American Museum *of* Natural History

EDUCATOR'S GUIDE

INSIDE

Essential Questions
Map of the Exhibition
Teaching in the Exhibition
Come Prepared Checklist
Correlation to Standards
Glossary

ONLINE

Student Worksheets
Additional Resources

amnh.org/impact-educators

Essential Questions

What is the end-Cretaceous mass extinction event?

One day 66 million years ago (mya), a huge **asteroid** hit Earth off the coast of what is now Mexico's Yucatán Peninsula. It struck with the force of 10 billion Hiroshima-size bombs, triggered tsunamis and earthquakes, set off wildfires, and darkened the sky with a blanket of dust, gas, and soot. For a year and a half, almost no sunlight reached Earth's surface. Plants died, and the planet cooled by an estimated 45 degrees F (25 degrees C). The planet stayed cold for at least 30 years. With no plants to eat, herbivores starved, as did their predators. **Mosasaurs** and **plesiosaurs**, the large predators living in the oceans, died out. So did all **dinosaur** species except a few species of birds, the ancestors of today's birds. About three-quarters of all species became extinct. Scientists call the **extinction** of such a large proportion of species in such a brief interval a **mass extinction**. At least five mass extinctions have occurred in the history of life on Earth. The fifth, caused by this asteroid impact, is the end-Cretaceous mass extinction event, also called the **Cretaceous-Paleogene mass extinction event** (**K-Pg** for short) or the Cretaceous extinction, because it marks the end of the Cretaceous Period. While mass extinctions are rare, extinctions of individual species happen frequently, usually a few at a time. They result from causes like alterations in **habitats** and **ecosystems**, such as changing environments and the introduction of new predators or competitors. Extinctions are an important part of evolution.

What was life like before the end-Cretaceous mass extinction event?

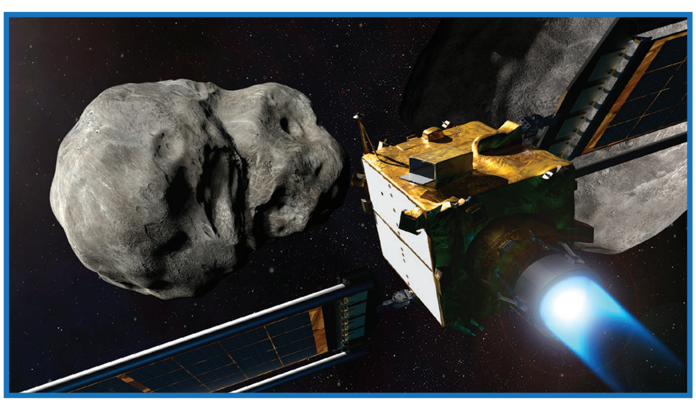
Before the asteroid struck, Earth teemed with an amazing variety of organisms; the planet's **biodiversity** evolved over hundreds of millions of years. At the time of the impact, large dinosaurs dominated Earth's diverse ecosystems as they had for more than 160 million years. Herbivorous dinosaurs browsed in lush forests and grazed across plains; carnivorous dinosaurs stalked them. Birds, which are a type of dinosaur, shared the air with insects and **pterosaurs**—reptiles that were the first vertebrates to evolve powered flight. Little **mammals** scrambled through the trees or crept on the ground. Wildflowers bloomed, cypresses grew, and palms swayed in the wind. There were no apple trees yet, no roses, and no butterflies. Mosasaurs and plesiosaurs hunted in oceans full of sharks, bony fishes, nautiluses, and ammonites.

How did life recover after the end-Cretaceous mass extinction event?

Despite the devastation of the impact, life persisted, thanks to Earth's incredible biodiversity. The greater the biodiversity in an ecosystem, the greater the likelihood that some organisms will survive changing conditions. After the impact, some animal species were able to shelter underground, living on insects and buried seeds. Some survived underwater, in ecosystems that used dead plant and animal material filtering down from above. After the skies cleared, new ecosystems eventually formed. Ferns, which are well adapted to grow after fires, sprang up from spores and dominated the landscape. Long-buried seeds sprouted again. New animal species evolved, taking advantage of opportunities left open by the extinction of other species. Nuts and legumes evolved, and animals evolved to eat them. Mammals, with their big brains, versatile teeth, speedy growth, and protective parenting, prospered and diversified. In less than 20 million years, new mammal species had evolved to live in the air, the ocean, and the treetops. Although most remained small, some eventually became giants, filling niches left open by large extinct dinosaurs. In the oceans, sharks filled niches left by extinct mosasaurs and plesiosaurs.

