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 animal adaptations.

This activity has three components:

1. **Before your visit**, students will read a content-rich article about scientists who study cave fish to understand how blindness evolves in organisms that live in dark environments. 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, videos, diagrams, and 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 biological, behavioral, and physiological adaptations.

Materials in this packet include:

For Teachers

- Activity Overview (p. 1-2)
- Article (teacher version): "Why Do Cave Fish Lose Their Eyes?" (p. 3-6)
- Answers to the student worksheets (p. 7-8)
- Essay scoring rubric (teacher version) (p. 9-10)

For Students

- Article (student version): "Why Do Cave Fish Lose Their Eyes?" (p. 11-14)
- Student worksheets (p. 15-16)
- Student writing task (p. 17)
- Essay scoring rubric (student version) (p. 18-19)

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 historical events, scientific procedures/ experiments, or technical processes.

New York State Science Core Curriculum

LE 3.1g

Next Generation Science Standards

DCI: LS4.C: Adaptation
Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment.

SEP 8: Obtaining, Evaluating and Communicating Information

- Integrate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question.
- Read scientific information from multiple authoritative sources.
- Communicate scientific information or ideas in multiple formats.

1. BEFORE YOUR VISIT

Students will read a content-rich article about scientists who study cave fish to understand how blindness evolves in organisms that live in dark environments. 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. 9-10, 17-19).
- Familiarize yourself with the teacher version of the article (p. 3-6), and plan how to facilitate the students' reading of the article.

Instructions

- Explain the goal: to complete a writing task about animal adaptations.
- Tell students that they will need to read an article before visiting the Museum, and read additional texts during the visit (including printed text, digital and physical/hands-on interactives, videos, diagrams, and models).
- 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.
- Distribute the student worksheet (p. 15-16). Have students fill in the "cave fish" section based on what they've learned from the article. Tell them that at the Museum, they will complete the rest of the worksheet.

2. DURING YOUR VISIT

At the Museum, students will read and engage with additional texts (including printed text, digital and physical/hands-on interactives, videos, diagrams, and 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/lal/educators**)

Instructions

- Explain the goal of the Museum visit: to read and engage with texts (including printed text, digital and physical/hands-on interactives, videos, diagrams, and models), and to gather information to help them complete the post-visit writing task.
- Review the worksheet. Clarify what information students should collect. Explicitly teach these three terms to students:
    - Anatomical adaptation: a feature of an organism's body that helps it survive and reproduce
    - Behavioral adaptation: a action an organism takes that helps it survive and reproduce
    - Physiological adaptation: a process that takes place in an organism's body that helps it survive and reproduce
- Note that there is space on the worksheet for students to note the definition for each term.

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.

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/lal/educators**. You can use this same activity with that article.

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 anatomical, behavioral, and physiological adaptations.

Preparation

- Plan how you will explain the student writing task and rubric (p. 17-19) to students.

Instructions

- Review the writing task and rubric with students. 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 prompt, have students underline or highlight all relevant passages and information from the article and from the notes taken at the Museum. Instruct each student to write down any useful information gathered by their peers.
- Students should write their essays individually.

ARTICLE: TEACHER VERSION

About this Article

- **Lexile:** 1059
- **Wordcount:** 1565
- **Text Complexity:** While the Lexile level for this article falls just short of the 9-10 CCSS band (1080–1305), several qualitative factors make this text appropriately complex for grades 9-10. The knowledge demands of this text on the reader are high, as evidenced by the high level of detail in which complex scientific processes are described. Additionally, some of the complex domain-specific vocabulary terms will likely be unfamiliar for many high school students.
- **Note:** Assign partners prior to reading this text aloud with students and have them assign a "partner A" and "partner B."

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

Why Do Cave Fish Lose Their Eyes?

How evolution can lead to losing abilities as well as gaining them

Think/Pair/Share: *What do you already know about evolution?*

Listen in and share out some of what you overheard students say. If there are misconceptions, make a note and consider if it can be addressed in this reading session, and if so, where.

Carlsbad Caverns National Park

Deep underground there are caves where the sun never shines. The only light that enters these subterranean spaces is from the headlamps of occasional cave explorers. If you found yourself in one of these caverns and turned off your headlamp, you would see nothing at all; no shadows, no shapes, just total blackness.

