones. In the film, Dr. Clarke says, “When scientists analyzed the skeletons of theropods and birds, they found too many similarities for any explanation but common ancestry.”

### **Nesting Behavior**

In the film, Dr. Jack Horner talks about his 1978 discovery of a large dinosaur nesting ground at “Egg Mountain” in Montana. The dinosaurs associated with this nest were given the name *Maiasaura*, meaning “caring mother lizard.” Vegetation found near the nests suggests that these dinosaurs covered the eggs, a practice employed by some species of living birds. Scientists also found fossils of baby individuals of *Maiasaura*, up to 1 meter long, associated with the nests. This suggests that the young remained for some time after hatching, likely fed by their parents—again, a behavior of many living birds. Nests were found at different layers at the site, suggesting that the dinosaurs returned year after year to the same place.

*Maiasaura* is an ornithischian dinosaur distantly related to theropods, which are saurischians. But there is evidence of nesting and parental care in theropods as well. A fossil of a dinosaur atop a nest of eggs was discovered in 1923. At the time, it was thought that the adult dinosaur was of a different species than the young within the eggs, and that it was caught in the act of stealing the eggs for food. It was given the name *Oviraptor*, or “egg seizer.” Further fossil finds, however, made it clear that the eggs were those of the *Oviraptor* itself, and it was in fact sitting on the nest brooding the eggs.



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### Similarities in Thermoregulation

The film uses the terms “cold blooded” and “warm blooded.” Although likely familiar to most people, these informal terms suggest that the blood itself is either hot or cold, and that’s not the case. For example, the blood of a snake basking in the sun could, at that moment, be warmer than the blood of a human. It is more appropriate to refer to how animals control their internal body temperatures. *Endothermic* (i.e., warm-blooded) animals, such as mammals and birds, generate internal heat and maintain a fairly constant body temperature. *Ectothermic* (i.e., cold-blooded) animals, such as typical reptiles and amphibians, rely primarily on external sources of heat to maintain their body temperatures.

In the film, Dr. Clarke says that with the discovery of *Deinonychus*, scientists started to see dinosaurs as agile predators that were possibly warm blooded, like birds. Because there are no living non-avian dinosaurs to study, the question of whether they were endotherms or ectotherms is one of active debate. Dr. John Grady, a biologist at the University of New Mexico, recently proposed that dinosaurs were actually something in between.

### What about Flight?

*Archaeopteryx* was initially described as the first true “bird” because it had feathers similar to the flight feathers found in living birds. *Archaeopteryx* was probably capable of flight based on the length of its arms relative to its legs and other anatomical features, but many feathered theropod dinosaurs had well-developed feathers but could not fly. So how did flight evolve?

There are two major schools of thought on the origin of flight—“trees down” and “ground up.” Trees down proposes that feathered dinosaurs spent some of their time in trees and used their feathers for gliding from tree to tree or from a tree down to the ground. Ground up proposes that the first birds took to the air by flapping their feathered arms to generate lift, perhaps in conjunction with clambering over obstacles or leaping into the air. There is evidence for both theories. Dr. Ken Dial, an expert on bird flight at the University of Montana, has proposed a third possibility. Dr. Dial discovered that the young of many species of birds that cannot yet fly flap their developing wings while running up ramps. They also flap their small “half wings” on the way down to slow their descent. It’s possible that flapping-assisted running up to higher ground and flapping-assisted descent would have given feathered theropods an advantage in helping them escape predators or catch prey. Over time, the behavior could have evolved into true flapping flight.

### What Color Were Dinosaurs?

One striking feature of birds is that many of them are brightly colored. Was that also true for the first feathered dinosaurs? Although this characteristic was not discussed in the film, it is a major area of Dr. Clarke’s research.

In living birds, feathers are colored by many pigments and structures, the most common of which is melanin, a pigment contained in structures called melanosomes inside cells. Melanosomes are also found in skin and hair cells in other animals. The shape of melanosomes varies depending on the type and amount of melanin within.

Dr. Clarke and colleagues have looked at fossilized melanosomes to get a hint of what feathered dinosaurs may have looked like—were they brightly colored or drab? In a study published in *Nature*,



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they compared the length and width of melanosomes found in fossils of 13 extinct species of lizards, turtles, and dinosaurs to those of melanosomes found in living mammals and birds. They discovered that dinosaurs with branched feathers have a variety of melanosome shapes and sizes similar to those of modern birds. So, like living birds, these feathered dinosaurs may have had brightly colored feathers. In contrast, dinosaurs with simple filaments (thought to be precursors to feathers), and extinct lizards and turtles, had melanosomes that did not show much diversity. Dr. Clarke and colleagues proposed that the coloration mechanisms we see in living birds today probably evolved first in feathered dinosaurs over 100 million years ago.

