



The Origin of Species: Lizards in an Evolutionary Tree

OVERVIEW

[Lizards in an Evolutionary Tree](#) is one of three films in HHMI's Origin of Species collection. This film describes how the more than 700 islands of the Caribbean are home to about 150 species of anoles, a closely related group of lizards (genus *Anolis*) that occupy diverse habitats and niches. Research on these lizards is enriching our understanding of evolutionary processes, such as adaptation by natural selection, convergent evolution, and the formation of new species—and it is helping to illuminate how and why there are so many different kinds of living organisms on Earth.



Figure 1. Diverse anoles share common features.

Anolis cristatellus is a common anole species found in Puerto Rico. It has a colorful flap of skin under its throat that it uses to communicate. All but two of the nearly 150 known species of Caribbean anoles have this flap. These species live in diverse habitats and vary greatly in size and other obvious physical features such as leg and tail length. (Photo courtesy of Luke Mahler, University of California, Davis.)

KEY CONCEPTS

- An adaptation is a structure or function that confers greater ability to survive and reproduce in a particular environment.
- Islands are good natural laboratories for scientists to conduct experiments on the role of natural selection in driving adaptations in populations because they are isolated and have relatively simple ecosystems.
- Microevolution refers to evolutionary changes or adaptations that occur within populations, and macroevolution refers to changes leading to the formation of new species.
- The biological definition of a species is a group of interbreeding individuals that are reproductively, and thus genetically, isolated from other groups.
- When two groups within one species become geographically isolated—separated by a physical barrier, such as a river, canyon, or mountain range—genetic changes in one group will not be shared with members of the other, and vice versa. Over many generations, the two groups diverge as their traits change in different ways.
- For two groups to become distinct species, traits must change in ways that will keep members of each group reproductively isolated—meaning that they will not mate or produce fertile offspring with members of the other group—even if they come to be in the same geographic location.
- DNA sequence comparisons among different populations and species allow scientists to determine how distantly related different species are and how long ago they shared a common ancestor.
- Organisms in different evolutionary lineages can independently evolve similar traits as a result of adapting to similar environments or ecological niches, a process known as convergent evolution.
- One reason there has been and continue to be so many different species on Earth is that there are so many different types of habitats and niches.

CURRICULUM CONNECTIONS

Standards	Curriculum Connection
NGSS (2013)	LS2.A, LS3.B, LS4.B, LS4.C
AP Bio (2015)	1.A.1, 1.A.2, 1.A.4, 1.B.2, 1.C.1, 1.C.2
IB Bio (2016)	5.1, 5.4, C.1
AP Env Sci (2013)	II.C
IB Env Systems and Societies (2017)	3.2
Common Core (2010)	ELA.RST.9-12.4, WHST.6-12.9, MP2
Vision and Change (2009)	CC1, CC5

PRIOR KNOWLEDGE

Students should

- have a basic understanding of natural selection, evolution, and adaptation;
- be familiar with the concept that organisms fill specific niches in their environments; and
- know that genes and their respective traits are inherited and that some traits provide organisms with a greater chance to survive and reproduce.

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
1	0:00	6:46	<ul style="list-style-type: none"> • Anole lizard species living in different habitats have different body types. • An adaptation is a structure or function that confers greater ability to survive and reproduce in a particular environment. • Differences in leg length and toe pad size are adaptations that enable anoles to live successfully in different habitats. 	<ul style="list-style-type: none"> • In what environment is long leg length an advantage for a lizard? • Why have anoles evolved different toe pads?
2	6:47	9:50	<ul style="list-style-type: none"> • Experiments in the Bahamas reveal that frequency of traits in an anole population can change within a few generations when the environment changes. 	<ul style="list-style-type: none"> • Does evolution happen quickly or slowly? Does it happen at the level of the individual or the population?
3	9:51	14:02	<ul style="list-style-type: none"> • Two groups of individuals are defined as different species when members of one group do not interbreed with members of the other group. Reproductive isolation can result in speciation. • Different anole species have different dewlaps, which they use for courtship and defining territory. Changes in certain traits result in reproductive isolation and speciation. • Microevolution refers to evolutionary changes or adaptations that occur within populations, and macroevolution refers to changes leading to the formation of new species. • Once new species are formed, competition drives the evolution of different body types. On the four major islands of the Caribbean, anoles living in the same habitat have the same basic body type. 	<ul style="list-style-type: none"> • What is the definition of a species? • How does speciation occur? • Why is a change in dewlap considered an important step in the formation of new anole species? • What is the difference between microevolution and macroevolution?