Could something like the end-Cretaceous mass extinction event happen again?

Scientists at NASA and around the world are carefully monitoring all asteroids and **comets** big enough to cause a mass extinction (and many smaller ones, too). There is very little chance that another big one will hit our planet in the next several million years. Scientists are also developing technology to divert dangerous objects away from Earth, should any threaten to collide with us. However, impacts are not the only potential triggers for mass extinctions. Previous mass extinctions have followed periods of massive volcanic activity, rapid changes in climate, and chemical changes to the atmosphere and oceans. Some scientists have argued that our planet is entering a sixth mass extinction brought on by human activities that are changing the climate and ecosystems. People around the world are working to protect Earth's biodiversity. Together, we can help ensure that the extraordinary life on our planet continues to flourish.



In 2021, NASA's Double Asteroid Redirection Test (DART) mission successfully demonstrated its ability to strike and redirect an asteroid.

Map of the Exhibition

This exhibition tells the story of an asteroid impact 66 million years ago that changed the course of life on Earth, leading to the extinction of most plant and animal species on the planet, including all dinosaurs except birds. The story continues with life's persistence and recovery. After the impact, new ecosystems, such as grasslands and closed-canopy rainforests, evolved. New species—including an astonishing diversity of mammals—evolved to fill the niches left empty by the mass extinction.

Life Before the Impact

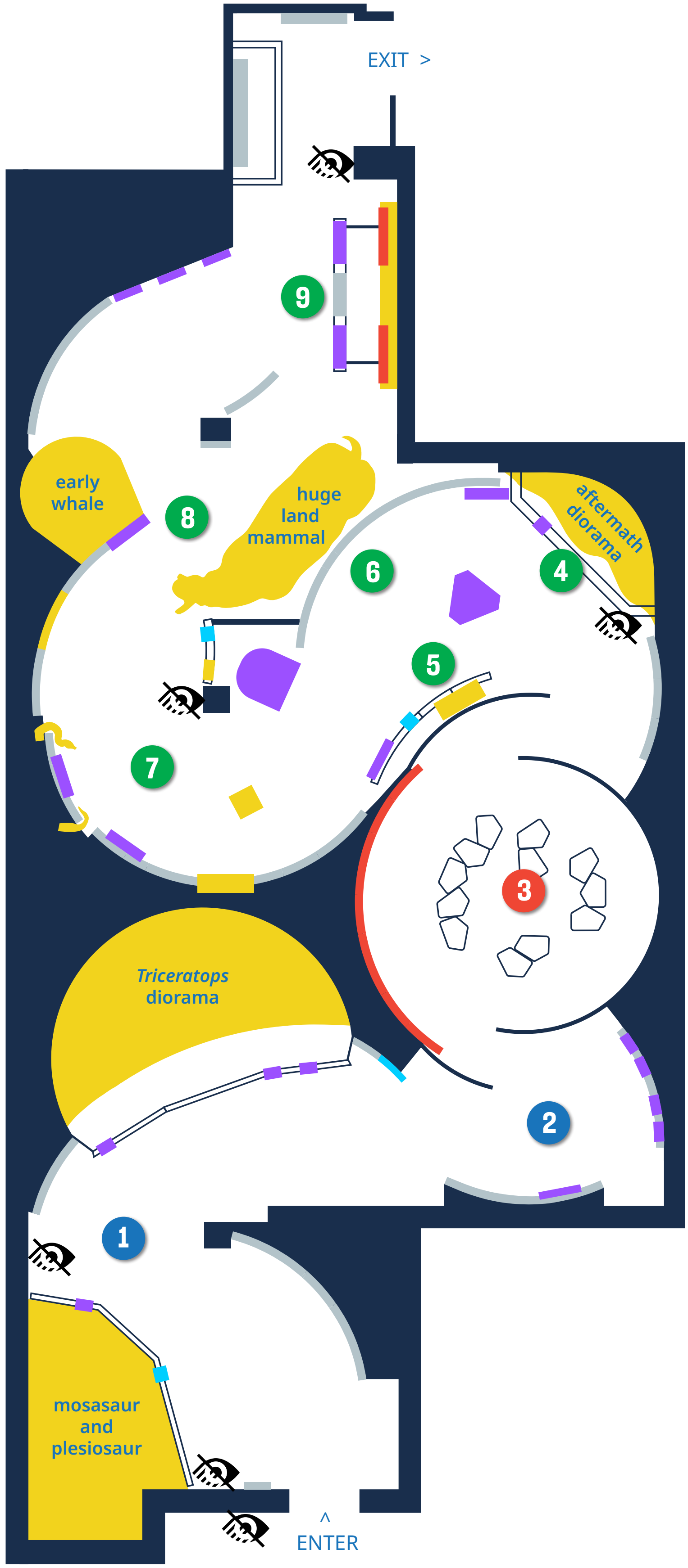
1. **Life-size models of a mosasaur, a plesiosaur, and *Triceratops***
2. **Global diversity section**