In some of these underground caves, there are fishes, crustaceans, salamanders and other organisms that have evolved to live without light. For example, more than one hundred species of cave fishes live their lives in perpetual darkness. They depend on senses other than sight to hunt, eat and reproduce.

Many of these species of fishes are blind or nearly blind—some don't even have eyes. Yet they all evolved from fishes that could see. Somehow, over millions of years, these fishes not only acquired the ability to live without sight—they lost the ability to see altogether.

How did that happen? How can evolution cause a species to lose a trait? It's a mystery that evolutionary scientists have been struggling to unravel, and the search for an answer gives us a fascinating look at how evolution works.

Stop here and ask students to **summarize** this introduction – "**stop and jot**."

After students have had time to do that independently, prompt them to **turn and talk**, comparing their summary to their partner's. While they are speaking in partners, listen in and select an exemplary summary to share with the class.

Alternately, for more scaffolding, demonstrate this process for students: Construct a summary in front of students, referring to the text and **thinking aloud** as you jot your summary. Make this process interactive by inviting students to make suggestions as you write the summary.

Regressive Evolution

Blind cave fish, Mammoth Cave National Park, Kentucky

We usually think of evolution in a positive sense, that is, as a process in which species *acquire new* traits. But in cave fishes we have an example of *regressive evolution*, a process in which species lose a trait —in this case, the ability to see.

Think aloud: *This part is making me think about the way we define evolution. Evolution does not only explain how species acquires a given trait, but also how they lose a trait.*

A common assumption is that the ancestors of cave fishes went blind in their evolution because they didn't use their eyes. Though at first this idea might seem to make sense, it actually has no basis in science. Genes determine the inheritance of traits. For example, the fact that you have five fingers on each hand is because of the genes you inherited from your parents. However, if you have an accident and lose a finger, your children will still be born with five fingers on each hand. If you lift weights and become a body builder, it doesn't mean your children will be born with bulging biceps. In each case, your genes haven't changed—even though your body has.

Think Aloud: *So, to clarify... an organism's activity or lack thereof (e.g., cave fish not using their eyes) does not impact their genes in any way... Something had to happen at the genetic level that resulted in the cave fish becoming blind… This paragraph ends by asking what that thing was… Let's read on and see if that question gets answered.*

Darwin Is Stumped

The fact that cave fishes' ancestors didn't use their eyes had absolutely no effect on the DNA in their chromosomes. Yet clearly, at some point in the past something happened to their genes that stopped the development of their eyes. This new condition passed on from parent to offspring. How can this sort of regressive evolution be explained?

Charles Darwin himself, the scientist who first established a modern understanding of evolution, had trouble answering this question. Darwin lived in the 19th century when DNA hadn't been discovered and so he didn't know about genes or their role in heredity. But he understood that traits were inherited and that differences within a species give some individuals an advantage over others. Animals with traits that make them more successful at having offspring will pass on those traits to succeeding generations. He called this process evolution by *natural selection*.

Lamarck's Mistake

Jean-Baptiste Lamarck was a French naturalist who lived from 1744 to 1829. He was a pioneer developing theories of evolution at a time when the very idea of evolution was not accepted. Lamarck tried to explain how species evolved but came to an incorrect conclusion–that traits acquired during an organism's lifetime could be passed down to its offspring. For example, he suggested that giraffes stretched their necks to reach higher leaves, and as a result their offspring were born with longer necks. The idea that cave fishes lost their eyesight because generations of fish didn't use their eyes is a Lamarckian mistake.

Prompt students to read this text box and **turn and talk**, asking, *How does this text box connect with the previous paragraph?* Listen in and select a student to share out.

Alternately, to provide more support, you might **think aloud** as follows: *This text box gives an example of the kind of misconception about evolution that was explained in the previous paragraph – the false idea that traits you have acquired during your lifetime are passed on to offspring, like the giraffe example.*

However, Darwin had trouble applying his theory of natural selection to the problem of why some cave fishes are blind. He could not explain how being blind gave those cave fishes an advantage. And if being blind is not an advantage, then how did natural selection lead to a species of blind cave fish? Surprisingly, Darwin was convinced that the loss of eyes could be explained entirely to disuse, which is in fact a Lamarckian explanation. Today, scientists know that this explanation is unfounded.

Think/Pair/Share: *What is the main idea of each paragraph? Re-read each paragraph if you need to, and talk your partner through what each paragraph is saying. Partner A can talk about paragraph the first paragraph; partner B can talk about the second paragraph.*

If clarification is needed, show students how you determine the main idea of each paragraph by **thinking aloud**. Jot the main idea in the margin.

