UNIT 9

Patterns of Evolution

Lemurs are primates that live only on the island of Madagascar.

FIGURE 1: Butterflies collecting salt from a caiman.

While salt is a crucial nutrient for insects such as Amazonian butterfly species, it is often difficult to find. Although the butterflies' usual diet of nectar is rich in sugars, it does not contain salt and minerals important for survival. While insects sometimes gather these precious nutrients from mineral-rich pools and puddles, these sources are not always available. Individuals of some species have adapted their behavior to collect salt from the "tears" of reptiles such as caimans.

Predict How do new behaviors develop? Do newly adapted behaviors provide a special advantage to individuals in a species?

DRIVING QUESTIONS

As you move through the unit, gather evidence to help you answer the following questions. In your Evidence Notebook, record what you already know about these topics and any questions you have about them.

1. How does evolution lead to new species?
2. What causes the extinction of some species?
3. What are some of the patterns we see in evolution?
4. Can behaviors be inherited?

UNIT PROJECT

Investigating Fogstand Beetle Adaptations

Go online to download the Unit Project Worksheet to help you plan your project.

The beetle species *Stenocara gracilipes*, also known as the fogstand beetle, lives in the Namib Desert in Africa, one of the most arid climates in the world. To survive there, the fogstand beetle has adapted both physically and behaviorally to collect water from the surrounding air. The beetles stand angled against moist desert breezes, relying on hydrophilic and hydrophobic structures on their wings to catch and trap tiny water droplets to drink. Explore the unique adaptations of this desert insect, and research how scientists are copying its strategy for use in new technologies.

9.1

Evolution of Populations

These Asian beetles vary in the color of their wings and in the number and color of spots on those wings.

CAN YOU EXPLAIN IT?

Ruffs are birds found mostly in parts of Europe and Asia. They typically make their homes in marshes and mudflats where they feed primarily on insects and seeds. During breeding season, males gather in groups and participate in staged "fights" to attract females. In this courtship ritual, three types of males in the population are involved: the independents, the satellites, and the faeders.

FIGURE 1: Ruffs differ in body size as well as in the size and color of the feathers on their heads and necks.

a An independent male

b A satellite male

c A female. Faeder males greatly resemble females.

About 84 percent of the male ruffs are "independent." These ruffs fight hard and expend a lot of energy to establish a territory and attract female ruffs. They can be easily identified, as they are the largest males and have large black and brown neck feathers. "Satellite" males are smaller and have white neck feathers. They move freely between independents' territories and do not fight. Though independent males may dominate them to attract a female, the satellites are often able to mate with the same females. The smallest males, called "faeders," look similar to females and generally mate with females by sneaking, often when independents and satellites are distracted or fighting.

Gather Evidence As you explore the lesson, make a list of biotic or abiotic factors that may have contributed to the evolution of this population.

Predict How can three types of males evolve in one population?

Genetic Variation

Meerkats are mammals that live in the deserts of Africa. They live together in cooperative groups.

FIGURE 2: Meerkats stand alert to look for predators.

Gather Evidence Record the similarities and differences you see between the meerkats in Figure 2. Why do traits vary between individuals in a population?

Differences in the Gene Pool

As you looked at the physical traits, or phenotypes, of the meerkats, you might have noticed variations in some of their traits. For instance, some are smaller than others. One has a light underside, while most have a darker underside. A few have more white on their faces, and others have more brown.

The phenotypic differences that you observed among the meerkats are due to differences in genes that code for those traits. Certain differences may offer a competitive advantage compared to the rest of the population. A particular phenotype may allow individuals to survive longer and reproduce more efficiently, both of which increase the total number of offspring produced. So, over time the phenotype becomes more prevalent. This gradual favoring of advantageous traits within a population is called natural selection, and it directly affects the population's gene pool. A gene pool is the collection of alleles found in all of the individuals of a population.

Collaborate Meerkats have a range of fur colors, from very light brown with more silver to a medium brown with less silver. Imagine a plant species with similar colors to the darker brown meerkats starts to grow in their habitat. With a partner, discuss what would happen to the meerkats and why.

The different alleles in a gene pool ultimately result from mutations. When mutations occur during meiosis, the gametes that result may carry these mutations. Genetic variation may also be a result of crossing over and recombination, which occur during meiosis. During this process, chromosomes condense and homologous chromosomes align. Homologous chromosomes have the same genes but could have different alleles. During the alignment, an exchange of genetic material may take place. This exchange could alter the rearrangement of the linked genes in the chromosomes. As a result, the gametes are not genetically identical.

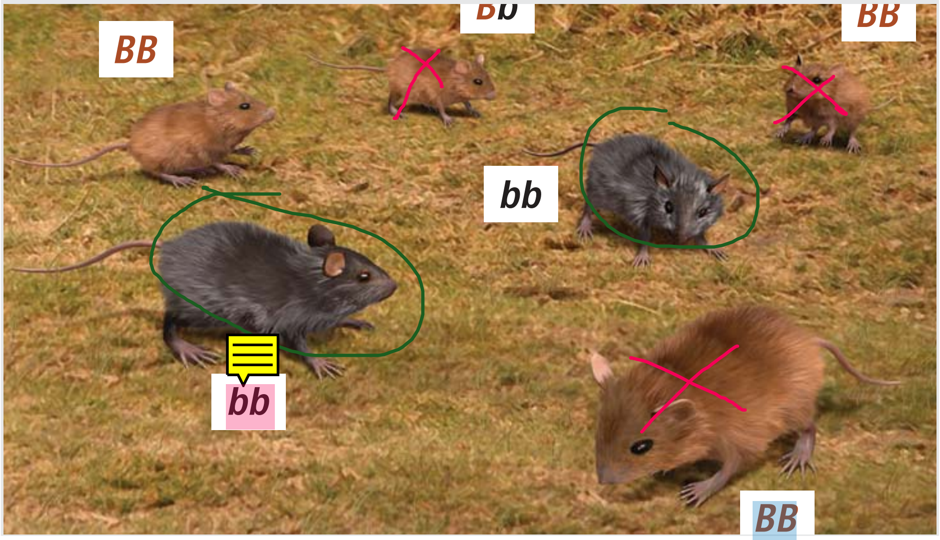
Explain How can mutations in gametes become widespread in the gene pool?

Variation in Alleles

Different combinations of alleles in a gene pool can be formed when organisms mate and have offspring. Alleles are different forms, or versions, of genes. For example, mice with either one or two copies of the dominant *B* allele have brown fur, while mice with two recessive *b* alleles have black fur, shown in Figure 3.

Gather Evidence Use the image to determine how many total alleles, dominant alleles (*B*), and recessive alleles (*b*), are in the gene pool of this mouse population.

FIGURE 3: Differences in fur color in mice are due to differences in allele combinations.



You can use the total number of alleles, the number of dominant alleles, and the number of recessive alleles to find the allele frequency in a population. Allele frequency is the proportion of one allele, compared with all the alleles for that trait, in the gene pool. To find the frequency of a particular allele, divide the number of times the allele is present by the total number of alleles in the population.

$$\text{Allele Frequency} = \frac{\text{Number of particular allele}}{\text{Total number of alleles}}$$

Allele frequency can also be expressed as a percentage by multiplying the frequency by 100. The frequencies of all the different alleles in a population should equal 1.0, or 100 percent.

Allele frequency is used to track genetic variation in populations and detect changes in alleles. Imagine that periodic fires blacken the ground in the field mice habitat in Figure 3. The black mice may be better camouflaged, providing more protection against predators. If they survive and reproduce more effectively than brown mice, the frequency of the *b* allele may increase over time relative to the *B* allele frequency.

Math Connection

Use Figure 3 and the allele frequency equation to answer the following questions:

1. What is the allele frequency of the dominant allele *B*? Express your answer as a decimal rounded to the thousandths place and as a percentage.
2. What is the allele frequency of the recessive allele *b*? Express your answer as a decimal rounded to the thousandths place and as a percentage.

Analyzing Population Evolution

Some chickens, ducks, and other birds can lay eggs that have either white or blue shells. Blue eggshells are dominant and are coded for by allele *O*. White eggshells are recessive and are coded for by allele *o*. The outcome of a heterozygous-heterozygous cross for eggshell color can be determined by creating a Punnett square. We can create a Punnett square to represent any dominant or recessive allele in a population for this type of cross. In this generic Punnett square, *p* represents any dominant allele and *q* represents any recessive allele. The Punnett square that gives the possible genotypes of the offspring of heterozygous parents for eggshell color is shown in Figure 4.

The Punnett square shows that the genotypic frequency of *OO* is represented as p^2, *Oo* is represented as $2pq$, and *oo* is represented as q^2. The frequency of all possible genotypes in a population must equal 1. If allele frequency can be found using the equation $p + q = 1$, then $p^2 + 2pq + q^2 = 1$. Scientists use these equations to predict the genotypic frequencies in a population. Then, they compare the predicted frequencies to the actual frequencies in a population.

Predict What could a scientist conclude if the genotypic frequencies in a population are different from the predicted values?

FIGURE 4: In this Punnett square, p represents any dominant allele and q represents any recessive allele.

	O (p)	o (q)
O (p)	OO (p^2)	Oo (pq)
o (q)	Oo (pq)	oo (q^2)

Data Analysis

In a population of 1,000 chickens, 840 hens lay blue eggs and 160 hens lay white eggs. Use the equation $p^2 + 2pq + q^2 = 1$ to determine the predicted genotypic frequencies for this population. Then compare those values with the actual genotypic frequencies in the population.

STEP 1 Solve for q^2 by dividing the number of *oo* chickens by 1,000.

$$q^2 = \frac{160}{1000} = 0.16$$

STEP 2 Solve for q by taking the square root of each side of the equation.

$$q = \sqrt{0.16} = 0.4$$

STEP 3 Determine p by substituting the value of q in the equation $p + q = 1$:

$$p + 0.4 = 1$$

$$p = 1 - 0.4 = 0.6$$

These are the predicted allele frequencies: $p = 0.6$ and $q = 0.4$.

STEP 4 Calculate the predicted genotypic frequencies from the predicted allele frequencies:

$$p^2 = (0.6)^2 = 0.36$$

$$2pq = 2\,(0.6)(0.4) = 0.48$$

$$q^2 = (0.4)^2 = 0.16$$

Analyze Answer the following questions in your Evidence Notebook:

1. What percentage of this population is expected to be *OO*, *Oo*, and *oo*? What do these values mean?
2. Through genetic analysis, scientists discovered the actual genotypic frequencies for the above population to be *OO* = 0.60, *Oo* = 0.14, and *oo* = 0.26. What can you infer by comparing these data to the values predicted above?

VARIABLES

p = frequency of O (dominant allele, blue shell)

q = frequency of o (recessive allele, white shell)

p^2 = frequency of chickens with OO (homozygous dominant genotype)

$2pq$ = frequency of chickens Oo (heterozygous genotype)

q^2 = frequency of chickens with oo (homozygous recessive genotype)

Always = 1

The equation $p^2 + 2pq + q^2 = 1$ is known as the Hardy-Weinberg equation. A Hardy-Weinberg population is in equilibrium, meaning it is stable and not evolving. Five conditions must be met for a population to be in equilibrium: no mutations, very large population, no natural selection, no new genetic material is introduced, and individuals are equally likely to mate with any other individual in the population.