## DISCUSSION POINTS

- The narration at the start of the short film *Great Transitions: The Origin of Birds* states that major groups of animals are characterized by key traits, such as fins, four limbs, or wings. Take this opportunity to review homologous and analogous traits, and to remind students that traits can be lost and traits can evolve multiple times. *Homologous* traits are inherited from a common ancestor. Having four limbs is a homologous trait of tetrapods, for example. *Analogous* traits are similar across groups, but they are not due to common ancestry. Butterflies and birds both have wings, but they did not inherit wings from a common ancestor. Instead, butterflies and birds evolved wings independently from two different ancestral lineages. So wings are an analogous trait when you're comparing butterflies and birds, but they are a homologous trait when discussing each group individually.

Ask students which is correct: All tetrapods have four limbs, *or* all tetrapods are descended from an ancestor with four limbs. The latter is more accurate. Snakes are tetrapods. They evolved from an ancestor with four limbs, but they no longer have those limbs.

- Archaeopteryx* is often described as a "missing link" between reptiles and birds. Although the term is descriptive, scientists avoid it because it suggests a predictable and linear pattern of evolution. Indeed, as the film emphasizes, all kinds of dinosaurs and birds lived at the same time. Theropods did not go away once birds evolved, just as fish did not go away when tetrapods evolved. Ask students what they would say to someone who asked, "If birds evolved from reptiles, then why are there still reptiles living today?"
- In the film, Dr. Clarke says, "When scientists analyzed the skeletons of theropods and birds, they found too many similarities for any explanation but common ancestry." Use this as an opportunity to review the concept of parsimony with your students. The concept of parsimony maintains that the simplest solution or explanation is most often correct. This principle can be applied to determine evolutionary relationships and to build phylogenetic trees. In such cases, the most likely relationships are those that imply the fewest changes. In other words, if almost every major group of mammals, amphibians, birds, and reptiles has four limbs, it's more likely that the trait of having four limbs evolved once (in the common ancestor of those groups) and was lost in a few lineages like snakes. It would be unparsimonious to imagine that every species with four legs evolved them independently in a separate evolutionary event.
- Your students may be interested to know that the dinosaur *Velociraptor*, made famous by the original *Jurassic Park* film, was a feathered dinosaur about the size of a small Labrador retriever. It seems that the *Velociraptor* portrayed in the film was in fact the much larger dinosaur *Deinonychus*. Dr. Jack Horner was not only an adviser on the *Jurassic Park* films, but he also



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inspired the character of paleontologist Dr. Alan Grant. Ask your students, Do all paleontologists look like Alan Grant or Jack Horner? Dr. Clarke, the film's host, is a well-known paleontologist. Her discoveries include the first fossil penguin with feathers.

- At one point, Dr. Clarke says, "It was long assumed that feathers evolved for flight. But . . . clearly, feathers predate flight and arose for some other purpose." What does this mean? Traits do not evolve on demand for a particular purpose. Mutation (a random process) caused the first feathers to appear, and feathers then became more common among dinosaur species. Why? Dinosaurs with feathers must have had an advantage over dinosaurs without feathers, making them more likely to reproduce and pass on their traits. The point Dr. Clarke is making in the film is that the advantage could not have been that the dinosaurs with feathers could fly, because they clearly couldn't. Scientists have suggested that the advantage might have had to do with insulation or communication. Later, further mutations that affected the structure of the feathers made flight possible, but again, these changes didn't occur so that the dinosaurs could fly.
- What's in a name? At the end of the film, Dr. Clarke says, "Dinosaurs are still with us; we just call them birds." Taxonomic names can be very confusing. What's the difference between a non-avian dinosaur and an avian dinosaur? Are birds dinosaurs? Are dinosaurs reptiles? These are the kinds of questions you can ask your students to make sure they understand the nested nature of taxonomic groups. Birds are avian dinosaurs, which are reptiles, which are tetrapods, which are vertebrates, and so on.
- You may have heard the Mesozoic era referred to as the "age of dinosaurs." Phrases like this subtly reinforce a "ladder of life" way of thinking. Dinosaurs dominated the available ecological niches for large land animals, but they coexisted with many different types of animals, including other reptiles, fish, amphibians, birds, and mammals. Stephen Jay Gould once said all eras of life should be called "the age of bacteria." Ask students whether they agree with him and why or why not.
- The film presents information about the importance of fossil evidence, specifically, transitional fossils, in clarifying the history of life. A common misconception is that intermediate species did not exist if transitional fossils are not found. In reality, the fossil record does not contain all the living organisms that have lived on Earth. This would be an absolutely exceptional number of species given that 99.99 percent of all life is extinct! Fossilization requires certain conditions to occur. Organisms that live far from water or have only soft body parts are less likely to fossilize than those that live near or in water and have hard body parts. Therefore, the fossil record can only provide a sample of Earth's history. It can be hard for students to understand that lack of fossil evidence for an intermediate species between two groups need not mean that such a species never existed.
- In the film, the Dr. Clarke says that living birds are a lineage of dinosaurs just as humans are a lineage of primates. This comparison can be interesting to discuss. It is sometimes difficult for students to be convinced of the evolutionary relationship between dinosaurs and birds because they look so dissimilar. Using the human-primate relationship may help students better accept this idea.
- About 66 million years ago, a massive asteroid hit Earth just off the coast of the Yucatán peninsula, triggering a mass extinction. Students may ask why some species survived while others did not. Some evidence suggests that avian dinosaurs were better able to survive the asteroid impact than non-avian dinosaurs, perhaps due to differences in size, growth rate, or the type of environment