4	14:03	17:44	<ul style="list-style-type: none"> Species that are closely related have very few differences in their DNA; distantly related species have more differences in their DNA. In a phylogenetic tree, a node represents a common ancestor. DNA sequencing data indicates that lizards on each island tend to be more closely related to each other than to similar species on other islands, indicating that the same types of anoles evolved independently on different islands. Evolution can repeat itself in similar habitats. Each habitat offers different ways to survive. One reason there have been and continue to be so many different species on Earth is that there are so many different types of habitats and niches. 	<ul style="list-style-type: none"> How did each island end up with each of the four anole body types? What evidence indicates that the same types of anoles evolved independently on different islands?
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BACKGROUND

“[W]e can clearly understand why analogical or adaptive character, although of the utmost importance to the welfare of the being, are almost valueless to the systematist. For animals, belonging to two most distinct lines of descent, may have become adapted to similar conditions, and thus assume a close external resemblance.” — Charles Darwin (1859)

In this excerpt from *On the Origin of Species*, Charles Darwin reasoned that when species with different evolutionary histories occupy similar habitats and are exposed to similar environmental conditions (e.g., climate, food, and interactions with other species), they are likely to evolve similar traits due to natural selection. The phenomenon is known today as convergent evolution: the independent evolution of similar features in organisms belonging to different evolutionary lineages.

The HHMI short film *The Origin of Species: Lizards in an Evolutionary Tree* follows Harvard University evolutionary biologist Jonathan Losos and his colleagues as they study the convergent evolution of lizards called anoles that live in the grasses, bushes, and trees on the islands in the Caribbean. On different islands, similar traits have evolved again and again as different populations of lizards adapted to similar environments. The film presents many factors that play into the evolution of the anoles, including natural selection, sexual selection, and genetic change.

Adaptation Has Led to Different Body Types

Losos has been studying the ecology and evolutionary biology of anoles for almost 30 years and has published over 125 scientific papers on this work. Much of his research focuses on the anoles that live on the larger Caribbean islands, including Puerto Rico, Jamaica, Cuba, and Hispaniola (see Figure 2).



Figure 2. Caribbean islands are home to the anoles. The anole species featured in the film live on the islands of Cuba, Jamaica, Hispaniola (which comprises Haiti and the Dominican Republic), and Puerto Rico. (Reproduced with permission from Losos, J. *Lizards in an Evolutionary Tree*. UC Press, 2011).

Species of Caribbean anoles can be categorized into six groups according to their body characteristics (morphology) and the ecological niches they occupy. The groups are referred to as ecological morphotypes, or ecomorphs. For example, in the film we first meet the grass-bush anoles, which live on grass and small bushes. These anoles are small and have long legs and strikingly long tails that help them balance on thin branches and blades of grass.

Table 1 below lists the six anole ecomorphs found in the Caribbean islands and their body features. (Note that the film only discusses four of the ecomorphs: the crown-giant, trunk-ground, twig, and grass-bush anoles. Not all of the four larger Caribbean islands have species of lizards belonging to each of the six ecomorph categories.)

Table 1: Six Ecomorphs of Anole Lizards Found on the Caribbean Islands

Ecomorph	Body length	Limb length	Toe pad lamellae*	Tail length	Color	Habitat
Crown-giant (canopy)	130-191 mm	Short	Large	Long	Usually green	High trunks and branches
Trunk-crown	44-84 mm	Short	Very large	Long	Green	Trunks, branches, leaves
Trunk	40-58 mm	Intermediate	Intermediate	Short	Gray	Trunks
Twig	41-80 mm	Very short	Small	Short	Gray	Narrow twigs
Trunk-ground	55-79 mm	Long	Intermediate	Long	Brown	Lower trunk and ground
Grass-bush	33-51 mm	Long	Intermediate	Very long	Brown	Bush and grasses

*Lamellae are scales found on the lizards' toe pads. In general, the greater the number of lamellae, the larger the toe pad.

The body features of the six ecomorphs are adaptations that enable the lizards to be successful in their particular habitats. (See Figure 3 for an illustration of the habitats the different types of lizards inhabit.) For example, Losos shows in the film how the long legs of the trunk-ground anoles enable them to move faster on the ground than the short-legged twig anoles. The long-legged adaptation helps the trunk-ground anoles not only catch prey on the ground but also avoid predators that live in their habitats. However, when placed in the habitat of the twig anoles, where twig anoles can move easily with their short legs, the trunk-ground anoles are clumsy. Losos also illustrates how the canopy anoles, with their large toe pads, are adapted to living on leaf surfaces in the canopy.



Figure 3. Anoles occupy a variety of ecological niches.

Different types of anole lizards have evolved adaptations that enable them to be successful in different ecological niches—different parts of trees, grasses, and bushes. The figure shows the six ecomorphs of anole lizards found in the Caribbean islands in their respective habitats. (Reproduced with permission from Losos, J. *Lizards in an Evolutionary Tree*. UC Press, 2011).

More than 400 species of anoles have been described worldwide, and about 150 of them are found on the Caribbean islands. In the Caribbean, the number of species on any particular island is roughly related to its size. Cuba, the largest island, has 63 species, and Hispaniola, the second largest, has 41. Many of the species on each island fall into one of the six ecomorphs listed below in Table 2. Note that not all the islands have species that belong to each of the six ecomorphs.