The Impact

3. **Theater**

Life After the Impact

4. **Aftermath diorama**
5. **Marine collapse section**
6. **Evidence section**
7. **Recovery section**
8. **Life-size models of an early whale and a huge land mammal**
9. **Models of organisms alive today**



KEY

- model
- touchable object
- digital / hands-on interactive
- video
- visual description QR code / NFC tag for blind and low vision access

Teaching in the Exhibition

Overview of Teaching Strategy: The **numbered stops** below explore what life on Earth was like before and after the asteroid impact. The suggested **open-ended questions** encourage students to use visual-thinking strategy, social-emotional learning, and phenomenon-based learning as they engage with the following standards. **SEP:** Ask Questions; Construct Explanations; Engage in Argument from Evidence. **DCI:** Structure and Function (LS1.A); Growth and Development of Organisms (LS1.B); Ecosystem Dynamics, Functioning, and Resilience (LS2.C); Adaptation (LS4.C); Biodiversity and Humans (LS4.D). **CC:** Patterns; Stability and Change; Structure and Function.

Life Before the Impact

1. Life-size models of a mosasaur, a plesiosaur, and *Triceratops*: Students compare and contrast a marine ecosystem and a terrestrial ecosystem from the Cretaceous Period. Based on their observations, they make inferences about what life was like before the asteroid impact: Earth teemed with all kinds of life, and abundant food sources and ample space allowed carnivores and herbivores alike to grow to impressive sizes on land and in the oceans.

Sample questions:

- How do the marine scene and the land diorama make you feel?
- What do you see?
- What kind of environment did these three large animals live in?
- What did these three large animals eat?
- What adaptations allowed the three animals to survive in their environment and to grow so large?

In this underwater scene (72 mya), two huge carnivorous reptiles—a mosasaur and a plesiosaur—battle for food and survival. The mosasaur uses its flippers to steer and its tail to propel itself through water quickly, ambushing the long-necked plesiosaur. It then uses its powerful jaws to chomp down on its prey.

This terrestrial diorama (66 mya) features *Triceratops*, a herbivorous dinosaur. The many small, overlapping teeth in its beak form a large grinding surface, allowing it to eat a variety of plants. It lives in a rich, interconnected ecosystem that includes insects, pterosaurs, and birds that share the sky; other dinosaurs, small mammals, and reptiles that share the land; and a lush forest with flowering plants that cover the landscape.

2. Global diversity section: To further explore the rich variety of life on Earth before the impact, students play a digital quiz game and explore wall displays of text, illustrations, and push-button sounds.

The Impact

3. Theater: In this 7-minute film, students watch a recreation of a 6–10-mile (10–16-km) asteroid striking Earth and the devastation that followed. (Note: There is a short break between showings; students who are sensitive to the material can proceed directly to the next area.)

Life After the Impact

Days after impact...

4. Aftermath diorama: Students observe the destruction of life on land caused by the asteroid impact. Based on their observations, they predict what might have happened to life in the oceans.