Cause and Effect

FIGURE 5: Peppered Moths

Selection on Peppered Moth Populations

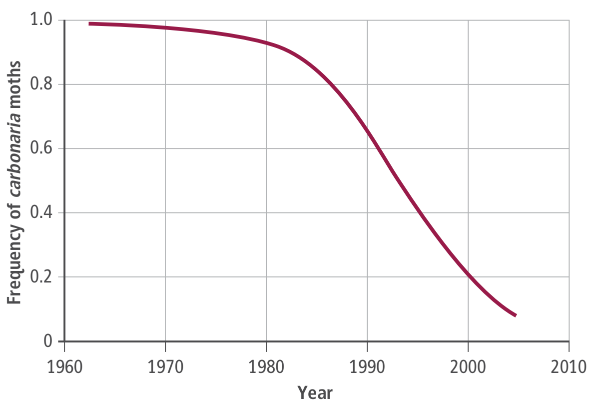
The peppered moth *Biston betularia* found in the English countryside, ranges in color from light (*Biston betularia typica*) to dark (*Biston betularia carbonaria*). Before the Industrial Revolution, light moths were more prevalent than dark moths. During the Industrial Revolution, trees became covered in dark soot from coal burned in factories. Over time, scientists observed that the number of dark moths increased relative to light moths. More recently, clean air laws returned the trees to their lighter coloring, and the dark colored moths decreased in frequency (Figure 6).

Recent studies found bird predation was one possible driving force behind the population shift. When trees were covered with soot, birds preyed on light moths. When the soot faded, birds preyed on dark moths (Figure 7). Other factors, such as migration, may have also influenced the population and require further study.

Analyze Create a graph of the shift observed in the peppered moth population. Place the color range on the *x*-axis and frequency of the trait on the *y*-axis.

Frequency of dark moths around Leeds, England, from 1970-2000

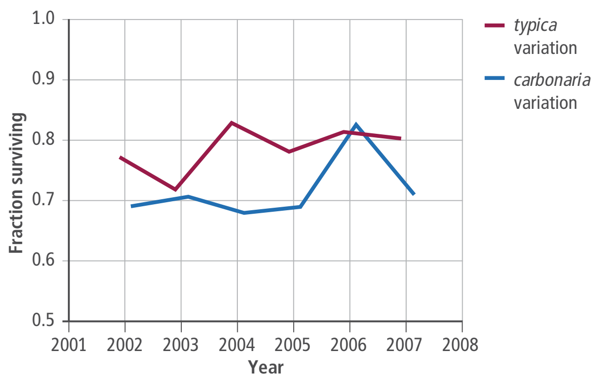
FIGURE 6: Frequency of Dark Moths



Source: John N. Thompson, *Relentless Evolution* (2013): 57, quoted in http://phenomena.nationalgeographic.com/2013/10/09/evolution-in-color-from-peppered-moths-to-walking-sticks/

Effect of bird predation on the population of light and dark moths

FIGURE 7: Effect of Bird Predation



Source: Cook, L. M., B. S. Grant, and I. J. Saccheri, J. Mallet. "Selective bird predation on the peppered moth: the last experiment of Michael Majerus." *Biol. Lett.* 2012. Published 8 February 2012. doi: 10.1098/rsbl.2011.1136.

Explain How does the Hardy-Weinberg equilibrium equation use genetic variation and allele frequencies in a population to describe whether a population is evolving?

Selection on Populations

Though king penguins look similar, members of the population differ in some of their physical traits. Some penguins may be larger and some smaller. Some individuals may have long beaks, and some may have short beaks. The majority of penguins have characteristics somewhere between these two extremes.

Normal Distribution

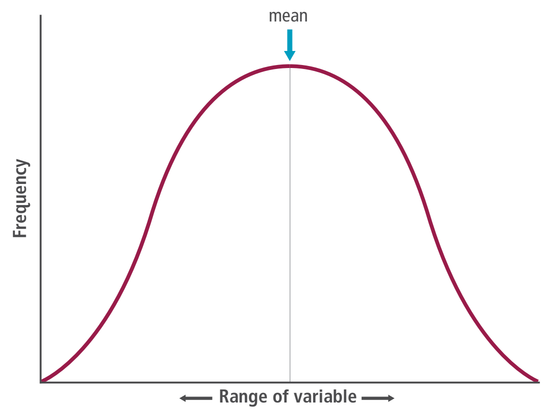
If penguin beak lengths and their frequencies are graphed, the result is a bell-shaped curve, shown in Figure 8. The shape of the curve shows that the beak length of the majority of the individuals is close to the mean length. Mean (also called average) beak length is determined by adding the beak lengths of all the individuals and then dividing the sum by the number of individuals. The graph also shows that there are not many individuals with extreme traits (very short or very long beaks).

Analyze Why do few individuals have very extreme phenotypes, such as very long or very short beaks, and more individuals show a trait somewhere in between?

A normal distribution shows an arrangement of data in which most of the values fall in the middle of the data set, represented by the mean. The curve that results is bell-shaped and symmetrical. The frequency is highest near the mean value and decreases toward each extreme end of the range. This means that for a population showing normal distribution, the alleles for the mean phenotype are more advantageous than the alleles associated with either extreme phenotype.

Normal Distribution

FIGURE 8: Most individuals in this population have traits that fall between two extreme phenotypes.



Changing Populations

King penguins live and breed on islands around Antarctica. Like other penguin species that live in cold areas, king penguins have features that allow them to live in this type of environment. They have layers of feathers as well as thick layers of fat to help keep them warm. Suppose the climate in this area warms up and continues to warm up. How might this continuing change in temperature affect the population?

Collaborate Suppose as a result of increasing temperatures, the trait for having a thick layer of fat was selected against and the thinner layer of fat was selected for. With a partner, discuss how the normal distribution graph will be affected.

FIGURE 9: King Penguins

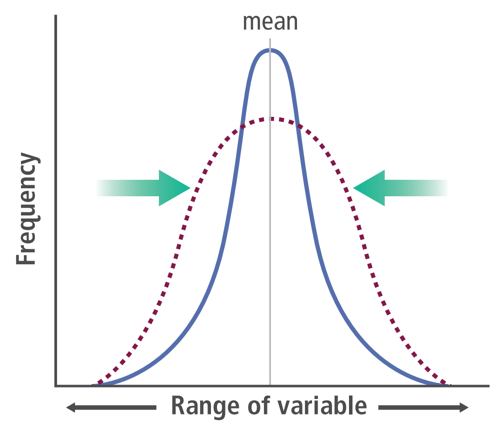
In populations, natural selection favors phenotypes that allow individuals in the population to adapt to their environment and selects against phenotypes that make individuals less able to adapt to their environment. This "favoring" and "selecting against" result in observable changes in the allele frequencies in a population. Microevolution is the observable change in the allele frequencies of a population over time. Microevolution occurs on a small scale—within a single population.

Stabilizing Selection

In humans, very low or very high birth weight can cause complications that affect a baby's health. Many infants with very low or very high birth weights do not survive to adulthood. Over many generations, these two phenotypes were selected against. More average birth weights, which had fewer weight-related complications, were selected for. Today, the frequency of individuals with an average birth weight is higher than those with extremely low or extremely high birth weights.

Stabilizing Selection Explore Online

FIGURE 10: In stabilizing selection, intermediate phenotypes are selected over phenotypes at both extremes.



This type of selection is called stabilizing selection. This is the type of natural selection in which intermediate phenotypes are selected over phenotypes at both extremes. In the example of birth weight in humans, individuals with average birth weights were more successful than those with very low or very high birth weights.

In stabilizing selection, extreme phenotypes are selected against. Over time, the survival rate of the individuals with these phenotypes decreases, so the frequency of these traits in the population also decreases. Phenotypes near the mean are selected for, so individuals that express these traits survive and reproduce more effectively than individuals without these traits. This results in an increase in the frequency of these phenotypes in the population.

Directional Selection

Another type of selection can be seen in the case of the peppered moth. Recall that before the Industrial Revolution, there were more sightings of light-colored (*typica*) moths and few sightings of dark-colored (*carbonaria*) moths. As factories were built during the Industrial Revolution, pollution increased. At this time, scientists observed that the number of *typica* moths decreased, while the number of the *carbonaria* moths increased and became more abundant in the population than the *typica* variety.

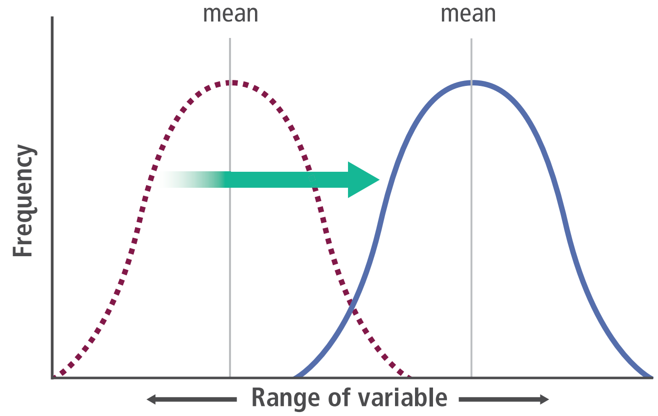
Model In your Evidence Notebook, draw a normal distribution graph for peppered moth coloration before the Industrial Revolution. Then, show how the frequencies of the phenotypes changed during the Industrial Revolution.

The type of selection observed in peppered moths is called directional selection. This is the type of natural selection in which one extreme phenotype is selected over the other extreme phenotype, shifting the mean toward one of the extremes. In the case of the peppered moths, the dark phenotype was selected over the light phenotype during the Industrial Revolution.

Directional Selection

Explore Online

FIGURE 11: After directional selection occurs, an extreme phenotype becomes the more abundant phenotype.



In directional selection, one extreme phenotype becomes more advantageous in the environment. Over time, individuals with this trait are more successful than individuals without the trait. Directional selection shifts the phenotypic frequencies, favoring individuals with genotypes that code for the extreme phenotype. The mean value of the trait shifts in the direction of the more advantageous phenotype.

Disruptive Selection

Lazuli buntings are birds found in the western part of the United States. The male birds have feathers with colors that range from brown to bright blue. The dominant adult males have the brightest blue feathers. They are the most successful in winning mates and have the best territories. For young buntings, the brightest blue and the dullest brown males are more likely to win mates than males with bluish-brown feathers.

Analyze In your Evidence Notebook, compare and contrast stabilizing, directional, and disruptive selection.

Research suggests that dominant adult males are aggressive toward young buntings they see as threats, including bright blue and bluish-brown males. The dullest brown birds can therefore win a mate because the adult males leave them alone. Meanwhile, the bright blue birds attract mates simply because of their color.

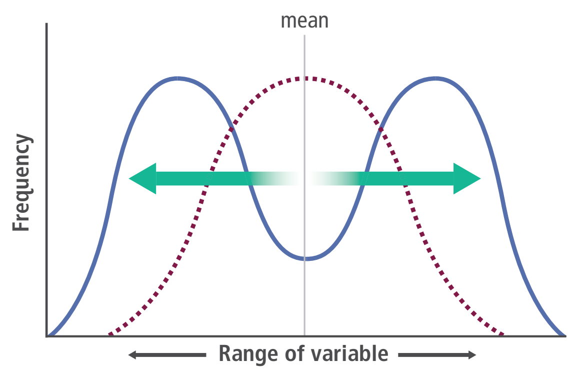
The type of selection observed in male lazuli bunting birds is called disruptive selection. This is the type of natural selection in which both extreme phenotypes (brown and bright blue feathers) are favored, while individuals with the intermediate phenotype (in between brown and blue) are selected against.

In disruptive selection, both extreme phenotypes are favored, while intermediate forms are selected against. The middle of the distribution graph is disrupted: individuals with genotypes that code for intermediate phenotypes are less successful that those with genotypes that code for extreme phenotypes. By favoring both extreme phenotypes, disruptive selection can lead to the formation of new species.