Table 2: Ecomorphs Found on Each Caribbean Island

Ecomorph	Crown-giant	Trunk-crown	Trunk	Twig	Trunk-ground	Grass-bush
Island						
Cuba	✓	✓	✓	✓	✓	✓
Hispaniola	✓	✓	✓	✓	✓	✓
Puerto Rico	✓	✓		✓	✓	✓
Jamaica	✓	✓		✓	✓	



Figure 4. Each species of anole belongs to one of six different body types.

Anole species in the Caribbean belong to one of six ecomorphs: crown-giant, trunk-crown, trunk-ground, trunk, twig, and grass-bush. *Anolis ophiolepis* on the left is a grass-bush anole found in Cuba. It has a very long tail that helps it balance on blades of grass and thin twigs. *Anolis sagrei* below is a trunk-ground anole found on the island of Hispaniola. It has long legs that enable it to run to catch prey on the ground and escape from predators. (Photos courtesy of Luke Mahler, University of California, Davis.)



Convergent Evolution Has Led to the Same Body Types on All the Islands

Two explanations for why similar ecomorph classes would be found on each of the different islands are possible. One hypothesis is that each type of anole evolved on one of the islands and then migrated to the other islands, where they found similar habitats; over time they speciated and maintained the same body type. Given this hypothesis, you would predict that DNA analysis would reveal, for example, that the crown-giant anoles on all of the islands are more closely related to each other than they are to the grass-bush, trunk-ground, and twig anoles on the same island.

An alternative hypothesis is that the ecomorphs evolved repeatedly and independently on each island. A prediction based on this hypothesis is that the anoles on each island would be more closely related to each other than they would be to their ecomorphs on other islands. This is what Jonathan Losos and colleagues have generally found to be the case.

When they examined DNA sequences from dozens of species of Caribbean anoles, they found that in general, species on the same island tend to be more closely related to one another than to species with similar body types found on different islands. This suggests that the same adaptations evolved independently in different anole populations on each of the islands.

The phylogenetic tree shown in the film is a simplified version of the entire result Losos and colleagues obtained, summarized in Figure 5 below. The common ancestor of all anole species probably came from the mainland and established populations of lizards on different islands.

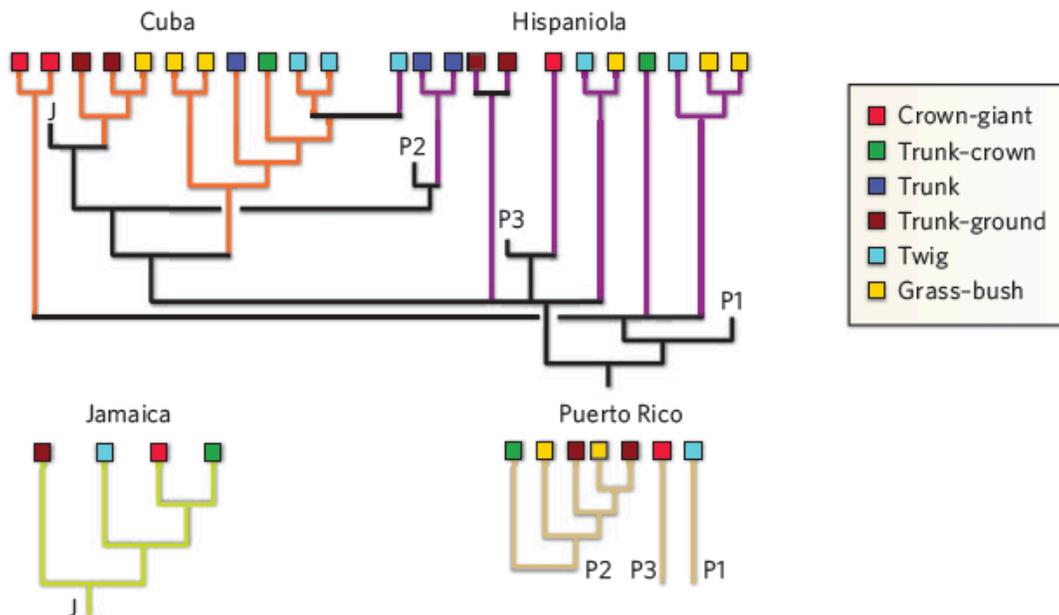


Figure 5. Lizard phylogenetic tree. Groups of related species that include a common ancestor and all the descendants (living and extinct) of that ancestor are referred to as clades. In this illustration, horizontal black lines connect clades on different islands. The island clades were established either by overwater dispersal or by ancient geological connections among islands. Colored lines represent the four islands. For ease of presentation, the Jamaican clade (J) and Puerto Rican clades (P1, P2, and P3) are shown separately. They fit into the phylogeny at the positions marked. The data show that in general, species on each island are more closely related to each other than to species on other islands with few exceptions. For example, some species of lizards in Puerto Rico are more closely related to species in Hispaniola than to other species in Puerto Rico; this suggests that on rare occasions some lizard populations migrated from one island to another, perhaps carried there by hurricanes. (Image reproduced with permission from Losos, B.J. and Ricklefs, R.E. Adaptation and diversification on islands. 2009. *Nature* 457:834.)