This diorama shows the same terrestrial ecosystem as Stop 1, but after the asteroid crashed into Earth. Clouds of dust and soot darken the sky, and large dinosaurs such as *Triceratops* are all gone, along with most of the other animals and plants that made up that once-thriving ecosystem.

Sample questions:

- How does this diorama make you feel?
- What do you think happened here?
- What do you see that makes you say that?
- Based on what you see happened on land, what do you think might have happened in the oceans at the same time? Why do you think that? (Note: Students will revisit their predictions at Stop 5.)

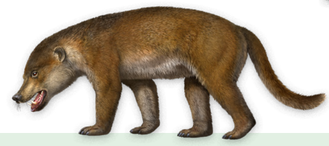
First 100,000 years after impact...

5. Marine collapse section: Students explore touchable fossils, models, text, and illustrations to find out what happened in the seas and oceans when the asteroid hit Earth—and if it matched their predictions (see Stop 4, last question). The impact caused catastrophic damage to life in the oceans as well as on land.

6. Evidence section: Students explore this area to see the evidence connecting an asteroid impact to the mass extinction 66 mya: a dark rock layer containing iridium from the asteroid, solidified droplets of molten rock, and photos of fossils of animals killed by floods and fires.

Thousands to millions of years after impact...

7. Recovery section: Despite the loss of so many species, life on Earth persisted. Throughout this area, students explore models, images, and text about the new plants, animals, and ecosystems that evolved to take the place of what was lost. Based on their observations, students make inferences about the adaptations and conditions that helped organisms and ecosystems thrive as our planet recovered from the impact. For example, as the diversity of plants increased, so did the variety of mammals, insects, birds, and reptiles that ate them. And the new abundance of plants, including palms, nuts, and beans, helped mammals greatly increase in size.



Eoconodon coryphaeus

bat

fern

Sample questions:

- Which animals are familiar to you? Which ones are completely new to you?
- How long after the impact did they appear?
- Notice that most of the animals shown are mammals. What adaptations helped them survive in their environments after the impact?

harbor seal

8. Life-size models of an early whale and a huge land mammal: Students observe and compare two models of mammals to make inferences about how mammals outgrew other animals, such as snakes, crocodilians, and birds, after the large dinosaurs died out.

Sample questions:

- What do you see?
- What kind of environments did these mammals live in?
- What did they eat?
- What adaptations allowed these two mammals to survive in their environments and to grow so large?

Ambulocetus was an early relative of whales that lived 18 million years after the asteroid impact. Its webbed feet enabled it to paddle in shallow water and to walk on land, and scientists think it used its powerful, snapping jaws to hunt in rivers.

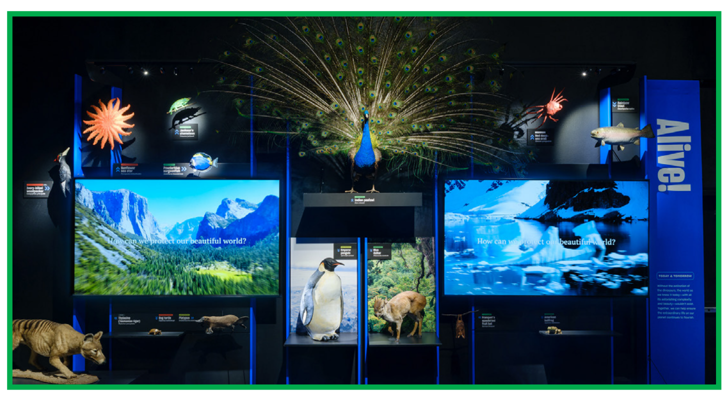
The biggest land mammal ever found, *Paraceratherium* (sometimes referred to as *Indricotherium*) lived 32 million to 43 million years after impact. This huge plant-eating mammal weighed up to 44,000 pounds (20,000 kg)—more than three times as much as an African elephant, the largest land animal living today.

Today

9. Models of organisms alive today: More species are alive today—on land and in the oceans—than at any other time in Earth's history. Students examine models and watch videos to explore this biodiversity, the threats posed by habitat loss and climate change caused by burning fossil fuels, and the steps people around the world are taking to protect Earth's biodiversity.

Sample questions:

- How does this part of the exhibition make you feel?
- What do you think of the ways people are protecting biodiversity?