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they favored. Small animals may have been more likely to survive because they can have greater population sizes than larger animals (a given land area can sustain more small animals than large animals, metabolic rates being equal). Marine environments, which were not as affected by the asteroid strike, or high-latitude environments far from the site of the impact, could have been favored by avian dinosaurs.

## RELATED BIOINTERACTIVE RESOURCES

**Short Film:** ***The Day the Mesozoic Died*** (<http://www.hhmi.org/biointeractive/day-mesozoic-died>)

The disappearance of the dinosaurs at the end of the Cretaceous period posed one of the greatest, long-standing scientific mysteries. This three-act film tells the story of the extraordinary detective work that solved it.

**Film Guide and Quiz:** ***The Day the Mesozoic Died*** (<http://www.hhmi.org/biointeractive/film-guides-day-mesozoic-died>) These film guides and quiz complement the short film *The Day the Mesozoic Died*.

**Video:** ***Discussion with Students on The Day the Mesozoic Died Short Film***  
(<http://www.hhmi.org/biointeractive/discussion-students-day-mesozoic-died-short-film>)

In this video, students discuss the short film after a screening at the 2012 Holiday Lectures on Science.

**Video:** ***How To Find a Dinosaur*** (<http://www.hhmi.org/biointeractive/how-find-dinosaur>)

During this video, paleontologist Tyler Lyson, PhD, describes dinosaur digs as well as his focus on prehistoric turtle fossils.

**Lesson:** ***Determining the Size and Energy of the K-T Asteroid***  
(<http://www.hhmi.org/biointeractive/determining-size-and-energy-k-t-asteroid-0>) In this lesson, students calculate the mass, size, and kinetic energy of the K-T asteroid based on the total abundance of iridium in the K-T boundary layer. These are the same types of calculations that were done by researchers who first discovered the high amount of iridium at the K-T boundary and provided key evidence for the asteroid-impact hypothesis.

**Short Film:** ***Great Transitions: The Origin of Tetrapods*** (<http://www.hhmi.org/biointeractive/great-transitions-origin-tetrapods>) This HHMI short film starring paleontologist Neil Shubin provides a firsthand account of the painstaking search for *Tiktaalik*, a creature with a mix of fish and tetrapod features. *Tiktaalik* illuminates key evolutionary steps in the transition of life from water to land.

**Click and Learn:** ***Great Transitions Interactive*** (<http://www.hhmi.org/biointeractive/great-transitions-interactive>) In this Click and Learn, students explore several fossils situated within the transition from fish to tetrapods, including *Tiktaalik*.

**Article:** ***It's A Fishapod!*** (<http://www.hhmi.org/biointeractive/article-fishapod>) This article by Dr. Sean B. Carroll tells the story of the search for and discovery of *Tiktaalik*.



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**Video: [Young Students Recognize a Transitional Tetrapod](http://www.hhmi.org/biointeractive/young-students-recognize-transitional-fossil)**

(<http://www.hhmi.org/biointeractive/young-students-recognize-transitional-fossil>)

This short video demonstrates the power of observation and the importance of fossil evidence. When Neil Shubin gives small children the opportunity to see a *Tiktaalik* fossil, they immediately notice the presence of characteristics of both fish and four-legged animals.

**Short Film: [Great Transitions: The Origin of Humans](http://www.hhmi.org/biointeractive/great-transitions-origin-humans)** (<http://www.hhmi.org/biointeractive/great-transitions-origin-humans>) In this film, Sean B. Carroll and Tim White discuss the most important human fossils and how they illuminate key phases of human evolution, focusing in particular on three traits: larger brains, tool use, and bipedality.

**Click and Learn: [Deep History of Life on Earth](http://www.hhmi.org/biointeractive/deep-history-life-earth)** (<http://www.hhmi.org/biointeractive/deep-history-life-earth>) The record of life on Earth stretches over 3 billion years. Deep time and Earth history are keys to understanding the present. This Click and Learn interactive presents a graphical way to help students understand when certain events occurred in relation to others.