Once ancestral populations were established on each island, lizard populations independently multiplied and diversified into the many species that exist today. This conclusion is consistent with the fact that in general most anole species on each island share a more recent common ancestor with each other than with lizard species from other islands. There are, however, some exceptions, which can be explained by a few interisland migration events.

While Charles Darwin could not have analyzed DNA among species, he observed that “animals, belonging to two most distinct lines of descent, may readily become adapted to similar conditions, and thus assume a close external resemblance.” Over 150 years later, Losos and his team have shown that indeed the forces of natural selection can be so intense that the same traits can evolve again and again, resulting in repeated occupation of habitats on each Caribbean island by anoles.

Reproductive Isolation and Speciation

Physical differences among anole species, for example in tails, limb proportions, and toe-pad size, evolved as a result of natural selection in different environments. But how did different anole populations come to occupy different habitats in the first place, evolve these adaptations, and start on the path toward speciation?

One very important force for niche specialization is competition for limited resources, such as food. When competition for resources is intense, there is positive selection for traits that favor the populations partitioning the environment. The anoles, for example, have moved into various habitats ranging from the grasses and bushes to the leaves in the forest canopy. Over many generations, natural selection favors those traits among individuals that enable the populations to live more successfully in their different environments. By specializing in a particular niche, each population can accrue a host of adaptations that enable them to better avoid predation, more easily find mates, procure food not available to other populations, and even find shelter.

The different niches may not be completely separated from each other. For example, the habitats of the twig anole and the canopy anole overlap high up in the trees, but when the two species encounter each other, they do not mate. Therefore, adaptations that foster niche exploitation alone are not sufficient for speciation to occur. In addition to those adaptations, traits that prevent mating and reproducing must also change.

In the film, Jonathan Losos describes how distinctive dewlap colors and shapes are traits that can keep different species of lizards reproductively isolated. He notes that no two anole species living in the same geographic location have dewlaps of the same color or shape. (Figure 6 shows a variety of dewlap shapes and colors.) Male anoles display their dewlaps as a social signal and in particular to attract females. The females of most species also have dewlaps, which are generally smaller than those of the males and are also used for signaling. Females choose mating partners of the same species, based on a variety of physical characteristic including dewlap shape and color.

Losos explains that if a group of anoles from a species with light-colored dewlaps migrated from dim forest habitats and ended up in a habitat that was open and sunny, the light dewlaps would not be very useful for communicating since they would be hard for other lizards to see. Over many generations, the lizards may develop dull-colored dewlaps that stand out better against a bright background. If the male members of the population then encountered females from the original forest population, the females would not choose them as mates because they have no preference for dull-colored dewlaps. The two populations would now be reproductively isolated.

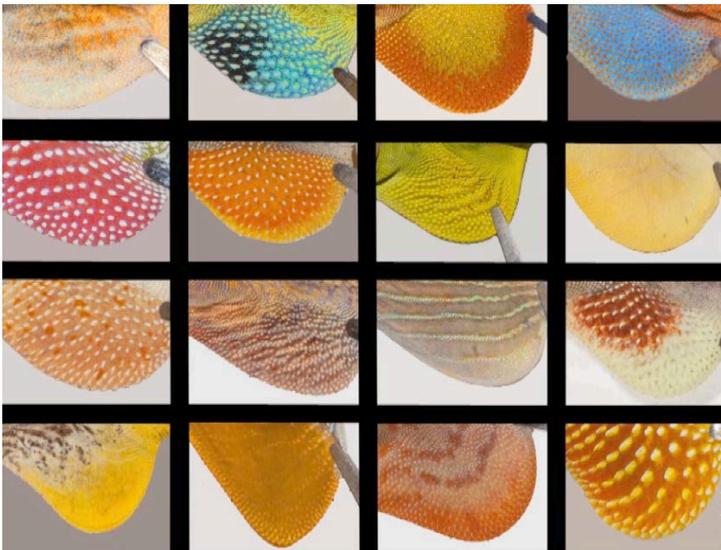


Figure 6. Different dewlap flavors. Male anoles use colorful flaps of skin under their throats, called dewlaps, to court females and confront other males. In addition, the dewlaps help lizards distinguish members of their own species from those of other species. No two species of anoles living in the same geographical location have dewlaps of the same size, shape, or color.

When lizards with different dewlap colors colonize neighboring niches such as the twigs or canopy of a tree, they will not interbreed. As they adapt to their particular environments, they will not share genetic changes and the two populations will be free to diverge even further in form and function. These processes have led to the different body types and skin colors of lizards that exist today.