Two Hypotheses

Most of what we know now is based on the study of the blind Mexican tetra (*Astyanax mexicanus*). Scientists have two competing explanations for blindness in the Mexican tetra, which likely apply in other cave fishes as well.

You should be listening for these two different hypotheses as we read on. As you listen, take notes on each one so that you are ready to discuss them with your partner.

Alternately, to offer more independence, give students these same instructions to take notes, but have them read the two paragraphs independently.

Mexican tetra (*Astyanax mexicanus*).

The first hypothesis assumes that blindness gives the fish some sort of evolutionary advantage. For example, it's possible that changes in the gene or genes that cause blindness are also responsible for some other seemingly unrelated change in the fish that is beneficial. Scientists call this *pleiotropy*—when multiple effects are caused by the same mutation in one gene. To support this hypothesis, scientists would have to look for some advantage to the cave fish that is linked to the same mutation that causes blindness.

The second hypothesis that could explain blindness in the cave fish is based on the fact that natural selection does not just reward success, it also weeds out failures. In a lake, where there is sunlight, a fish born blind would have trouble competing with other fish that can see. It probably would not survive to have offspring. But a fish born blind in a dark cave would not be at a disadvantage, since in the darkness eyes are useless. In those conditions, natural selection will not work to weed out the mutation for blindness. Over one to two million years, many more mutations disrupting the development of the eyes will accumulate and eventually the entire population of fish will be blind. This is called the *neutral mutation* hypothesis, based on the idea that the mutations for causing blindness have no effect (or have a neutral effect) on the survival of the fish living in a dark cave.

Before moving on, pause to discuss the two hypotheses, clarifying misconceptions.

An Eye-Opening Experiment

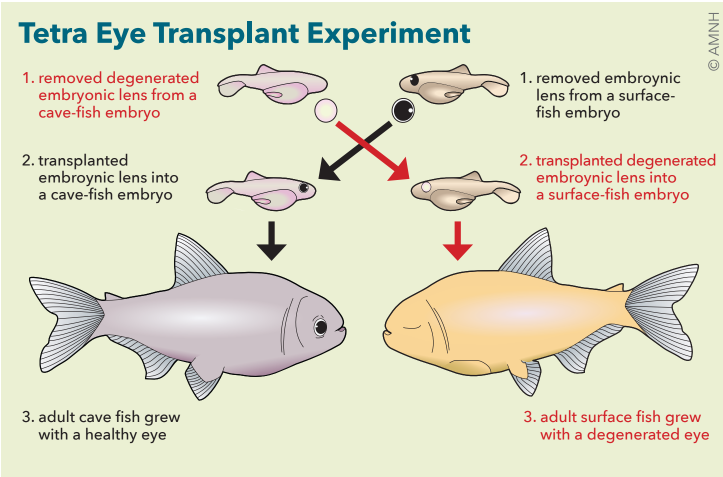
A group of scientists at the University of Maryland set out to investigate the developmental causes of blindness in the cave fish. They carried out an experiment with two varieties of the same species of Mexican tetras. One variety lives in bodies of water near the surface where there is sunlight and can see. The other variety of tetras lives in dark caves and is blind.

The scientists transplanted a lens from the eye of a surface tetra embryo into the eye of a cave tetra embryo. The result was striking—the surface tetra lens transplanted into the cave tetra caused all of the surrounding tissues to develop into a healthy eye. This experiment demonstrated that despite the degeneration of the eye in the tetra, the genes involved in eye development were still totally functional. This would seem to rule out the neutral mutation theory because, if blindness were caused by an accumulation of many neutral mutations over time, the transplant would not have resulted in the development of a healthy eye. The scientists knew that there are many genes responsible for the development of each part of an eye (for example, the retina, iris, cornea and lens), which develops independently. However, the results of the experiment showed that blindness in the Mexican tetra was not due to mutations in all those genes. Instead, it suggested a small number of mutations in genetic "master switches." These master switches are genes that control the function of many other genes, including, in this case, those responsible for eye development. These "master switches" have the ability to disable the eye genes so that these remain intact, but inactive. Putting a healthy lens into the cave tetra embryo seems to trigger master switches to send a signal to the inactive eye genes, allowing cave tetras to develop eyes.