## USING THE QUIZ

The quiz is designed as a summative assessment that probes student understanding of the key concepts addressed in the film. However, some teachers use the quiz before and during the film to assess students' prior knowledge and to guide students as they watch the film. You are encouraged to choose the use that best fits your learning objectives and students' needs. Moreover, because the vocabulary and concepts are complex, we also encourage you to modify the quiz (e.g., only ask some of the questions, explain complicated vocabulary for ELL students) as needed.

## QUIZ QUESTIONS AND ANSWERS

The student version of this quiz is available as a separate file. We note the key concepts covered by each question here. You may wish to use some or all of the questions below to test your students' knowledge, depending on the content you wish to emphasize.

1. (Key Concept A) *In 1859, Charles Darwin published On the Origin of Species by Means of Natural Selection. In it, Darwin hypothesized that all major groups of organisms are connected through evolution. Just two years later, an important discovery was made that supported Darwin's hypothesis. What was it?*
  - A. DNA
  - B. The microscope
  - C. The large-bodied dinosaur *Apatosaurus*
  - D. **The transitional fossil *Archaeopteryx***
2. (Key Concept E) *Dr. John Ostrom discovered a fossil of a claw from a small dinosaur called *Deinonychus*. How did this fossil change the way scientists viewed dinosaurs?*

**Dinosaurs had long been thought of as large, lumbering animals, unlike birds. John Ostrom's discovery showed that dinosaurs could also be warm blooded and quick moving, like birds.**



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3. (Key Concepts C, D, and E) Which evidence supports the fact that birds evolved from theropod dinosaurs?
- Birds and theropods could all fly.
  - Birds and theropods have wishbones.
  - Birds and theropods have hollow bones.
  - Birds and theropods have S-shaped necks.
  - Birds and theropods have elongated fourth digits that support the wing.
- i and v only
  - i, ii, and iii only
  - ii, iii, and iv only**
  - ii, iii, iv, and v only
4. (Key Concepts D and E) Which of the following best describes how Dr. Jack Horner's discovery of dinosaur nesting grounds supported the hypothesis that birds evolved from dinosaurs?
- It provided evidence that, like birds, some dinosaurs laid eggs.
  - It provided evidence that, like birds, some dinosaurs cared for their young.**
  - It provided evidence that, like birds, some dinosaurs migrated to reproduce.
  - It provided evidence that, like birds, some dinosaurs huddled together for warmth.
5. (Key Concept F) True or false. "The discovery of feathered fossil theropods such as Sinosauropteryx and Caudipteryx supported the hypothesis that feathers were not initially involved in flight." Explain your answer in one or two sentences.
- True. These theropods could not fly, but they had feathers. Therefore, feathers must have evolved before flight.**
6. (Key Concept F) Structures involved in one function can evolve to serve new functions in organisms, a process called co-option or exaptation. Each of the structures in Table 2 has been modified from a preexisting structure (Table 1). Match the preexisting and novel structures below.
- |          | Preexisting Structure          |
|----------|--------------------------------|
| <b>b</b> | 1. Fish fins                   |
| <b>d</b> | 2. Feathers not used in flight |
| <b>a</b> | 3. Reptilian rib cage          |
| <b>c</b> | 4. Tetrapod forelimbs          |
- | Novel Structure    |
|--------------------|
| a. Turtle shell    |
| b. Tetrapod limbs  |
| c. Bird wings      |
| d. Flight feathers |
7. (Key Concept C) Which of the following statements about the transition from theropods to birds is most accurate?
- Like most of the great transitions in evolutionary history, it happened in a very few big steps so that there are very few intermediate forms.
  - Like most of the great transitions in evolutionary history, it happened in many small steps leading to many intermediate forms.**
  - Like no other transition in evolutionary history, it happened in many steps, so there are many intermediate forms.
  - Like most of the great transitions in evolutionary history, it happened in a single step with no intermediate forms.



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8. (Key Concept C) Circle the characteristic in each pair that is typical of modern birds.

<b>No teeth</b>	<i>Teeth</i>
<b>No claws on forelimbs</b>	<i>Claws</i>
<i>Separate (nonfused) fingers</i>	<b>Fused fingers</b>
<b>Short, bony tail</b>	<i>Long, bony tail</i>
<i>Flat sternum</i>	<b>Deep, keeled sternum</b>

9. (Key Concept C) Did the characteristics you circled in Question 8 evolve in a simple linear sequence? What evidence supports your claim?

**There are fossils that have different combinations of these traits, so they couldn't have evolved in a linear sequence. For example, one animal had a short tail but no teeth and claws, while another had teeth but no claws.**

10. (Key Concept G) The film concludes by stating, "Dinosaurs are still with us." How can this be true?  
**Birds are a group of dinosaurs just as humans are a group of primates. The classification of flight is a nested hierarchy.**

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