DISCUSSION POINTS

- If your students also watched the related short film *The Origin of Species: The Beak of the Finch*, discuss with them the similarities and differences between the two stories. Both films stress the role of geographic isolation for establishing differences in traits between two populations. In the finch story, populations of birds became isolated on different islands; in contrast, lizard populations became isolated within the same island, as these islands are much larger than those of the Galápagos. In both scenarios, for speciation to happen, a phase of geographic isolation must occur until reproductive isolation evolves. Then even if the two populations share the same geographic location, they will not mate or produce fertile offspring. In the finches, differences in song and appearance keep species separate; in the lizards, dewlaps play a key role. Both finches and lizards have partitioned their habitats among different species. Different species of finches eat different food, whereas the lizards have occupied different niches in trees, grasses, and bushes.
- In an upper level biology course, students may learn about allopatric, parapatric, and sympatric speciation. These are the three major mechanisms for speciation described in textbooks. Allopatric speciation takes place when two populations are completely geographically isolated from each other and no gene flow occurs between them. Genetic changes in one population are never shared with the other population. In parapatric speciation, there is occasional gene flow between two populations that have adjacent geographic ranges. Populations of finches on nearby islands may still have intermittent gene flow between them, but it is rare. In sympatric speciation, gene flow is common because the two populations live in the same geographic area but occupy different habitats. When speciation occurs in sympatric populations, one or more traits are likely selected for that will keep the populations reproductively isolated. Such traits may include ones that affect appearance, the ability to tolerate certain environmental extremes, and the timing of reproduction for the two populations (e.g., spring or summer). In the case of the anoles, most researchers think that species originally formed following geographic isolation (or allopatric speciation). For example, two groups may have become isolated on different sides of a river or on one of the smaller islands that surround the large islands. These different populations acquired different traits and became distinct species primarily due to behavioral isolating mechanisms, such as a change in dewlap color, which kept members of different species separate if and when they came into contact. The cichlid fish that have extensively radiated throughout freshwater lakes in parts of Africa, Central America, and Asia may have undergone sympatric speciation. However, many

biologists consider sympatric speciation very difficult to occur because ongoing gene flow prevents species from evolving different features that would then preclude genetic exchange.

- Stress to students that Losos has been able to do what few evolutionary biologists have done. He has been able to conduct experiments to test how natural selection drives adaptations. Losos uses islands that have recently been cleared of anoles by hurricanes as natural laboratories to test natural selection. In one experiment, Losos and his team transplanted breeding pairs of male and female long-legged anoles from a larger island to several small hurricane-scrubbed islands which had only bushes left. In the film, we see how after only a few generations, the populations on islands where the anoles were introduced evolve shorter and shorter legs—adaptations driven by natural selection that help the anoles be successful in their new environment.
- Students may ask whether there are examples of convergent evolution in groups other than the anoles. Ask students to come up with explanations for the torpedo body shape among groups of unrelated species like dolphins, sharks, tunas, penguins, and extinct ichthyosaurs. Students may also find it fascinating that the branching pattern found in trees today evolved independently in several groups of plants and evolved several different times throughout the evolutionary history of plants.
- The most famous case of repeated adaptive radiation is the cichlids of the East African Great Lakes, which comprise approximately 2,000 species. In Lake Tanganyika, 250 cichlid species have evolved in the past 9 million to 12 million years, and in Lake Malawi 1000 species have evolved in the past 2 million to 5 million years. Remarkably, Lake Victoria, which is less than 200,000 years old, has 500 to 1000 species. These lakes have experienced independent evolutionary radiations and have each produced a dazzling array of similar ecomorph classes, including plankton grazers, algae scrapers, sand filterers, egg predators, and so on, and many of these ecomorphs have evolved convergently in two or all three lakes. However, our understanding of this convergent evolution of cichlids lags behind that of anoles.
- The film’s narrator, Sean Carroll, explains that two groups of organisms are defined as different species when individuals from one group don’t mate with those from the other, or they do not produce fertile offspring if they do. This is the biological species concept first introduced by evolutionary biologist Ernst Mayr and the definition most often taught to students. This concept emphasizes reproductive isolation. However, in practice, evolutionary biologists focus more on size, shape, and color to group individuals into distinct species. In general, they assume that species that look distinct are unlikely to interbreed. Differences in leg length, body size, body color, and dewlap size and color distinguish different species of anoles. When studying the fossil record, for example, morphological species criteria are the only ones available. For the most part, data from various approaches for defining species, such as observing behavior, studying physical characteristics, and even testing the ability to mate and produce fertile offspring, agree with one another. Species definitions are trickiest for phyla other than animals, such as protozoans, plants, fungi, and of course bacteria.
- Near the end of the film, the narrator, Sean Carroll, says, “The simple reason why there are so many species in the world is that there are so many habitats. And each habitat provides myriad ways to survive.” Carroll gives the example that in the Serengeti, zebras eat the tallest, coarsest grass, wildebeests the medium-height grass, and Thomson’s gazelles the shortest. Ask students to list as many different habitats as they can think of that exist on the land that surrounds your city or town. Ask students to then list all the habitats they can think of that were on that same land 200 years ago. What, if anything, has changed? Ask students how some of the evolutionary processes they learned about in the film, like adaptation and natural selection, may have been affected by changes in the local and regional habitats. You may also consider having students perform the same exercise using your entire state as the landscape.
- Jonathan Losos has shown that contrary to what Charles Darwin thought, species can evolve rapidly. When he conducts his experiments on the islands, leg length changes within one or two generations. Even so, it is important to help students understand that most speciation events are infrequent, and it often requires long