Think/Pair/Share: *What did the results of the experiment show?*

Follow-Up Question: *What did scientists learn from these results?*

Listen in and select a student to share out. Allow for questions and clarification. It is important to check for understanding at this point in the text. Direct students to refer to the illustration on the next page as needed.



If scientists could find the genetic "master switches" that made cave tetras blind, they could discover if the same switches had effects on other traits of the fish that do give it an evolutionary advantage for surviving in caves.

The researchers did indeed find one of those genes. It is nicknamed *Hedgehog* or the *Hh* gene. They discovered that the *Hedgehog* gene does more than cause blindness in cave tetras—when the fish develops without eyes, the skull bones move into the empty eye socket, which at the same time enlarges the nose. Unlike other vertebrates, fishes use their nose only for smelling. It could be that the same control gene (*Hh*) that stops eye development in the fish also is responsible for enhancing its sense of smell. An enhanced sense of smell would be a definite advantage for a fish that lives in darkness.

As a result of these and other experiments, it now seems highly likely that blindness in cave tetras is in part the result of pleiotropy—one mutation that causes blindness in the fish and at the same time, gives them an enhanced sense of smell.

Evolution Works

Scientists are still studying cave fishes, and new discoveries are sure to be found. But one thing is already clear—the answer lies in the basic processes of evolution that are already well understood. With new tools that give scientists the ability to map genes, find specific mutations, and understand the development of embryos, we are increasing our understanding of how evolution works.

Article adapted from "Why Do Cave Fish Lose Their Eyes?" by Luis and Monika Espinasa, Natural History magazine, June 2005.

This section concludes with an explanation of the new understanding that scientists gained after the experiment, and provides the support for the first hypothesis mentioned earlier in the text, pleiotropy.

After reading this section, ask students to go back to their notes where they described both hypotheses and add on. Specifically, prompt them to 1) explain the evidence for the hypothesis that the experiment yielded, and 2) elaborate on the new thinking/explain pleiotropy in more detail. It is important to require students to use their own words in their notetaking and not simply copy from the text.

For formative assessment purposes, you may consider reading through students' notes to check for this. If students are merely retelling verbatim from the text, they may need more explicit instruction on the difference between retelling and paraphrasing, including modeling and guided practice.

After you have finished reading the text as a group, you may want to ask students to complete an exit slip in which they 1) explain the key ideas of the text and 2) list any lingering questions they have after reading the text.

STUDENT WORKSHEET - page 1 Name: *ANSWER KEY*

Before your visit to the Museum, use the information you learned from the article, "Why do Cave Fish Lose Their Eyes?", to complete the definitions for anatomical, behavioral, and physiological adaptations in the first column and the top row on cave fish.

During your visit, select three animals in *Life at the Limits* and use information from the exhibition to complete the rest of the rows. Be sure to fill in the name for each animal you choose.

Type of adaptation	For each animal, draw and label an illustration of it. Then, describe the adaptation.
anatomical adaptation Definition: *a feature of an organism's body that helps it survive and reproduce*	cave fish *Using information and illustrations from the article "Why do Cave Fish Lose Their Eyes?", students should complete this box in the classroom before the Museum visit.* *Scientists in the article think that the cave fish are blind because the genetic mutation that causes blindness also gives them an enhanced sense of smell. So blindness itself isn't an adaptation, but the fact that it allows the fish to have a better sense of smell, which is more useful in the dark than vision, is an adaptation.*
	an animal from the exhibition: ______________ *A majority of the animals in the exhibition show examples of anatomical adaptations. Examples include:* • *axolotl: gills for breathing* • *sawfish: electrosensory pores in saw for detecting prey* • *tarsier: huge eyes* • *boreal Owl: assymetrical ear openings for excellent hearing* • *saturniid moths: feathery antennae for amazing sense of smell* • *mantis shrimp: striking limbs to punch prey* • *mimic octopus: by changing coloring and body shape, can mimic many other species to protect itself*