More species are alive today—on land and in the oceans—than at any other time in Earth's history. People around the world are working to protect this biodiversity, which is being threatened by habitat loss and rapid climate change caused by the burning of fossil fuels.

Come Prepared Checklist

- **Plan your visit.** For information about reservations, transportation, and lunchrooms, visit amnh.org/field-trips.
- **Read the Essential Questions** in this guide to see how themes in the exhibition connect to your curriculum. Identify the key points that you'd like students to learn.
- **Review the Teaching in the Exhibition** section for an advance look at what your class will encounter. Download the online guide for expanded content: amnh.org/impact-educators
- **Download student worksheets** at amnh.org/impact-educators. Designed for use during your visit, these worksheets focus on themes that correlate to the standards.
- **Decide how your class will explore the exhibition:**
  - You and your chaperones can facilitate the visit using the Teaching in the Exhibition section.
  - Students can use the worksheets and/or map to explore the exhibition on their own or in small groups.

Correlation to Standards

Next Generation Science Standards

Science & Engineering Practices • 4. Analyzing and interpreting data • 6. Constructing explanations • 7. Engaging in argument from evidence

Crosscutting Concepts • 1. Patterns • 2. Cause and effect: mechanism and explanation • 4. Systems and system models • 6. Structure and function • 7. Stability and change

Disciplinary Core Ideas • ESS1.C: The history of planet Earth • ESS3.C: Human impacts on Earth systems • ESS3.D: Global climate change • LS1.A: Structure and function • LS1.B: Growth and development of organisms • LS2.C: Ecosystem dynamics, functioning, and resilience • LS4.A: Evidence of common ancestry and diversity • LS4.C: Adaptation • LS4.D: Biodiversity and humans

Glossary

asteroid: a relatively small rocky or metallic object orbiting the Sun; the **Asteroid Belt** is a region of asteroids orbiting the Sun between the orbits of Mars and Jupiter

biodiversity: the rich variety of life on Earth, including variety in genes, among species, and of ecosystems

comet: a relatively small ball of frozen gas, rock, and dust orbiting the Sun

Cretaceous-Paleogene mass extinction event: the mass extinction triggered by an asteroid impact at the end of the Cretaceous Period and just before the Paleogene Period, abbreviated as **K-Pg**; Cretaceous is abbreviated to K because the C was already taken for the Carboniferous Period

dinosaurs: a diverse group of animals that includes tens of thousands of extinct species, from *T. rex* to *Triceratops*, and all birds; a defining feature of dinosaurs is their vertical hindlimb, shared with birds today, and enabled by features in the skeleton including an in-turned head of the thigh bone

ecosystem: a community of organisms and their environment functioning together as an ecological unit

extinction: the death of all members of a species; a **mass extinction** is the extinction of a high proportion of living species within a brief period of geologic time

habitat: a place where an organism or a community of organisms lives and grows

mammals: a group of vertebrates characterized by the possession of hair, three middle ear bones, and mammary glands that produce milk for the young

mosasaurs and **plesiosaurs:** two extinct groups of large predatory marine reptiles that coexisted during the Cretaceous Period

pterosaurs: an extinct group of flying reptiles that lived from the Late Triassic Period through the end of the Cretaceous Period; pterosaurs were the first vertebrates to develop powered flight

Batodanoides vanhouteni, the smallest mammal that ever lived

CREDITS

The Museum gratefully acknowledges the
Richard and Karen LeFrak Exhibition and Education Fund.

Generously sponsored by J. and G. Jacobson and family.

IMAGE CREDITS: Front and back cover: asteroid, © iStockphoto; star field, Mark Garlick/Science Source; *Triceratops* and *Batodanoides*, Illustration by Zhao Chuang; courtesy of PNSO PTE. LTD. **Essential Questions:** DART, © NASA/Johns Hopkins APL. **Teaching in the Exhibition:** all models and dioramas, Alvaro Keding & Daniel Kim/© AMNH; *Eoconodon coryphaeus*, Illustration by Zhao Chuang; courtesy of PNSO PTE. LTD; bat, Shutterstock; ferns, Craig Lovell/Eagle Visions Photography/Alamy; harbor seal, David Fleetham/Alamy.

American Museum *of* Natural History