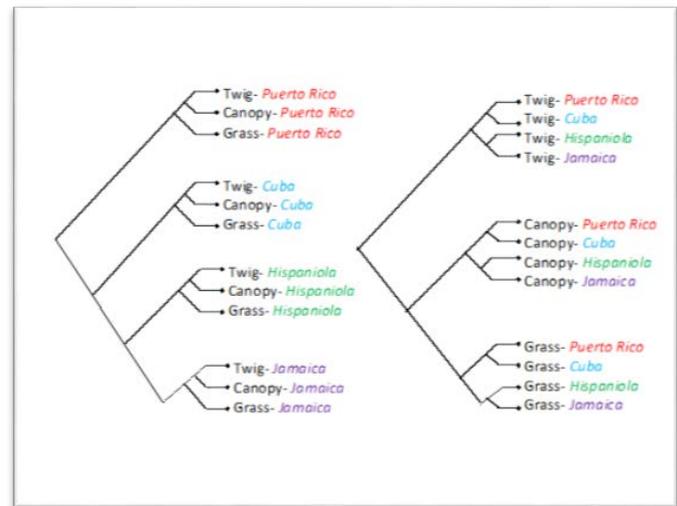
spans of geological time—millions of years—for two species to become truly distinct and genetically incompatible with each other. However, sometimes speciation occurs at high rates, and the island experiments Losos and others are conducting with the Caribbean anoles show that adaptations, the first steps toward speciation, can arise rapidly, especially when the forces of natural selection are strong.

STUDENT HANDOUT

We designed the student handout as a learning assessment that probes students’ understanding of the key concepts addressed in the film, which can be used to assess students’ prior knowledge before watching the film or to guide students as they watch the film. We encourage you to choose the use that best fits your learning objectives and your students’ needs. Moreover, because the vocabulary and concepts are complex, we encourage you to modify the handout as needed (e.g., reducing the number of questions, explaining complicated vocabulary for English learner students).

ANSWER KEY

1. (Key Concept G) Puerto Rico, Cuba, Jamaica, and Hispaniola have species of anole lizards with distinct body types, including the grass lizards, which have long tails; the canopy lizards, which have large toe pads; and the twig lizards, which have short legs. Anole species with each of these three body types exist on each of the four islands. The phylogenetic trees in the figure below illustrate two hypotheses for how these types of lizards may have evolved.



a. Select the pair of statements in the table below that accurately describe the phylogenetic trees in the figure above:

	Tree on the Left Side of the Figure	Tree on the Right Side of the Figure
A	The twig lizard on Puerto Rico evolved first and is the ancestor of all the other lizards.	The twig lizard evolved first on all of the islands, and then the canopy and grass lizards evolved from the twig lizard.
B	<i>Body types evolved repeatedly and independently on each island.</i>	<i>Different body types evolved once, and then populations of individuals with those body types ended up on different islands.</i>
C	Different body types evolved only once, and then populations of individuals with those body types ended up on different islands.	There are two ancestors to all the lizards, the twig lizard and the canopy lizard.
D	Puerto Rico is the origin of all three lizard body types.	Each body type evolved repeatedly and independently on each island.

b. Select which tree in the figure illustrates the most likely hypothesis for how the different species of anole lizards evolved on the Caribbean islands according to the film:

 X the tree on the left _____ the tree on the right

c. Using evidence presented in the film, explain the reasoning behind your answer in the question above (Part b).

In the film, Jonathan Losos and his colleagues sequenced the DNA of anoles from each island. The DNA revealed that the lizards on each island tend to be more closely related to each other than to similar-looking lizards elsewhere. That means that generally the same types of lizards evolved independently on each island.

2. (Key Concept F) Over many generations, natural selection favors those traits that enable populations to live successfully in a particular habitat. A scientist discovered two species of anole lizards that live in different habitats and display the characteristics listed in the table below. (The scientists based these observations on a sample of 20 lizards from each species.)

Observations of Two Species of Anoles		
Species	A	B
Habitat	High trunks and branches	Lower trunk and ground
Body length	130-191 mm	55-79 mm
Limb length	Short	Long
Toe-pad size	Large	Intermediate
Color	Green	Brown
Tail length	Long	Long

- a. Describe two differences between the two species of anoles.

Answers will vary. One difference is that species A lives high up on tree trunks and branches, whereas species B lives lower down on trunks and on the ground. A second difference is that the limbs of species A are relatively short and those of species B are long. The sizes of the two lizard species' bodies and toe pads are also different.

- b. Formulate two hypotheses to explain why each of these differences may have evolved.

Answers will vary. Using the differences mentioned above, students may say that (1) by living higher up on the trunks and in the branches of trees, species A avoids competition for resources with species B, and (2) longer limbs are an adaptation for living lower in the trees and on the ground because individuals with longer limbs can run faster and escape predators on the ground, whereas lizards with shorter legs can move more easily on thin branches high up in the trees. Another answer may argue that toe pads make it easier for lizards to climb on the slick surfaces of leaves.