Disruptive Selection

Explore Online

FIGURE 12: In disruptive selection, the extreme phenotypes are selected over the intermediate phenotypes.



Explain Using evidence from this lesson, explain why populations, and not individuals, evolve.

Effects of Gene Flow

Predict Explain how the difference in gene flow between populations could cause them to evolve in different or similar ways.

Roses can grow in the wild or be cultivated. A bee may transport pollen from a farm that cultivates roses of different colors to a nearby area where wild red roses grow. The pollen can fertilize a wild rose flower, introducing new genetic material into the wild population. This is an example of gene flow, which is the movement of alleles from one population to another. Gene flow can cause a population to evolve.

Genetic Drift

Small populations are more likely to be affected by chance than large populations. Let's look at how a chance event can affect the alleles that code for a lizard's tail shape.

Hands-On Activity

Modeling Population Changes

Use a deck of cards to represent the lizard population. The four suits represent four different alleles for tail shape. The allele frequencies of the original population are 25% spade, 25% heart, 25% club, and 25% diamond tail shapes.

Predict How can random chance affect the allele frequencies in a population?

MATERIALS
- deck of cards

PROCEDURE

1. Shuffle the cards. Holding the deck face down, turn over 40 cards. These cards represent the alleles of 20 offspring produced by random mating of the individuals in the initial population.
2. Separate the 40 cards by suit and then find the allele frequencies for the offspring by calculating the percentage of each suit. Record these values in your Evidence Notebook.
3. Suppose a storm isolates a few lizards on another island where they start a new population. Reshuffle the deck and draw 10 cards to represent the alleles of five offspring produced in this smaller isolated population.
4. Repeat Step 2 to calculate the resulting allele frequencies. Record the results in your Evidence Notebook.

ANALYZE

Answer the following questions in your Evidence Notebook:

1. Compare the original allele frequencies to those calculated in Steps 2 and 4. How did they change?
2. Does this activity demonstrate evolution? Why or why not? Does it demonstrate natural selection? Why or why not?

What you observed in the activity is called genetic drift, which is a change in allele frequencies due to chance. For example, chance events such as natural disasters or birds dropping seeds on an island can change allele frequencies in a population. This phenomenon of genetic drift is typically observed in small populations because small populations are more likely to be affected by chance alone than large populations. The chance event causes some alleles to decrease in frequency, which may cause them to eventually disappear from the population all together. It causes other alleles to increase in frequency and possibly become fixed in the population.

Scientists have identified two processes that can cause population sizes to decrease enough for genetic drift to occur. Each of these processes results in a population with different allele frequencies than those that existed in the original population.

Bottleneck Effect

In the late 1800s, northern elephant seals were severely overhunted for their blubber, which was used in lamp oil. It is estimated that by 1890, there were fewer than 100 individuals left. After hunting ended, the population rebounded, and now there are more than 100,000 individuals.

FIGURE 13: The hunting of northern elephant seals greatly depleted the species' numbers and genetic diversity.

Analyze Use the model in Figure 13 to explain the change in genetic variation between the initial elephant seal population and the population after it rebounded.

The northern elephant seal suffered from the bottleneck effect. This is genetic drift resulting from an event that drastically reduces the size of a population. Through genetic drift, some alleles can be completely lost from the gene pool and others can be fixed in the population, resulting in lower genetic diversity.

Founder Effect

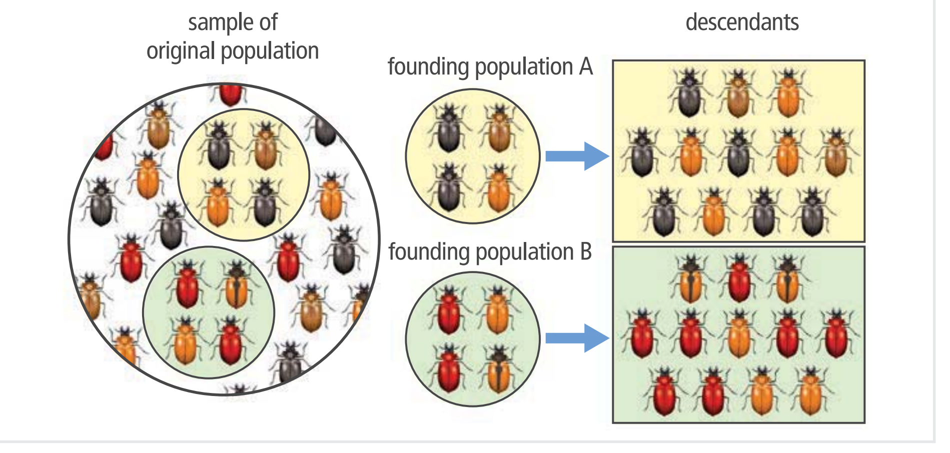
The Old Order Amish communities were founded in North America by small numbers of migrants from Europe. The gene pools of these smaller populations are very different from those of the larger populations. For example, the Amish of Lancaster County, Pennsylvania have a high rate of Ellis-van Creveld syndrome. Although this form of dwarfism is rare in other human populations, it has become common in this Amish population through genetic drift. Geneticists have traced this syndrome back to one of the community's founding couples.

Image Credits: (l) ©National Geographic Magazines/Marc Moritsch/Getty Images

Consider what would happen to a population of beetles that were nearly wiped out due to a natural disaster, such as the population shown in Figure 14. The original population had high levels of genetic diversity. After the disaster, two smaller populations of beetles survived, but there was no gene flow between the populations. The descendants of founding population A would have a different gene pool from the descendants of population B. For example, founding population A had beetles with genes coding for black exoskeletons. The descendants of these individuals also had black exoskeletons. Founding population B, however, had no individuals with genes for a black exoskeleton, so this gene was lost in population B.

Gather Evidence How does the genetic variation of the new population compare to that of the old population? Use evidence to support your answer.

FIGURE 14: Genetic variation decreases when a small number of individuals colonize new areas.



The founder effect is genetic drift that occurs when a small number of individuals become isolated from the original population and colonize a new area. Figure 14 demonstrates genetic drift due to the founder effect in a beetle population. The founding populations each represent a distinct gene pool observed in the founding population. As a result, allele frequencies within the founding populations change from the original population reducing genetic variation.

Sexual Selection

Male peacocks have elaborate tails made of long, colorful feathers. These tail feathers not only make male peacocks easy targets for predators, they also make flying away from predators harder. Female peacocks, though, are a muted, brown color and do not possess long tail feathers like the males. These flashy colors and ornamental traits seem to be in contrast with what should have evolved from natural selection, so how did they evolve?

FIGURE 15: The winner of a fight increases his chances of mating with a female.

In general, mating is less costly to a male than a female. Males produce many sperm, so they can invest in mating without much cost. Females, on the other hand, produce a limited number of offspring. They tend to select males that will give their offspring the best chance of survival. This difference in reproductive costs can make females choosier than males about mates. Sexual selection occurs when certain traits increase reproductive success.

Prior to the mating season, male animals like deer, elk, and moose fight other males. The winner in this competition establishes his dominance over other males and his fitness to mate with the females in the population. This type of competition among male members for the right to mate is known as intrasexual selection.

The superb bird of paradise, like other species of birds of paradise, engages in courtship behavior that increases mating success by attracting females. Superb males have feathers on their backs that are not used for flying. During courtship, the male birds use the back and chest feathers to form a funnel-like structure around their heads. This posture highlights their bright-colored breast feathers. They also flick their feathers and dance. Other birds of paradise have bright colors, large plumes, and long tail feathers and perform dances to attract the attention of females.

FIGURE 16: The male superb bird of paradise has bright feathers and large plumes to attract females.

Intersexual selection is a form of sexual selection in which males display certain traits that attract females. Males involved in intersexual selection are often more brightly colored, have larger features, or have other characteristics to attract females.

In birds of paradise, long feathers, bright plumes, and courtship behavior are due to intersexual selection. These traits are costly to develop, so males who possess them are usually healthy and strong. Scientific data show that, in some species, bright colors indicate parasite resistance. Sick males may have muted coloring and likely do not possess characteristics attractive to females. Females are able to pick the males in the best condition or that have better genes for mating.

Collaborate With a partner, discuss what a female might learn about a male through his color, size, and ornamental features, like bright tail feathers.

Stability and Change

A population is stable and in genetic equilibrium when its genetic makeup does not change over time. Because the conditions that lead to this genetic stability are rare in the natural world, evolution occurs.

There are five mechanisms that can lead to evolution:

- Mutation can lead to the formation of new alleles. Mutations produce genetic variation.
- Natural selection affects populations, acting on traits that increase an individual's ability to survive and reproduce.
- Sexual selection selects for traits that give members of a population a competitive advantage in mating and reproducing.
- Genetic drift affects small populations and is caused by random events that affect the population.
- Gene flow occurs when individuals move in and out of populations. This movement introduces and removes alleles from the gene pool.

Explain Why is genetic drift more likely in small populations than in large populations? Consider the male ruffs from the beginning of this lesson. How could genetic drift or sexual selection explain the different types of males in the population? Use evidence from the lesson to support your claims.

Data Analysis

Antibiotic-Resistant Bacteria

Antibiotics are medicines used to kill disease-causing bacteria. Studies have shown that certain species of disease-causing bacteria evolved to be resistant to antibiotics. The Centers for Disease Control and Prevention (CDC) found that doctors were prescribing antibiotics when they weren't necessary. Additionally, patients were not taking their full antibiotic doses. Both practices have led to bacteria developing resistance against various antibiotics.

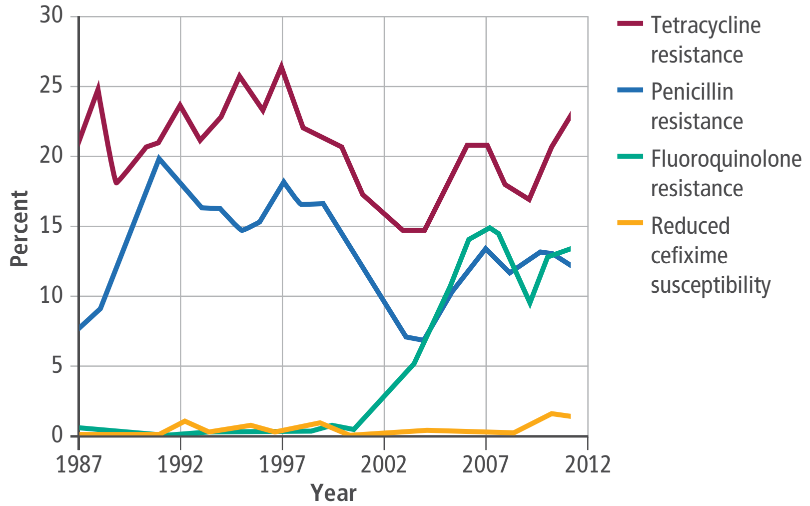
Consider a population of bacteria. In the population, most bacteria have genes that make them susceptible to antibiotics, but a very small percentage of the population do not have these genes. These bacteria are antibiotic resistant. When exposed to antibiotics, the bacteria population experiences the bottleneck effect. The bacteria in the population that are susceptible to antibiotics are killed. The remaining resistant individuals reproduce, passing on the resistance genes to their offspring. Eventually, the population consists of more antibiotic-resistant bacteria.

The bacterium *N. gonorrhoeae* causes the disease gonorrhea. This disease affects organs of the reproductive system, as well as parts of the urinary tract. If not treated, an affected person may lose the ability to produce offspring. The bacteria are transferred from one person to another through sexual activity.

N. gonorrhoeae has now developed varying levels of resistance to most antibiotics, including penicillin.

***N. gonorrhoeae* Resistance, United States, 1987-2011**

FIGURE 17: *N. gonorrhoeae* shows some level of resistance to many types of antibiotics.