STUDENT WORKSHEET - page 2

Name: *ANSWER KEY*

Type of adaptation	For each animal, draw and label an illustration of it. Then, describe the adaptation.
behavioral adaptation Definition: *a behavior that an animal does that helps it survive and/or reproduce*	an animal from the exhibition: ______________ *Behavioral adaptations in the exhibition are harder to find. The bowerbird is the first and perhaps most obvious example that students will encounter; this bird builds an elaborate bower to attract mates. Another section that highlights some behavioral adaptations is the section on shelter towards the end of the exhibition; examples here include the structures constructed by termites, prairie dogs, tailor birds, and hornets.*
physiological adaptation Definition: *a behavior that an animal does that helps it survive and/or reproduce*	an animal from the exhibition: ______________ *There are several places in the exhibition where physiological adaptations are highlighted.* • *On the panel titled "Altitude and Depth," there are many examples of how animal systems deal with the height above, or depth below, sea level. For example, humans, birds, and aquatic mammals.* • *The section dealing with hibernation, across from the elephant seal model, also gives some good examples, such as bears and bumblebees.* • *In the area on eating, there is a panel labeled "eating and Heating" that discusses animal metabolism in the context of feeding. Examples here include the polar bear and the European hare.* • *The lungfish shown towards the end of the exhibition demonstrates estuation, a process similar to hibernation that takes place in extreme heat rather than cold.* • *The tardigrade display at the back of the exhibition, more than the one at the front, discusses how this tiny animal is able to go through such extremes by regulating its body systems and changing form.*

ESSAY SCORING RUBRIC: TEACHER VERSION - page 1

Scoring Criteria		Exceeds	Meets	Approaches	Needs Additonal Support
		4	3	2	1
RESEARCH (worth 1/3)	**Article: "Why Do Cave Fish Lose Their Eyes?"**	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 accuracy and sufficient detail.	Presents information from the article relevant to the purpose of the prompt with minor 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
	Museum Exhibition: *Life at the Limits*	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 accuracy and sufficient detail.	Presents information from the exhibition relevant to the purpose of the prompt with minor lapses in accuracy or completeness and/or information is copied from the exhibit 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 (worth 1/3)	**Science Explanations**	Integrates relevant and accurate science content with thorough explanations that demonstrate in-depth understanding of anatomical, behavioral, and physiological adaptations	Accurately presents science content relevant to the prompt with sufficient explanations that demonstrate understanding different types of animal adaptations	Briefly notes science content relevant to the prompt; shows basic or uneven understanding of different types of animal adaptations; minor errors in explanation	Attempts to include science content in explanations, but understanding of different types of animal adaptations is weak; content irrelevant, inappropriate, or inaccurate
WRITING (worth 1/3)	**Focus**	Maintains a strongly developed focus on the writing prompt for the entire essay	Maintains focus on the writing prompt for the majority of the essay	Addresses the prompt but is off-task some of the time	Does not address the prompt for most or all of the essay
		Clearly introduces the topic of anatomical, behavioral, and physiological adaptations	Introduces the spiny pufferfish and two other animals	Mentions the spiny pufferfish and one other animal	Only mentions one animal
		Provides a relevant concluding statement/section	Provides a concluding statement/section	Provides a sense of closure	Provides no sense of closure
		Thoroughly and accurately defines "anatomical, behavioral, and physiological adaptations"	Defines "anatomical, behavioral, and physiological adaptations"	Defines 1-2 of the adaptation types	Does not define any type of adaptation
	Development	Clearly describes anatonmical, behavioral, and physiological adaptations of animals that are well-suited to survive and reproduce in detail	Describes physical, behavioral, and physiological adaptations of animals that are well-suited to survive and reproduce	Attempts to describe both physical and behavioral adaptations of animals that are well-suited to survive and reproduce but lacks sufficient development	Does not describe both physical and behavioral adaptations of animals that are well-suited to survive and reproduce

ESSAY SCORING RUBRIC: TEACHER VERSION - page 2

Scoring Criteria		Exceeds	Meets	Approaches	Needs Additonal Support
		4	3	2	1
WRITING (worth 1/3)	Clarity	Consistent and effective use of precise and domain-specific language	Some use of precise and domain-specific language	Little use of precise and domain-specific language	No use of precise and domain-specific language
		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

Why Do Cave Fish Lose Their Eyes?

How evolution can lead to losing abilities as well as gaining them

Carlsbad Caverns National Park

Deep underground there are caves where the sun never shines. The only light that enters these subterranean spaces is from the headlamps of occasional cave explorers. If you found yourself in one of these caverns and turned off your headlamp, you would see nothing at all; no shadows, no shapes, just total blackness.

In some of these underground caves, there are fishes, crustaceans, salamanders and other organisms that have evolved to live without light. For example, more than one hundred species of cave fishes live their lives in perpetual darkness. They depend on senses other than sight to hunt, eat and reproduce.