- c. Describe an experiment that would test one of your hypotheses stated above.

Answers will vary depending on the hypotheses presented above. A complete answer should include the hypothesis being tested, a controlled method of testing the hypothesis, and a quantifiable prediction that supports the hypothesis. Example:

Hypothesis – Longer limbs are an adaptation for living on the ground because it enables lizards to run faster.

Method – Lizard races. Create a rectangular enclosure on the classroom floor and compare the running speeds of species A and species B.

Prediction – Lizards with longer legs will run faster.

Students could also test the ability of the two species of lizards to climb a slick surface like glass or a mirror.

3. (Key Concept D) Two organisms are considered to belong to different species if they
- have differences in appearance, such as different color or leg length.
 - live in different geographical areas, such as on different islands.
 - do not mate or produce fertile offspring.**
 - eat entirely different types of foods.
4. (Key Concepts B and C) In the film, you saw Jonathan Losos place a male and female trunk-ground anole on an island that did not have any trees but had short grass and shrubs. Losos and colleagues visited the island the following year. What had happened?
- The two anoles died because there were no trees for them to live in.
 - The two anoles reproduced and their offspring adapted to living in bushes.**
 - The legs of the two anoles got shorter and their offspring inherited shorter legs.
 - The two anoles reproduced and there were no significant differences in traits from one generation to the next.
5. (Key Concept B) Which statement best explains why islands can be used as natural laboratories?

- a. The climate among islands varies from very wet to very dry.
- b. Islands are smaller in size than the mainland, so in that sense they are like a laboratory.
- c. The islands have similar habitats, but they differ from the mainland habitat.
- d. *There are many small islands, meaning that researchers can repeat their observations and experiments on several similar islands.*

6. (Key Concept C) Describe the similarities and differences between the terms *microevolution* and *macroevolution*.

Microevolution and macroevolution are similar in that both involve genetic changes in populations over time.

Microevolution and macroevolution are different in that microevolution involves changes within populations that do not prevent breeding between one group and another. With macroevolution, changes within populations accumulate until individuals from one group no longer recognize individuals from another group as potential mates or they are no longer able to produce fertile offspring.

7. (Key Concept F) List two lines of evidence that Jonathan Losos has gathered through observation and experimentation that support the theory of natural selection developed by Charles Darwin.

A complete answer should include the following lines of evidence:

- *On each of the Caribbean's four largest islands, Puerto Rico, Jamaica, Cuba, and Hispaniola, Losos observed the same distribution of similar-looking lizards.*
- *Each island has lizards with the same basic body types: slender grass-bush anoles with long tails, long-legged stocky trunk-ground anoles, small short-legged twig anoles, and canopy anoles with large toe pads.*
- *Losos tested natural selection theory by transplanting breeding pairs of long-legged anoles from a larger island to several small hurricane-scrubbed islands, which had only bushes left.*
- *Losos collected evidence suggesting that after only a few generations, the populations on all of the islands evolved shorter and shorter legs—adaptations driven by natural selection that help the anoles be successful in their new environment.*

Use the following information and figure to answer Questions 8-9.

In 2003, Jonathan Losos and his research team experimentally introduced curly-tailed lizards (*Leiocephalus carinatus*) to islands populated by trunk-ground anoles that live primarily on the ground and have relatively long legs (Losos, J. B., T. W. Schoener, and D. A. Spiller. 2004. Predator-induced behaviour shifts and natural selection in field-experimental lizard populations. *Nature* 432: 505-508). The scientists wanted to know how the presence of curly-tailed lizards, which are anole predators, would affect the habitat in which the anoles lived.

In one experiment, Losos and colleagues measured the “perch height” (or how high off the ground a lizard was perched) for 24 individual anoles. They then placed either a curly-tailed lizard (experimental population) or an inanimate object of the same size (control population) in front of individual trunk-ground anoles and measured the perch height 10 minutes later. They then calculated the average change in the anole’s perch height in the experimental and control populations. The results of this experiment are summarized in Figure 1.

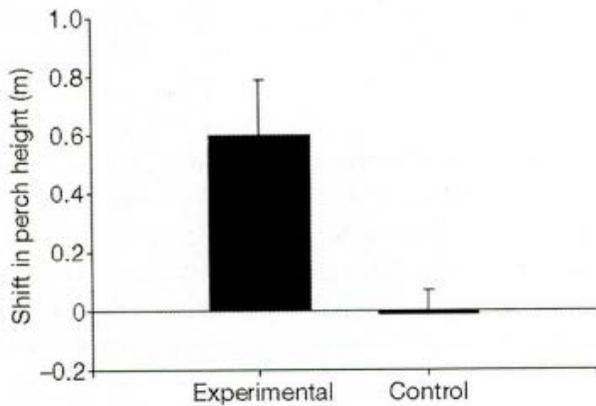


Figure 1. Mean change in perch height (± 1 standard error) 10 minutes after introduction of either a large predatory lizard (experimental) or an inanimate object of the same size (control). (Image reproduced with permission from Losos, J. B., T. W. Schoener, and D. A. Spiller. 2004. *Nature* 432: 505-508.)