Source: The Gonococcal Isolate Surveillance Project (GISP), quoted in "Antibiotic Resistance Threats in the United States, 2013" (CDC)

N. gonorrhoeae is also developing resistance to the drug cefixime. It is recommended that cefixime be used with other antibiotics, or not at all, so the bacteria do not become fully resistant to it.

Figure 17 shows resistance patterns of *N. gonorrhoeae*. This graph shows an increased resistance to fluoroquinolones around 2000. This can be attributed to the increased use of this antibiotic during this time. It also shows that the bacteria has been resistant to penicillin since the 1980s and continues to be resistant. For this reason, scientists need to continuously develop new antibiotics to treat gonorrhea. However, new antibiotics can lead to new resistances.

Data Analysis

Answer the following questions in your Evidence Notebook:

1. What happened to penicillin resistance from 1987 to 1990?
2. What type of natural selection is observed in antibiotic-resistant bacteria?
3. Make a model to show the changes in the population of bacteria over time as they are were exposed to antibiotics.

EXAMINING SELECTION | NATURAL SELECTION IN AFRICAN SWALLOWTAILS | RUNAWAY SELECTION | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 18: There are three types of male ruffs, and all can occur in a single population.

a An independent male

b A satellite male

c A female. Faeder males greatly resemble females.

Recall that there are three types of males in the ruff population. The dominant "independent" males are territorial and fight other independent males to attract females. The smaller "satellite" males do not fight. Satellites freely move between independents' territories and are able to mate with some females. The "faeder" males look like female ruffs. They generally mate with females sneakily while the other males are distracted or fighting.

Explain Refer to the notes in your Evidence Notebook to explain how three very different types of males evolved in a single population.

Scientists think that the independent males expend a lot of energy and incur the risk of being injured in a fight when establishing a territory to attract females. The independents (84 percent of the population) attract females by showing dominance.

Types that pay fewer of these costs also have evolved within the population. The satellites (14 percent of the population) mate with the females in the independent males' territories. Though independent ruffs may mate with more females, they are at risk of being injured in territorial fights and are more susceptible to predators because of their elaborate plumage and larger size. The faeders (1 percent of the population) are able to reproduce by sneaking into an independent male's territory and quickly mating with a female.

Interestingly, scientists have discovered that the behavior and physical traits that differentiate the three types are controlled at a single genetic location, a "supergene." Studies indicate that the faeders are a result of a chromosome inversion that occurred 3.8 million years ago. The satellite type was a result of a chromosomal rearrangement between the original sequence and the inverted sequence that happened about 0.5 million years ago. The differences in traits and behavior among these types allow them all to be successful and persist in the population.

CHECKPOINTS

Check Your Understanding

Use the following information to answer Questions 1-4.

In a population of 900 pea plants, 530 are homozygous purple, 250 are heterozygous purple, and 120 are homozygous white. Purple color (*P*) is dominant and white color (*p*) is recessive.

1. Determine the genotypic frequency in the population for *PP*, *Pp*, and *pp* individuals.
2. What is the total number of alleles in this gene pool?
3. What is the allele frequency of *P*? Express the frequency as a decimal rounded to the nearest hundredth.
4. What is the allele frequency of *p*? Express the frequency as a decimal rounded to the nearest hundredth.

Use the information in the table below to answer Question 5.

Color Variation	Frequency in Original Population (%)	Frequency in New Population (%)
Gray	15	45
Gray and white	60	20
White	25	35

5. The frequencies of a color trait among rabbits living in a mountainous area have changed over time. What type of selection most likely occurred?
   a. directional
   b. disruptive
   c. stabilizing
   d. sexual
6. Scientists observed a population of monkeys on an island. The monkeys were observed to have different finger lengths. Some monkeys had long fingers, some had short fingers, but the majority of them had finger lengths that were closer to the short finger length. Explain how this trait in the population of monkeys would evolve over time if tree branches on the island grew thicker. Would this be an example of stabilizing, directional, or disruptive selection?
7. Widowbirds are members of a bird species found in the southeastern part of Africa. The females have dull brown feathers and the males have black feathers, including tail feathers that measure an average of 41 centimeters long. Studies have shown that females prefer and choose to mate with males that have longer tails. Which outcome can be expected to occur in this scenario?
   a. Over time, there will be more males with 41 centimeters tails.
   b. Over time, there will be more males with tails longer than 41 centimeters.
   c. Over time, there will be more males with tails shorter than 41 centimeters.
   d. Over time, there will be more males with no tails.
8. Model how the bottleneck effect can lead to evolution by putting the following events in order.
   a. Many of the individuals die in the population.
   b. Population increases with less variation.
   c. A random event acts on a population.
   d. Surviving individuals reproduce.
9. Determine if the scenarios will likely result in an increase or a decrease in genetic variation over time. Copy and then complete the table below in your notebook by writing “increase” or “decrease” in the second column.

Scenarios	Genetic Variation within Individual Population
Mosquitos become resistant to pesticides.	
Arabian horses mate with wild horses.	
A population becomes lactose intolerant through mutation.	
A smaller body is selected for in cheetahs.	

MAKE YOUR OWN STUDY GUIDE

10. The Florida panther is a type of mountain lion. About a hundred years ago, Florida panthers scattered and mated with other subspecies of mountain lions in nearby populations.

a. Explain how the gene flow in this population would be affected by the introduction of the Florida panthers.

b. Would genetic variation increase or decrease in the mountain lion population?

11. Give an example of the way sexual selection can cause extreme phenotypes in a population.

Use the information in the table below to answer Question 12.

Trait	Frequency of Trait (%)	
Color Variation	Predicted Frequencies Using the Hardy-Weinberg Equation	Observed Frequencies after Three Generations
Large flowers	75	44
Medium flowers	10	22
Small flowers	15	34

12. Study the table to compare predicted and actual frequencies of flower size in a flower population. What conclusion is best supported by the data in the table?

a. The population is evolving.

b. The population's gene pool remained the same.

c. The population is in equilibrium.

d. The population selected for an intermediate trait.

13. Why must allele frequencies in a gene pool always add up to 100 percent?

14. Explain how the process of genetic drift occurs completely by chance.

15. What are the differences and similarities between natural selection and sexual selection?

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Changing allele frequencies can be an indication of the evolution of a population.

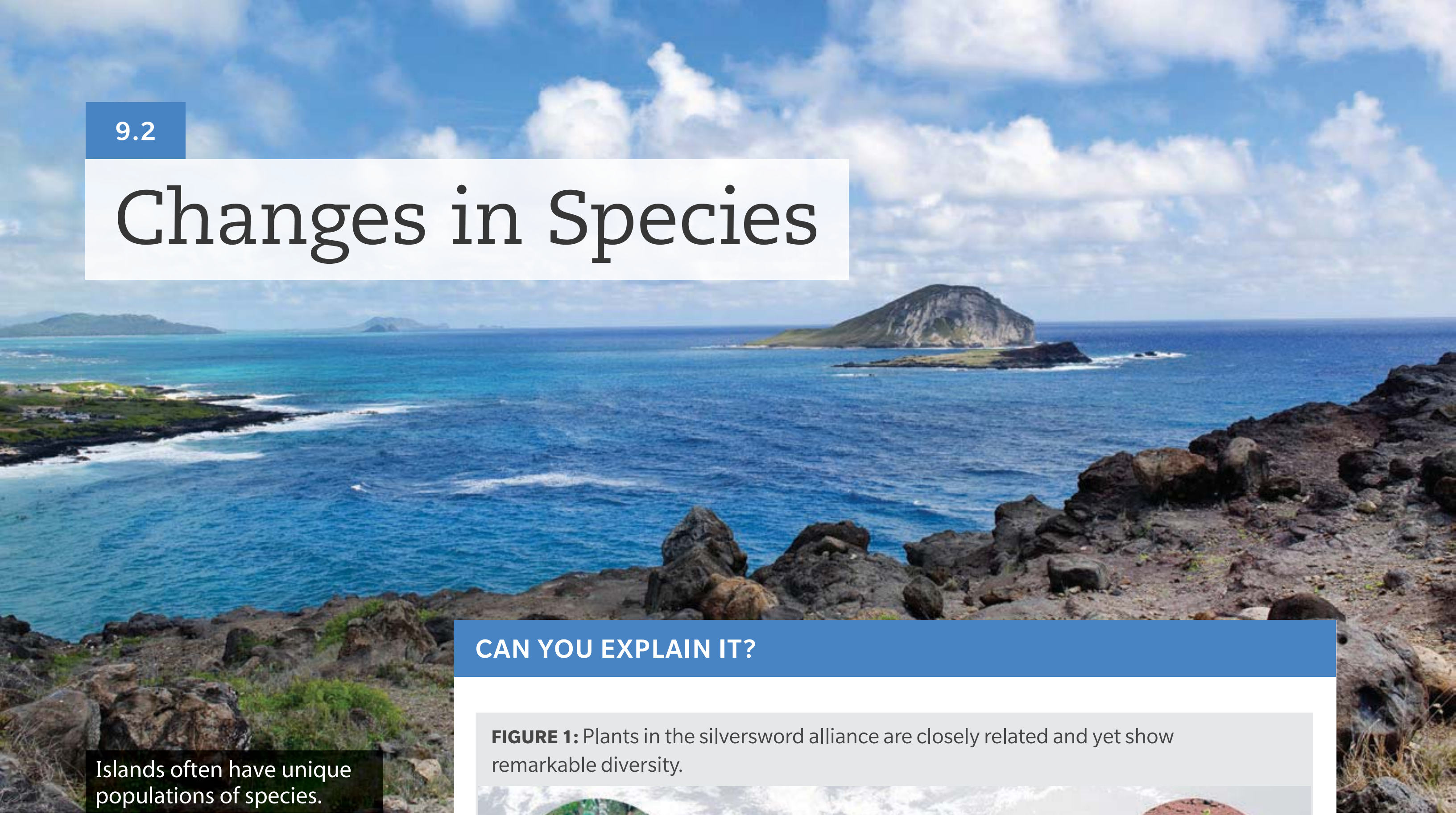
Selective pressures, such as competition and predation, can shift the distribution of traits in a population.

Small populations are more susceptible to genetic drift because large populations are able to lessen the impact of random events.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how the evolution of populations relates to the assumption that natural laws operate today as they did in the past and will continue to do so in the future.



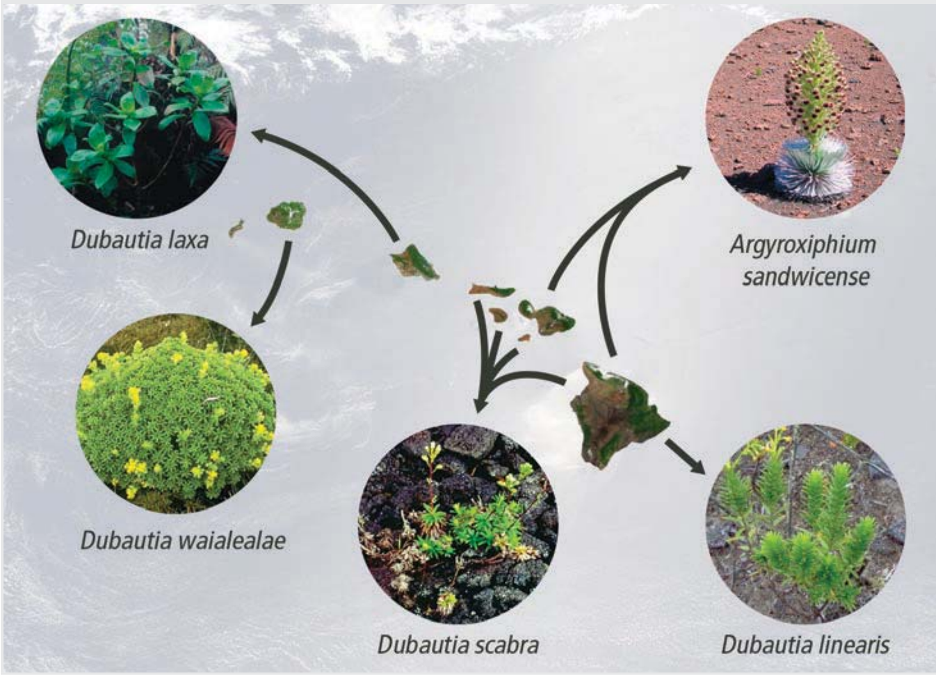
9.2

Changes in Species

Islands often have unique populations of species.