Many of these species of fishes are blind or nearly blind—some don't even have eyes. Yet they all evolved from fishes that could see. Somehow, over millions of years, these fishes not only acquired the ability to live without sight—they lost the ability to see altogether.

How did that happen? How can evolution cause a species to lose a trait? It's a mystery that evolutionary scientists have been struggling to unravel, and the search for an answer gives us a fascinating look at how evolution works.

Regressive Evolution

We usually think of evolution in a positive sense, that is, as a process in which species *acquire new* traits. But in cave fishes we have an example of *regressive evolution*, a process in which species lose a trait —in this case, the ability to see.

Blind cave fish, Mammoth Cave National Park, Kentucky

A common assumption is that the ancestors of cave fishes went blind in their evolution because they didn't use their eyes. Though at first this idea might seem to make sense, it actually has no basis in science. Genes determine the inheritance of traits. For example, the fact that you have five fingers on each hand is because of the genes you inherited from your parents. However, if you have an accident and lose a finger, your children will still be born with five fingers on each hand. If you lift weights and become a body builder, it doesn't mean your children will be born with bulging biceps. In each case, your genes haven't changed—even though your body has.

Darwin Is Stumped

The fact that cave fishes' ancestors didn't use their eyes had absolutely no effect on the DNA in their chromosomes. Yet clearly, at some point in the past something happened to their genes that stopped the development of their eyes. This new condition passed on from parent to offspring. How can this sort of regressive evolution be explained?

Charles Darwin himself, the scientist who first established a modern understanding of evolution, had trouble answering this question. Darwin lived in the 19th century when DNA hadn't been discovered and so he didn't know about genes or their role in heredity. But he understood that traits were inherited and that differences within a species give some individuals an advantage over others. Animals with traits that make them more successful at having offspring will pass on those traits to succeeding generations. He called this process evolution by *natural selection*.

Lamarck's Mistake

Jean-Baptiste Lamarck was a French naturalist who lived from 1744 to 1829. He was a pioneer developing theories of evolution at a time when the very idea of evolution was not accepted. Lamarck tried to explain how species evolved but came to an incorrect conclusion—that traits acquired during an organism's lifetime could be passed down to its offspring. For example, he suggested that giraffes stretched their necks to reach higher leaves, and as a result their offspring were born with longer necks. The idea that cave fishes lost their eyesight because generations of fish didn't use their eyes is a Lamarckian mistake.

However, Darwin had trouble applying his theory of natural selection to the problem of why some cave fishes are blind. He could not explain how being blind gave those cave fishes an advantage. And if being blind is not an advantage, then how did natural selection lead to a species of blind cave fish? Surprisingly, Darwin was convinced that the loss of eyes could be explained entirely to disuse, which is in fact a Lamarckian explanation. Today, scientists know that this explanation is unfounded.

Two Hypotheses

Most of what we know now is based on the study of the blind Mexican tetra (*Astyanax mexicanus*). Scientists have two competing explanations for blindness in the Mexican tetra, which likely apply in other cave fishes as well.

Mexican tetra (*Astyanax mexicanus*).

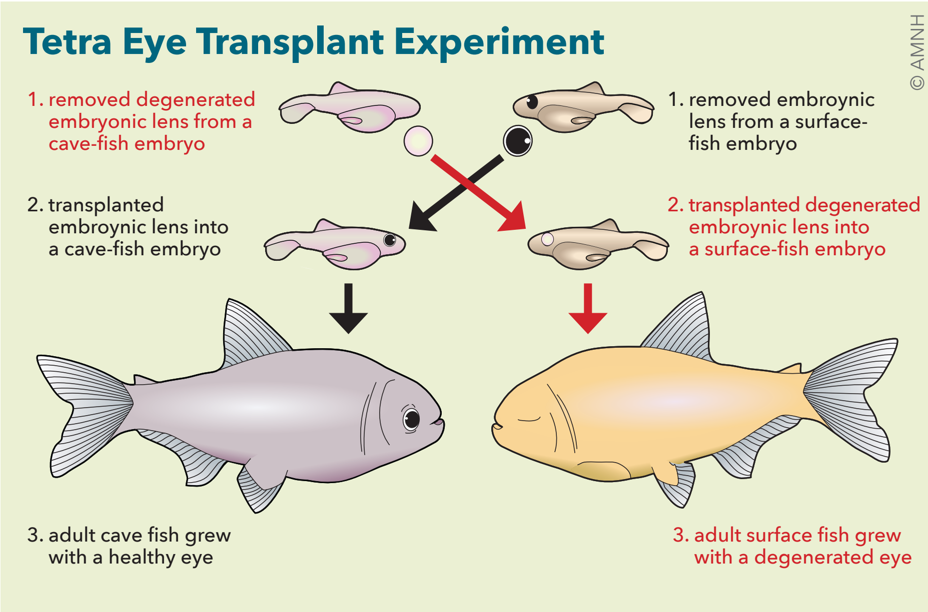
The first hypothesis assumes that blindness gives the fish some sort of evolutionary advantage. For example, it's possible that changes in the gene or genes that cause blindness are also responsible for some other seemingly unrelated change in the fish that is beneficial. Scientists call this *pleiotropy*—when multiple effects are caused by the same mutation in one gene. To support this hypothesis, scientists would have to look for some advantage to the cave fish that is linked to the same mutation that causes blindness.