8. (Key Concepts A and B) Based on the information above, what research question did the scientists ask that led to this experiment?

How do ground anoles evolve in the presence of a potential predator?

or

Do ground anoles change perch height in the presence of a potential predator?

9. (Key Concepts A and B) Using the information in Figure 1, describe the results of the experiment.

In the presence of a live curly-tailed lizard, the ground anoles started living higher off the ground. The data show that they shifted their perch height by an average of 0.6 meters. The average perch height did not change for the anoles that were exposed to an inanimate object the same size as a curly-tailed lizard.

Additional Notes: Discuss with students why Losos and colleagues used an inanimate object in the control experiment. To minimize the number of variables that change from the experimental to the control condition, scientists try to use exactly the same protocol. In this particular experiment, both experimental and control protocols involved placing something in front of the anoles and taking a measurement 10 minutes later. The only variable that changed was the presence or absence of a predator.

Use the following information and figure to answer Questions 10-12.

In another experiment, the scientists left the curly-tailed lizards on the islands for several weeks. They counted the number of anoles living on the ground at the beginning of the experiment in May and then again in July and November. The figure below shows the percentage of anoles living on the ground on islands with curly-tailed lizards (experimental population) and without curly-tailed lizards (control population).

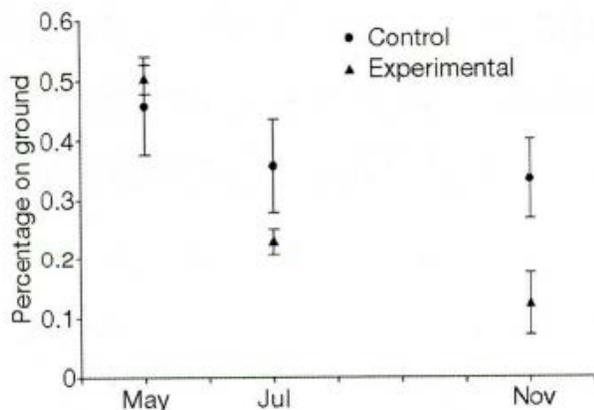


Figure 2. Differences in proportions of anoles observed on the ground in experimental and control populations. Values are mean and ± 1 standard error of the mean for all 12 islands. Only four islands were surveyed in July. (Image reproduced with permission from Losos, J. B., T. W. Schoener, and D. A. Spiller. 2004. *Nature* 432: 505-508.)

10. (Key Concepts A and B) Based on the information above, what research question did the scientists ask that led to this experiment?

How will the presence of a predator affect the habitat occupied by ground anoles over several weeks?

11. (Key Concepts A and B) Using the information in Figure 2, describe the result of the experiment.

After several weeks, the percentage of ground anoles in the experimental population that were living on the ground had dropped from 0.5 to almost 0.1, whereas the percentage of ground anoles in the control population that were living on the ground had dropped to 0.35. Some students may point out that there is a general trend for anoles to be on the ground less frequently from May to November, and that trend is accentuated in the presence of the predators. (According to Jonathan Losos, the reason for this trend is unclear but may have to do with the changing weather.)

12. (Key Concepts A and B) Provide a scientific explanation for the results of the two experiments summarized in Figures 1 and 2. (Hint: Imagine that you are one of the anoles in each experiment.)

The experiments basically show that in the presence of a predator, the anoles move higher up into the trees, and when the predator is on the island, they are less likely to be found on the ground. Presumably they aren't up in the trees all the time because the predator isn't always right in front of them.

13. (Key Concepts C–F) If the curly-tailed lizards were left on the islands for several years, predict how the bodies of the trunk-ground anoles might change after many generations of living in the presence of curly-tailed lizards.

The anoles living in the shrubs will likely have shorter limbs after several generations.

Additional Notes: This is a reasonable prediction for students to make. What Losos actually found is that during the first few months, the anoles on the island had, on average, longer limbs. The longer limbs gave anoles an advantage because they could run faster and escape from the predator when they are on the ground. Over many generations, however, the average limb length decreased. This can be explained by the fact that the anoles started living higher off the ground, where shorter limbs were advantageous.

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AUTHORS

Paul Strode, PhD, Fairview High School, Boulder, Colorado, and Laura Bonetta, PhD, HHMI; quiz by Paul Strode and Mary Colvard, Cobleskill-Richmondville High School (retired), Deposit, New York

Edited by Susan Dodge, Laura Bonetta, PhD, and Dennis Liu, PhD, HHMI, and Ann Brokaw, Rocky River High School, OH; copyedited by Linda Felaco

Reviewed by Jonathan Losos, PhD

Field tested by Marty Buehler, Hastings High School; Deborah Charles, Amityville Union Free School District; Robin Cochran-Dirksen, Lead-Deadwood High School; Karen Davis, Canyon High School; David Knuffke, Deer Park High School; Noreen Kohler, Phoenix Academy; Katie Lodes, St. Joseph's Academy; Valerie May, Woodstock Academy; Patricia Richards, Walter Johnson High School