CAN YOU EXPLAIN IT?

FIGURE 1: Plants in the silversword alliance are closely related and yet show remarkable diversity.



Gather Evidence As you explore the lesson, gather evidence that supports the claim that changes in environmental conditions result in the emergence of new species over time and the extinction of other species.

If you were asked to compare the plants in Figure 1, you might note that each of them looks very different from one another. These plants are all members of the silversword alliance, a group of over 30 related species native to the Hawaiian Islands. Like other groups of related species, the silversword alliance shows huge variety in appearance even though the plants are closely related. In fact, all of the plants in this group are thought to be descended from a single tarweed species found in the dry shrublands of California and Mexico.

Predict These plants have a common ancestor. How did they develop different characteristics?

Image Credits: (t) ©W. Scott/Fotolia; (c) ©MODIS Land Rapid Response Team/Jacques Descloitres/NASA Goddard Space Flight Center; (tcl) ©Mark W. Skinner at USDA-NRCS PLANTS Database; (tcr) ©National Park Service, Hawaii Haleakala National Park; (bl) Photo by A. C. Medeiros, courtesy of Smithsonian Institution; (bc) (br) Photo by J. Price, courtesy of Smithsonian Institution

Mechanisms of Speciation

In general, a species is a group of similar organisms that can breed and produce fertile offspring. The millions of species that live on Earth today emerged over time, with each new species arising from an already existing species. This diversification of one species from another is supported by genetic, developmental, and anatomical similarities among species. In addition, geological and fossil evidence show how species have changed over time.

Collaborate Kaibab and Abert's squirrels live on opposite sides of the Grand Canyon. Though closely related, they do not share all of the same characteristics. How did these differences come about? Make a list with a partner to explain your reasoning.

FIGURE 2: These squirrels are closely related but have different characteristics.

a Kaibab squirrel

b Abert's squirrel

Speciation

Where do new species come from? Speciation is the rise of two or more species from a single existing species. Experiments can be used to model speciation. In one such experiment, an existing population of fruit flies, *Drosophila melanogaster*, was divided into two groups. One group was given maltose-based food and the other was given starch-based food. The goal of the experiment was to determine what changes would occur from the isolation of species and the presence of different food sources.

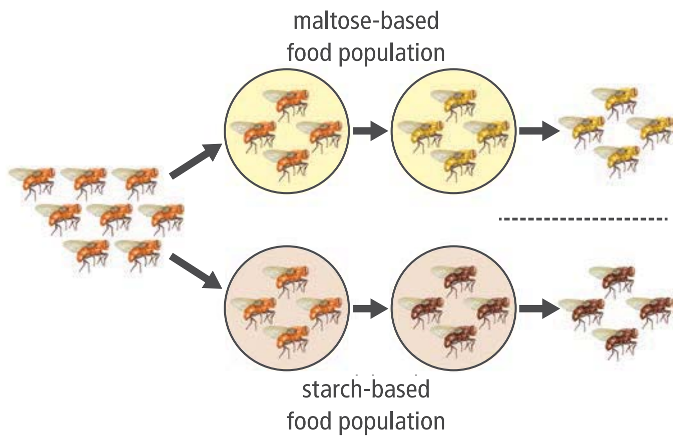


FIGURE 3: Changes in fruit flies can occur due to differing food sources.

Many generations later, the mating preference of the flies was analyzed. The scientists found that the flies raised on maltose-based food, called maltose flies, preferred to mate with other maltose flies. The flies raised on starch-based food, called starch flies, preferred to mate with other starch flies. However, cross-breeding between the two groups could still occur. This experiment shows a distinct mating preference and the beginning of reproductive isolation within a species. If the two groups of fruit flies were eventually unable to breed successfully, then speciation would occur.

Analyze What happened during the many generations that these flies were kept separated? How might this period of isolation have contributed to the mating preferences shown?

Reproductive Isolation

Predict How can reproductive isolation lead to speciation?

If gene flow is interrupted between two populations of the same species, the populations are said to be isolated. Isolated populations are prevented from mating and exchanging genes. This means natural selection acts upon a different gene pool for each population. Different mutations will accumulate, different variations will be selected for or against, and eventually adaptations will occur that prevent mating between the two populations. Isolated populations that are in different environments, and therefore exposed to different selective pressures, will diverge from one another more quickly. It becomes more likely that reproductive isolation will occur as the two populations become more different. Even isolated populations in similar environments can undergo speciation if genetic drift takes the two gene pools in opposite directions.

Reproductive isolation occurs when members of different populations can no longer mate successfully. Sometimes members of the two populations are not physically able to mate with each other. In other cases, they cannot produce offspring that survive and reproduce. Reproductive isolation is the final step of becoming a separate species.

Physical Separation

An isthmus is a strip of land with sea on both sides that links two larger landmasses. The Isthmus of Panama formed through a combination of volcanic island formation and uplift of the ocean floor. These two geological factors made solid land where there was once an open passage between the Atlantic and Pacific oceans.

Collaborate With a partner, make a list of other physical barriers that can lead to geographic isolation as happened with snapping shrimp.

Around 3 million years ago, the isthmus closed in, permanently separating populations of snapping shrimp. Once separated, each population of shrimp adapted to a different environment and became genetically different. Over time, the groups became different enough to be reproductively isolated and speciation occurred. The physical separation of two or more populations can lead to speciation through geographic isolation.

FIGURE 4: Speciation in snapping shrimp occurred due to geographic isolation.

Source: Carl Hansen and Nancy Knowlton, 2001, The Smithsonian Institution, as quoted by PBS, Evolution Library; Arthur Anker, 2016, Smithsonian Newsdesk

Behavior and Timing

Behavioral isolation is caused by differences in courting or mating behaviors. If two populations do not use the same courting or mating behaviors, then mating, and therefore gene flow, between the two groups is unlikely to occur. When gene flow is interrupted, natural selection acts upon the different gene pools. Reproductive isolation and speciation may eventually occur.

Male songbirds sing to defend their territories and attract mates. An eastern meadowlark and a western meadowlark are shown in Figure 5. As you can see, they look almost the same. The major difference between these species is their songs. The eastern and western meadowlarks use completely different songs to attract mates. This means eastern meadowlark males cannot successfully attract western meadowlark females, and western meadowlark females cannot give eastern meadowlark males the correct breeding cues. The two species have become behaviorally isolated.

FIGURE 5: The eastern meadowlark and western meadowlark look almost identical but use different songs to attract mates.

Explore Online

a Eastern meadowlark

b Western meadowlark

The red-legged frog and the yellow-legged frog are closely related. The development of mating seasons that occur at different times caused these species to become temporally isolated. Temporal isolation occurs when timing prevents reproduction between populations. Red-legged frog populations breed from January to March while yellow-legged frog populations in the same area breed from late March to May. Speciation from a common ancestor occurred as the overlap in mating seasons shrank. The flow of genes between the two groups also shrank and the two groups diverged.

FIGURE 6: Red-legged frogs and yellow-legged frogs have different mating seasons.

a Red-legged frog

b Yellow-legged frog

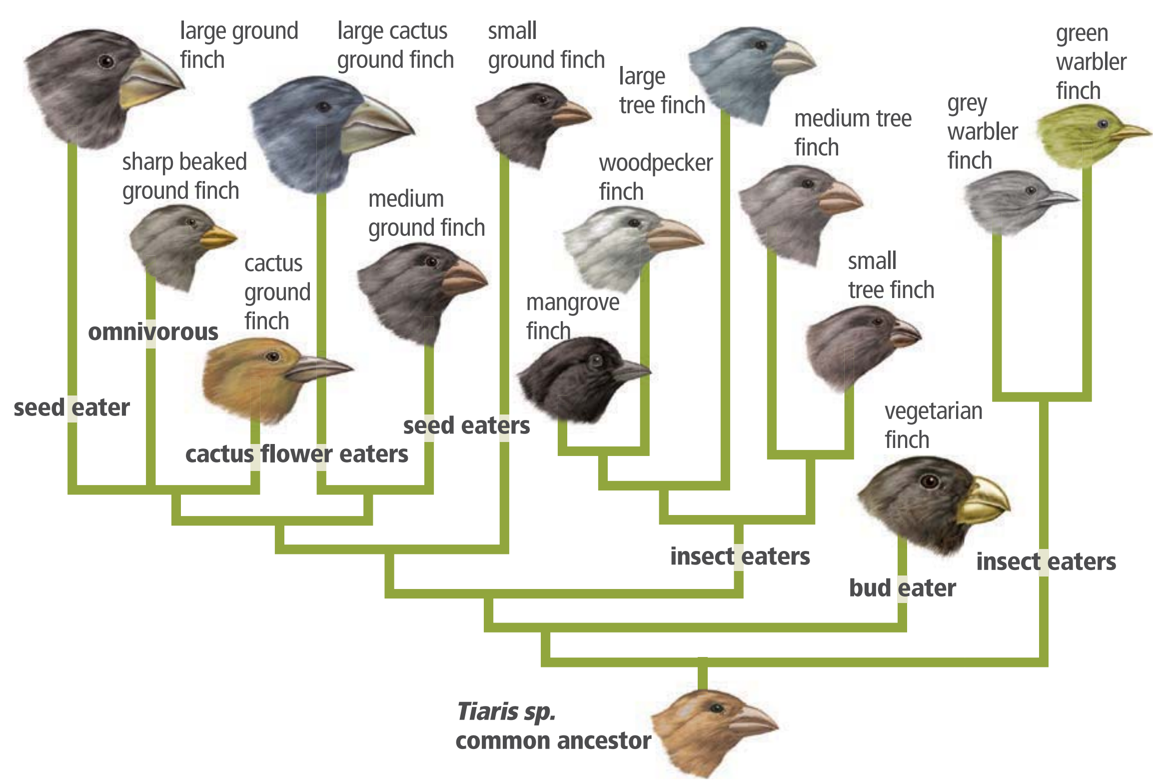
Data Analysis Draw a graph to explain why different mating seasons were likely the cause of red-legged frog and yellow-legged frog speciation.

Image Credits: (tl) ©Sarah Jessup/Shutterstock; (tr) ©William Leaman/Alamy; (bl) ©Chris Mattison/Alamy; (br) ©Vibe Images/Fotolia

Adaptive Radiation

Speciation through the diversification of one ancestral species into many descendant species is called adaptive radiation. Adaptive radiation typically happens quickly as species benefit from less competition, new niches, or specializations that give a selective advantage.

FIGURE 7: The diverse finches of the Galápagos Islands came from a common ancestor.



Darwin's finches are an example of adaptive radiation that occurred on an island system. The 14 species of finch found on the Galápagos Islands came from a common ancestor. The descendants have diversified and specialized to take advantage of different niches. The finch species minimize competition among themselves by specializing in different food sources. For example, populations of finches with larger beaks can crack harder and larger seeds. Populations of finches with smaller, pointy beaks can catch insects. Darwin's finches are a classic example of changes in environmental conditions driving the adaption and expansion of species.