The second hypothesis that could explain blindness in the cave fish is based on the fact that natural selection does not just reward success, it also weeds out failures. In a lake, where there is sunlight, a fish born blind would have trouble competing with other fish that can see. It probably would not survive to have offspring. But a fish born blind in a dark cave would not be at a disadvantage, since in the darkness eyes are useless. In those conditions, natural selection will not work to weed out the mutation for blindness. Over one to two million years, many more mutations disrupting the development of the eyes will accumulate and eventually the entire population of fish will be blind. This is called the *neutral mutation* hypothesis, based on the idea that the mutations for causing blindness have no effect (or have a neutral effect) on the survival of the fish living in a dark cave.

An Eye-Opening Experiment

A group of scientists at the University of Maryland set out to investigate the developmental causes of blindness in the cave fish. They carried out an experiment with two varieties of the same species of Mexican tetras. One variety lives in bodies of water near the surface where there is sunlight and can see. The other variety of tetras lives in dark caves and is blind.

The scientists transplanted a lens from the eye of a surface tetra embryo into the eye of a cave tetra embryo. The result was striking—the surface tetra lens transplanted into the cave tetra caused all of the surrounding tissues to develop into a healthy eye. This experiment demonstrated that despite the degeneration of the eye in the tetra, the genes involved in eye development were still totally functional. This would seem to rule out the neutral mutation theory because, if blindness were caused by an accumulation of many neutral mutations over time, the transplant would not have resulted in the development of a healthy eye. The scientists knew that there are many genes responsible for the development of each part of an eye (for example, the retina, iris, cornea and lens), which develops independently. However, the results of the experiment showed that blindness in the Mexican tetra was not due to mutations in all those genes. Instead, it suggested a small number of mutations in genetic "master switches." These master switches are genes that control the function of many other genes, including, in this case, those responsible for eye development. These "master switches" have the ability to disable the eye genes so that these remain intact, but inactive. Putting a healthy lens into the cave tetra embryo seems to trigger master switches to send a signal to the inactive eye genes, allowing cave tetras to develop eyes.



If scientists could find the genetic "master switches" that made cave tetras blind, they could discover if the same switches had effects on other traits of the fish that do give it an evolutionary advantage for surviving in caves.

The researchers did indeed find one of those genes. It is nicknamed *Hedgehog* or the *Hh* gene. They discovered that the *Hedgehog* gene does more than cause blindness in cave tetras—when the fish develops without eyes, the skull bones move into the empty eye socket, which at the same time enlarges the nose. Unlike other vertebrates, fishes use their nose only for smelling. It could be that the same control gene (*Hh*) that stops eye development in the fish also is responsible for enhancing its sense of smell. An enhanced sense of smell would be a definite advantage for a fish that lives in darkness.

As a result of these and other experiments, it now seems highly likely that blindness in cave tetras is in part the result of pleiotropy—one mutation that causes blindness in the fish and at the same time, gives them an enhanced sense of smell.

Evolution Works

Scientists are still studying cave fishes, and new discoveries are sure to be found. But one thing is already clear—the answer lies in the basic processes of evolution that are already well understood. With new tools that give scientists the ability to map genes, find specific mutations, and understand the development of embryos, we are increasing our understanding of how evolution works.

Article adapted from "Why Do Cave Fish Lose Their Eyes?" by Luis and Monika Espinasa, Natural History magazine, June 2005.

STUDENT WORKSHEET - page 1 Name: ______________________________

Before your visit to the Museum, use the information you learned from the article, "Why do Cave Fish Lose Their Eyes?", to complete the definitions for anatomical, behavioral, and physiological adaptations in the first column and the top row on cave fish.

During your visit, select three animals in *Life at the Limits* and use information from the exhibition to complete the rest of the rows. Be sure to fill in the name for each animal you choose.

Type of adaptation	**For each animal, draw and label an illustration of it. Then, describe the adaptation.**
anatomical adaptation Definition:	cave fish
	an animal from the exhibition: ______________________

STUDENT WORKSHEET - page 2 Name: ______________________________

Type of adaptation	**For each animal, draw and label an illustration of it. Then, describe the adaptation.**
behavioral adaptation Definition:	an animal from the exhibition: ______________________
physiological adaptation Definition:	an animal from the exhibition: ______________________

STUDENT WRITING TASK

After reading "Why Do Cave Fish Lose Their Eyes?" and taking notes in the *Life at the Limits* exhibition, write an essay in which you describe the different types of adaptations of animals that are well suited to survive and reproduce.

On your worksheet you have notes about the cave fish from the article that illustrates anatomical adaptations, as well as three animals from the exhibition that illustrate anatomical, behavioral, and physiological adaptations. Use all four examples in your essay.

In your essay, be sure to define the words anatomy, behavior, and physiology in the context of animal biology.

ESSAY SCORING RUBRIC: STUDENT VERSION - page 1

Scoring Criteria		Exceeds 4	Meets 3	Approaches 2	Needs Additonal Support 1
RESEARCH (worth 1/3)	**Article: "Why Do Cave Fish Lose Their Eyes?"**	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 accuracy and sufficient detail.	Presents information from the article relevant to the purpose of the prompt with minor 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
	Museum Exhibition: *Life at the Limits*	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 accuracy and sufficient detail.	Presents information from the exhibition relevant to the purpose of the prompt with minor lapses in accuracy or completeness and/or information is copied from the exhibit 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 (worth 1/3)	**Science Explanations**	Integrates relevant and accurate science content with thorough explanations that demonstrate in-depth understanding of anatomical, behavioral, and physiological adaptations	Accurately presents science content relevant to the prompt with sufficient explanations that demonstrate understanding different types of animal adaptations	Briefly notes science content relevant to the prompt; shows basic or uneven understanding of different types of animal adaptations; minor errors in explanation	Attempts to include science content in explanations, but understanding of different types of animal adaptations is weak; content irrelevant, inappropriate, or inaccurate
WRITING (worth 1/3)	**Focus**	Maintains a strongly developed focus on the writing prompt for the entire essay	Maintains focus on the writing prompt for the majority of the essay	Addresses the prompt but is off-task some of the time	Does not address the prompt for most or all of the essay
		Clearly introduces the topic of anatomical, behavioral, and physiological adaptations	Introduces the spiny pufferfish and two other animals	Mentions the spiny pufferfish and one other animal	Only mentions one animal
		Provides a relevant concluding statement/section	Provides a concluding statement/section	Provides a sense of closure	Provides no sense of closure
		Thoroughly and accurately defines "anatomical, behavioral, and physiological adaptations"	Defines "anatomical, behavioral, and physiological adaptations"	Defines 1-2 of the adaptation types	Does not define any type of adaptation
	Development	Clearly describes anatonmical, behavioral, and physiological adaptations of animals that are well-suited to survive and reproduce in detail	Describes physical, behavioral, and physiological adaptations of animals that are well-suited to survive and reproduce	Attempts to describe both physical and behavioral adaptations of animals that are well-suited to survive and reproduce but lacks sufficient development	Does not describe both physical and behavioral adaptations of animals that are well-suited to survive and reproduce

ESSAY SCORING RUBRIC: STUDENT VERSION - page 2

Scoring Criteria		Exceeds	Meets	Approaches	Needs Additonal Support
		4	**3**	**2**	**1**
WRITING (worth 1/3)	Clarity	Consistent and effective use of precise and domain-specific language	Some use of precise and domain-specific language	Little use of precise and domain-specific language	No use of precise and domain-specific language
		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 demon-strate standard English conventions, but lacks cohesion and control of grammar, usage, and mechanics