Analyze What factors would support the idea that adaptive radiation occurred in the finches of the Galápagos Islands?

For adaptive radiation to take place, there must be adaptation by a species that leads to speciation. For example, dinosaur extinctions led to more resources and fewer predators for mammals. The open niches left by dinosaurs may have been the trigger for adaptive radiation of mammals after dinosaurs became extinct. Mammals diversified and adapted to new niches producing new species in many cases. This is an example of a catastrophic change in the environment leading to the expansion of an entire family of species.

Explain Which type of reproductive isolation could have led to the speciation of plants in the silversword alliance? Use evidence to support your claim.

Expansion of Species

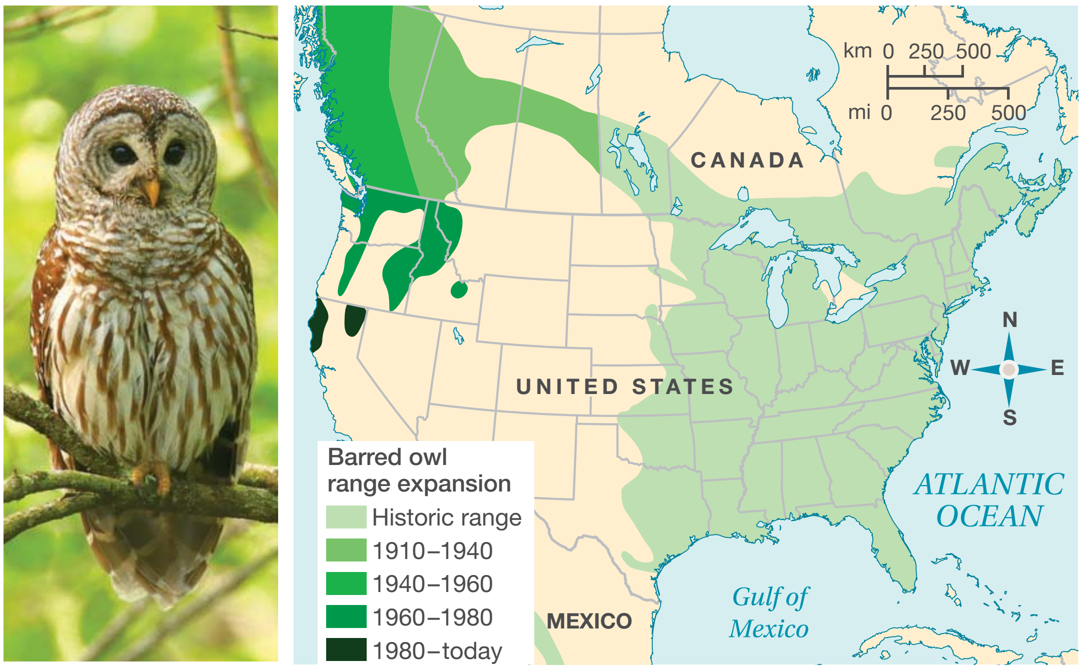
Natural environmental changes such as droughts can lead to the expansion of a species' range. For example, a long-lasting drought can change an ecosystem to make it more suitable for plants adapted to dry conditions. These plants could expand into the ecosystem and outcompete plants that are less well-adapted to the dry conditions. Humans can also cause environmental changes that lead to the expansion of species.

Increasing Populations

Historically, the barred owl lived in the eastern United States. The Great Plains served as a barrier to the westward expansion of many species that lived in forests, including the barred owl. The Great Plains were maintained in part due to regular burning by Native Americans and the disturbance caused by massive herds of buffalo. Much has changed in these ecosystems over the past 100 years. The plains are no longer burned, herds of buffalo no longer shape the landscape, wildfires are put out, and the climate has warmed. These environmental changes are potential causes for the barred owl range expansion across British Columbia in Canada into Washington, Oregon, and northern California in the Pacific Northwest region of the United States. The warming climate could have made Canada's northern boreal forests more suitable for the barred owl. The owls may have used this habitat as a bridge to reach the Pacific Northwest. Another possibility is that the barred owl worked its way across the plains as settlers planted trees and encouraged tree growth along streams. The owls could have used these intermediate habitats to journey from eastern forests to western forests.

Gather Evidence Why might it be easier for plants than animals to expand their ranges?

FIGURE 8: Barred owls benefited from environmental changes that increased suitable habitat.



Source: The University of Minnesota and *The Oregonian* as quoted by Bryant, Peter J., "Draft Recovery Plan for the Northern Spotted Owl" 26 August 2016 <http://darwin.bio.uci.edu/~sustain/issueguides/Northern Spotted Owl/index.htm>.

Climate Change and Species Expansion

Climate change is affecting different areas in different ways, from rising sea levels to an increase in average global temperature. As areas warm, they may become more suitable for organisms that were previously kept out due to uninviting habitat conditions. For example, polar bear habitat in northern Canada was once too cold and inaccessible for grizzly bears. As this area warms, it becomes more suitable habitat for grizzly bears. Because of these environmental changes, grizzlies have expanded their range into polar bear habitat. This movement could lead to a wider expansion of grizzly bear populations in the long term.

Language Arts Connection Using library and Internet resources, research the potential long-term effects of grizzly bears moving into polar bear habitat. Is this a problem? Write a short magazine-style article detailing your findings and position. Use images, graphs, and data to support your claims.

FIGURE 9: Grizzly bears have expanded their range into polar bear habitat.

Analyze How can climate change lead to the expansion of a species?

The expansion of species into new territories can also lead to hybridization. Hybridization occurs when two distinct, but closely related, species are able to successfully mate together. Sometimes, the features shown by the hybridized species fall within the range of characteristics shown by one or both of the original populations. Over time, as the two species continue to interact with one another, they may become a single species.

In the case of grizzly bears, as climate change lets them expand their territories northward, they are interacting more and more with polar bears. Because both bear species are closely related, they are able to successfully mate and produce viable offspring. Some scientists worry that this inbreeding may result in the disappearance of the polar bear as a separate species, particularly as it is already being threatened by habitat loss due to climate change.

Explain How would population expansion most likely occur in the silversword alliance, assuming these plants underwent adaptive radiation?

Extinction of Species

Just as birth and death are natural events in the life of an individual, the rise and fall of species are natural processes of evolution. The elimination of a species from Earth is called extinction. Extinction often occurs when a species as a whole cannot adapt to a change in its environment.

FIGURE 10: The northern spotted owl is native to the Pacific Northwest region of the United States.

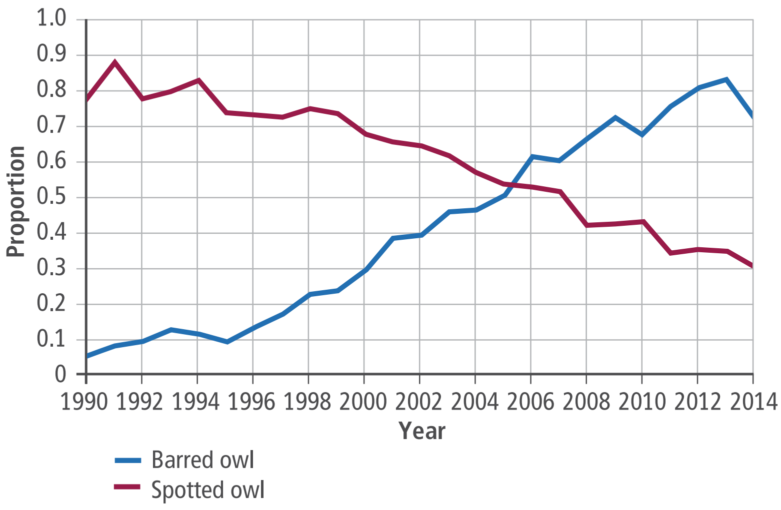
Causes of Extinction

Let's return to the example of the barred owl territory expansion. The expansion has been good for the barred owl, as seen by its increasing success and growing population numbers. Unfortunately, the appearance of the barred owl in the forests of the Pacific Northwest has negatively impacted a closely related species, the northern spotted owl. This bird is listed as a threatened species under the Endangered Species Act. Historically, the northern spotted owl has been most threatened by habitat loss due to logging, land development, and natural disasters. Now, the small amount of northern spotted owl habitat that remains is being invaded by the barred owl.

Barred owls and northern spotted owls use the same habitat in many of the same ways. Both species use old growth forests for food and nesting. Advantages of the barred owl over the northern spotted owl include a larger body, more aggressive behavior, smaller overall territory needs, the hunting of a wider range of prey, and more breeding success. In short, the barred owl is outcompeting the northern spotted owl. If the northern spotted owl is driven from its entire range, then the species could become extinct.

Comparing Owl Populations

FIGURE 11: The northern spotted owl is being displaced by the larger barred owl.



Source: Forsman, Eric D. et al. Demographic characteristics of spotted owls in the Oregon Coast Ranges, 1990-2014.

Source: Smithsonian Magazine, 2009

Collaborate Discuss with a partner how the expansion of a species into a new habitat might affect the native species that are already living there.

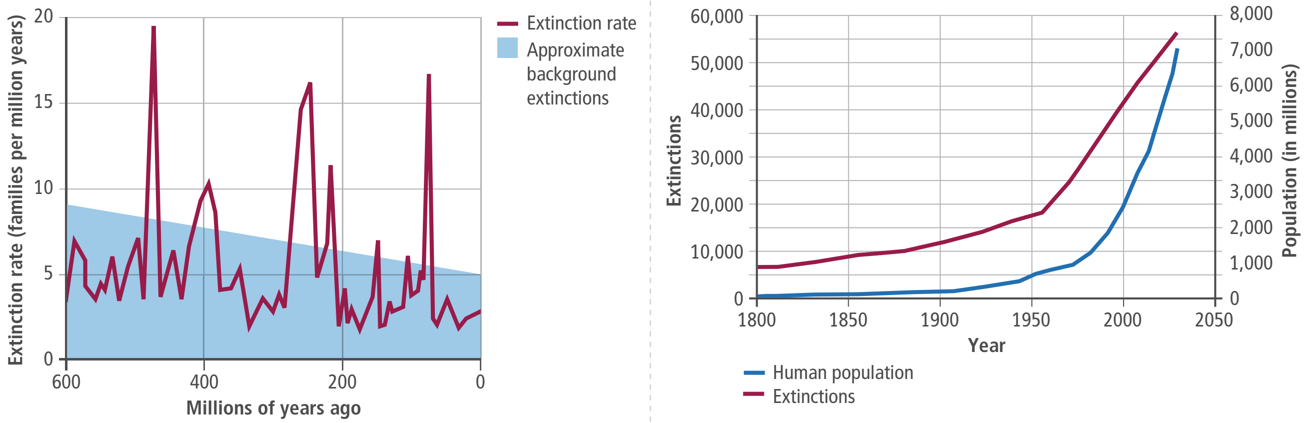
Extirpation, or local extinction, occurs when a species no longer exist in a specific portion of their range but still can be found elsewhere. For example, wolves have been extirpated from much of their historic range due to overhunting and habitat loss. Extinctions have occurred throughout time as shown in the fossil record. Natural events such as droughts, volcanic eruptions, and floods can cause extinctions if species cannot adapt to the new environment.

Background Extinctions and Mass Extinctions

Extinctions that occur continuously but at a very low rate are called background extinctions. These extinctions occur at roughly the same rate as speciation. This type of extinction typically affects one or a few species in relatively small areas. Background extinction is common and occurs due to factors such as disease, loss of habitat, or loss of a competitive advantage. Mass extinctions are more rare, but have a larger impact on Earth's biodiversity. Entire orders or families may be wiped out by mass extinction events. Mass extinctions are thought to occur suddenly in geologic time, usually because of a catastrophic event such as an ice age or asteroid impact. An example of a mass extinction is the K-T event that occurred at the end of the Cretaceous period 65 million year ago. A large meteor that crashed on Earth triggered this mass extinction. The aftermath of the meteor strike caused the extinction of 70 percent of Earth's species. The fossil record confirms that there have been at least five mass extinctions in the past 600 million years.

Cause and Effect

FIGURE 12: Comparing Extinction Rates



Source: University of California, Berkeley

Source: Scott, J.M. 2008. *Threats to Biological Diversity: Global, Continental, Local*. U.S. Geological Survey, Idaho Cooperative Fish and Wildlife, Research Unit, University of Idaho.

a Extinction Rates Through Time

b Human Population Growth and Extinction Rates

Analyze Use the graphs in Figure 12 to answer the following questions:

1. What patterns or trends are shown in the first graph (a)? What is the cause of these patterns?
2. What patterns or trends are shown in the second graph (b)? What is the cause of these patterns?
3. Is there a relationship between the two graphs? Explain your answer.

Climate Change and Extinction

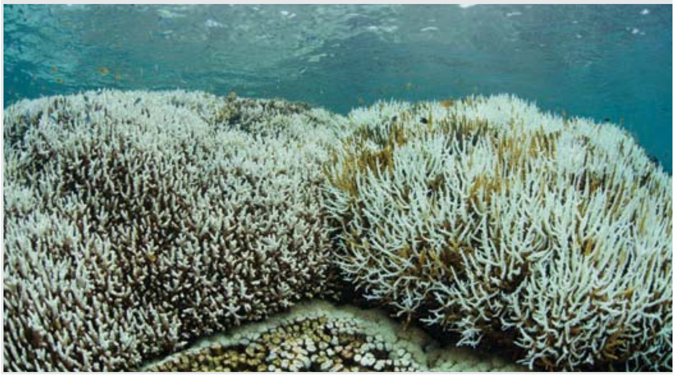
Many scientists think that Earth is currently experiencing a sixth mass extinction. The sixth mass extinction is characterized by extinction rates that are 1000 to 10,000 times the background rate. The current extinction event is caused almost entirely by human behaviors such as the burning of fossil fuels, destruction of habitat, and introduction of invasive species.

Analyze What is the cause-and-effect relationship between humans and the sixth mass extinction? Describe the relationship in terms of the growing human population and the causes and effects of climate change.

Climate change is caused by the release of large amounts of greenhouse gases—such as carbon dioxide—into the air, mostly from the burning of fossil fuels. Climate change is causing rapid changes to environments, from increasing temperatures to rising sea levels. Some species may find an increase in suitable habitat due to climate change. Other species may go extinct if their populations cannot adapt quickly enough to the changing environmental conditions. Corals are an example of a group of species that are being negatively affected by climate change.

Increasing Sea Temperature

FIGURE 13: Coral Bleaching



Coral bleaching is a stress response in corals. When conditions are poor, the corals lose the symbiotic algae living inside of them. The photosynthetic algae are the corals' main source of food. Without the algae, the corals weaken and turn white. Rising sea temperatures are the leading cause of bleaching events on coral reefs. Other causes include pollution, increased intensity of sunlight, and extremely low tides.

Ocean Acidification

Ocean acidification occurs when carbon dioxide is absorbed by seawater. The reaction between carbon dioxide and seawater also uses dissolved carbonate ions, which results in a decreased concentration of carbonate ions in the water. Many corals need carbonate in the form of calcium carbonate to build their skeletons. Coral reef growth will decline without enough carbonate for skeleton formation. If reef growth is slower than reef erosion, the reef could eventually stop functioning.

Extreme Weather Events

Many coral reefs are located in areas with extreme weather events such as hurricanes. The reef structure and species have adapted to recover after storms, though the recovery period can take a long time. It is predicted that climate change will increase the frequency and intensity of severe storms in some areas. Corals affected by more frequent storms may be unable to maintain reef structures. The increasing effects of coral bleaching, ocean acidification, and extreme weather present a bleak outlook for coral reefs in the future.

Explain What might happen if a species that is well adapted to lower pH and higher temperatures was introduced to coral reefs in the Hawaiian Islands?

Language Arts Connection

Patterns in Evolution and Speciation

FIGURE 14: The stinging ant *(Pseudomyrmex ferrugineus)* and acacia are an example of coevolution.

Species interact with each other in many different ways. For example, they may compete for the same food source or be involved in a predator-prey relationship. Most of these interactions do not involve evolutionary changes. However, sometimes the evolutionary paths of two species become connected.

Coevolution

The process of coevolution occurs when two or more species evolve in response to changes in each other. These relationships might be mutually beneficial, or they might be good for one species, but bad for the other, such as predator-prey or parasite-host relationships.

Many types of flowers and pollinators have coevolved to maximize pollination success for the plants and nectar capture for the pollinators. The plant-pollinator dynamic is typically mutually beneficial. The plants gain the pollination necessary for reproduction and the pollinators gain a food source. For example, the hawk moth has an especially long tongue that lets it drink from the narrow, nearly foot-long structure of a star orchid that holds the flower's nectar.

The bullhorn acacia is a plant species found throughout Central America that has branches covered in hollow thorns. Although the thorns protect the plant from being eaten by large animals, small herbivores such as caterpillars can fit between them. A species of stinging ants (*Pseudomyrmex ferrugineus*) is a key part of the plant's defense against these smaller predators. As shown in Figure 14, these wasp-like ants live inside the plant's thorns and feed on its nectar. The ants protect the plant by stinging animals that try to eat the leaves. In turn, the acacia plant provides the ants with both the shelter and food resources they need to survive.

The relationship between the acacia and the ants is much more than a simple cooperation between two species. The acacia and the ants share an evolutionary history. The hollow thorns and nectar-producing leaves of the acacia and the stinging of the ants have evolved due to the beneficial relationship between the two species. Relatives of these species that are not involved in this type of relationship do not have these same traits.

Evolutionary Arms Race

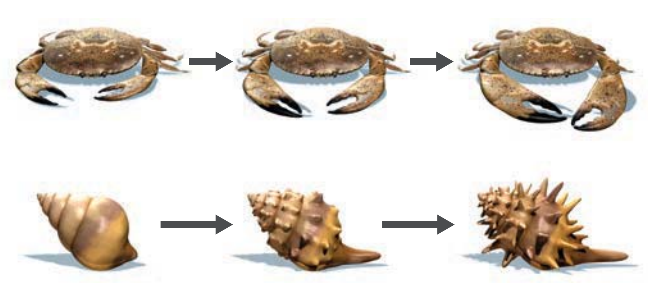
Coevolution does not just occur in species that share a beneficial relationship. It also occurs in two species that have a competitive relationship with one another. These competitive interactions can lead to "evolutionary arms races," in which each species responds to pressure from the other through a series of adaptations over the course of many generations.

For example, many plants produce defense chemicals to discourage plant-eating species from nibbling on them. Natural selection then favors herbivores that can overcome the effects of the chemicals. After many generations, some herbivore species may build up a level of resistance to the chemicals and are again able to safely eat the plant without getting sick. Natural selection then favors plants that have evolved even more potent chemicals to thwart their herbivore predators.

One researcher is using a mustard plant and a fruit fly relative to model coevolution in insects and plants. The research shows that the flies use the plants for all stages in their life cycle. The plant has developed proteins that cause the digestive tract in the flies to malfunction. Now it's up to the fly population to develop a resistance to this latest defense mechanism.

Arms races can be seen in animals as well, as shown in Figure 15. Crabs are predators that feed on snails as their prey. This makes a selective pressure for the snails to develop spines and a harder shell as a defense from crabs. As a result, the crabs then develop bigger claws and more powerful jaws to break into the harder shells. This pattern in speciation continues as evolution is influenced by evolution in another species.

FIGURE 15: Evolutionary Arms Race



Patterns in Speciation

Speciation often occurs in patterns, including gradualism and punctuated equilibrium. Gradualism is the steady, gradual change of species as mutations slowly give rise to variations and adaptations. Gradualism is closest to the type of evolution predicted by Charles Darwin that supports his ideas of descent with modification. That is, each generation is slightly different than the last, individuals with increased fitness preferentially breed, and advantageous alleles slowly build in a population. These small changes add up to become the wide variety of characteristics seen among species on Earth today.

Punctuated equilibrium is characterized by long periods of no change interspersed with short periods of big change. Punctuated equilibrium is often tied to speciation events, such as a natural disaster, in which species are forced to adapt or die off. For example, the isolation of a small population in a new environment with unique selective pressures can drive short bursts of evolution as beneficial and harmful traits are selected for or against.

A new species can arise through either gradualism or punctuated equilibrium. Some lines of evolution show gradualism patterns and some lines of evolution show punctuated equilibrium patterns. Gradualism occurs at a constant background rate, much like the rate of background extinction. Punctuated equilibrium occurs irregularly and is more intense, much like mass extinctions.

Language Arts Connection Does evidence support the claim that species can evolve through either gradualism or punctuated equilibrium?

Find support for the information given in this text by researching and finding evidence of gradualism and punctuated equilibrium in Earth's history.

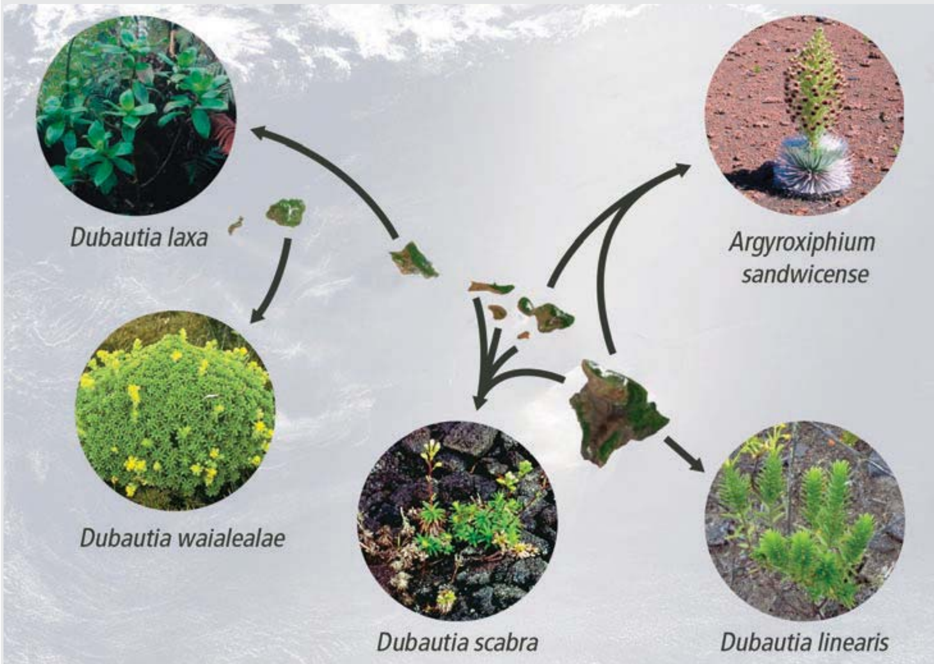
Prepare a one-page blog post that analyzes how two different species evolved (one through gradualism and one through punctuated equilibrium), and include an image that represents the pattern of speciation each species experienced.

CAREER: BIOINFORMATICS | MIMICRY | HYBRIDIZATION | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 16: Plants in the silversword alliance are descendants of a common ancestor.



The silversword alliance in the Hawaiian Islands is the product of the adaptive radiation of a tarweed ancestor. Each species in the silversword alliance is adapted to use a particular ecological niche. The radiation has caused extreme differences in the characteristics of each plant even though they are all very closely related.

Explain The plants in the silversword alliance have a common ancestor. Refer to the notes in your Evidence Notebook to explain how they developed different characteristics. In your answer, consider how changes or differences in the environment affect the emergence and disappearance of species.

Scientists think that this plant family came from a species similar to Muir's tarweed. This alpine shrubland species is found in California and Mexico. It has barbed fruits, and scientists think that it might have been carried to Hawaii by a bird. Over the course of millions of years, this single ancestral species evolved into over 30 separate species.

Three distinct lines of genetic evidence—including analyses of nuclear ribosomal DNA, chloroplast DNA, and a comparison of two specific developmental gene sequences—support the idea that this group of plants came from a mainland ancestor. Because there were so few species that originally colonized the newly formed Hawaiian Islands, there were plenty of habitats open to new species. Over time, the original tarweed species adapted to the conditions in these different environments, leading to a diversification of characteristics. Each plant is well adapted to its habitat as shown by their diverse sizes and shapes, ranging from small shrubs and mat-like formations to large trees and vines.

CHECKPOINTS

Check Your Understanding

1. Two tree species that grow on the Monterey Peninsula in California are very closely related. However, they have different pollination periods. Which type of reproductive isolation do these two tree species exhibit?
   a. adaptive radiation
   b. geographic isolation
   c. temporal isolation
   d. physical isolation

2. What environmental changes caused by climate change may be leading to the extinction of corals? Select all correct answers.
   a. extreme weather
   b. air pollution
   c. ocean acidification
   d. rising sea temperature

3. What adaptations in an isolated population would likely contribute to speciation? Select all correct answers.
   a. higher-pitched alarm call
   b. adoption of daytime feeding over nighttime feeding
   c. female enzyme targets eggs fertilized by individuals outside of the isolated populations
   d. development of different sexual anatomy
   e. higher temperature range tolerance

4. Why are island systems favorable to adaptive radiation?

5. How can extinctions and expansions occur in the same habitat? Explain your answer.

6. Give examples of how climate change may lead to the emergence, expansion, and extinction of species.

7. Draw a map that shows a parent population, a geographically isolated population, a behaviorally isolated population, and a temporally isolated population of the same species.

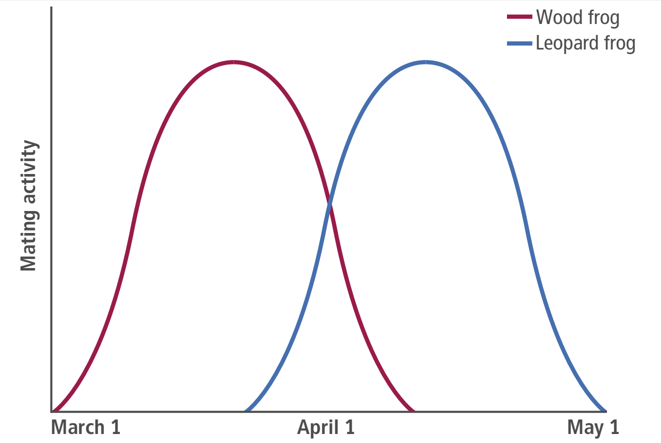
8. What are some of the causes of background and mass extinctions?

9. What process keeps the number of total species on Earth from growing exponentially through speciation?

10. Use the following words to complete this statement: *adapted, common ancestor, niches*
    A species of lizard arrived on an island after a big storm. The population expanded into all of the empty _________ on the island. Speciation occurred as populations _________ to different environments. Over 20 descendant species trace their lineage back to a _________.

Use the graph in Figure 17 to answer Question 11.

FIGURE 17: Reproductive Isolation



11. Wood frogs and leopard frogs are found in the same ecosystems, but they do not interbreed. Use evidence from the graph to explain what type of reproductive isolation these frogs exhibit.

MAKE YOUR OWN STUDY GUIDE

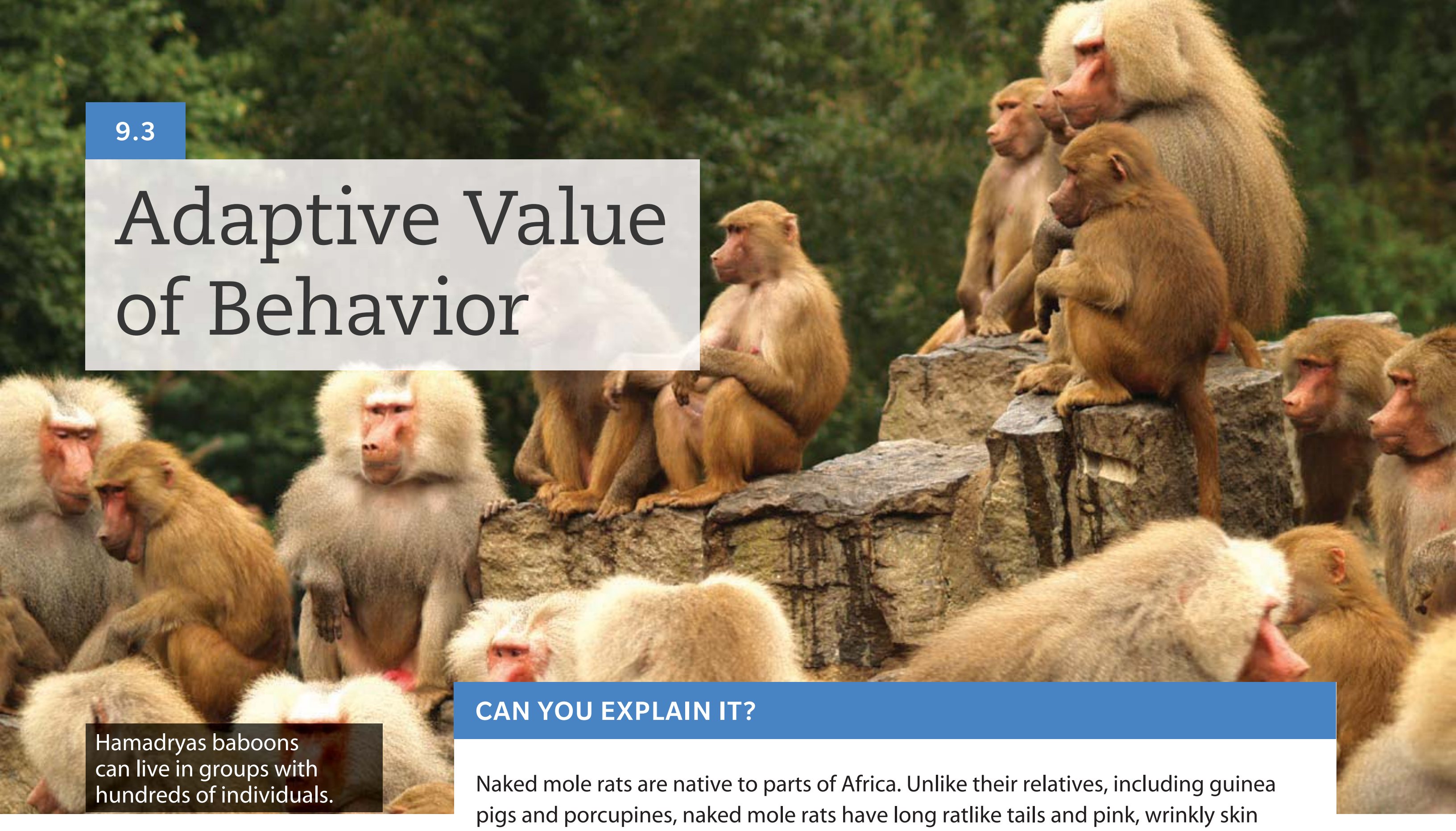
In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Changes in the environment can lead to the emergence of a new species, the expansion of some species, and the extinction of some species.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how cause and effect is demonstrated by the sequences of events that lead to speciation, expansion, and extinction.



9.3

Adaptive Value of Behavior

Hamadryas baboons can live in groups with hundreds of individuals.

CAN YOU EXPLAIN IT?

Naked mole rats are native to parts of Africa. Unlike their relatives, including guinea pigs and porcupines, naked mole rats have long ratlike tails and pink, wrinkly skin that is nearly hairless. They spend almost their entire lives in darkness, living in underground community burrows. With an average 30-year life span, naked mole rats live longer than any other rodent.

FIGURE 1: A colony of naked mole rats has a single queen and many workers.

Naked mole rat communities are organized in caste systems. A caste system places people or organisms in groups according to their jobs or roles in society. The two primary groups in a naked mole rat colony are reproducers and non-reproducers. Typically, a colony has one breeding female—the queen—and a few breeding males.

The non-reproducers, both male and female, will never mate. They are the workers of the colony. They carry food, build nests, clean, dig tunnels, and care for the queen and her young. The significantly larger queen steps over the workers as she moves about the burrow, using chemical odors to establish her dominance.

Gather Evidence As you explore the lesson, make a list of questions you have about the social system of the naked mole rat. Return to your list throughout the lesson.

Predict How could a population, such as the naked mole rats, evolve to the point where not all individuals reproduce?

Evolution of Behavior

FIGURE 2: Normally motionless, this sea anemone will swim away when it detects a sea star.

Explore Online

a Sea Star, *Dermasterias imbriacata*

b Sea Anemone, *Stomphia coccinea*

The sea anemone, *Stomphia coccinea*, has no brain or spinal cord and usually sits motionless. Yet, when it comes in contact with the sea star, *Dermasterias imbriacata*—its predator—the anemone detaches itself from its perch and swims away to safety. At other times, with other organisms, the anemone will not swim away.

Predict How does the sea anemone know when it comes into contact with a sea star versus some other object?

Responsive Behavior

The environment of every organism constantly changes. In order to thrive, organisms, such as the sea anemone, must respond to these changes. Anything that triggers a response is called a stimulus (*pl. stimuli*). An internal stimulus triggers a response to a change in an organism's internal environment, such as an infection. An external stimulus is any change in the external environment, such as contact with a predatory sea star, that causes a response.

Sense organs have specialized cells with receptors that detect changes in the environment and communicate information through nerves to the brain. The brain then sends a message back to the appropriate system telling it how to respond. This works well in organisms with complex nervous systems. However, this feedback mechanism also works in organisms such as the anemone, which only has a network of neurons with no centralized brain. Receptor cells on the outer surface of the anemone detect an external stimulus, which elicits an escape response.

Model Draw a model of the processes that occur when you interact with an internal or external stimulus, such as touching something very hot.

The sea anemone in Figure 2 never learned to swim away from the sea star, but it still knows to move to safety. This is an example of an innate behavior, sometimes called an *instinctive behavior*. Innate behaviors are passed from generation to generation without learning. An innate behavior is performed correctly the first time an animal tries it, even when the animal has never been exposed to the stimulus that triggers the behavior.

Innate behaviors are typically found where mistakes can have severe consequences. A sea anemone that does not swim away from the sea star, *Dermasterias imbriacata*, may be attacked. By having set reactions to particular stimuli, animals can automatically respond correctly in a life-or-death situation.

Function of Behavior

Collaborate With a partner, discuss how innate behaviors help organisms maintain homeostasis.

A lizard sunning itself on a rock is likely not just relaxing. If the rock becomes shaded, the lizard will shift its position to a warmer part of the rock. These behaviors actually help the lizard regulate its internal body temperature. Too hot? No problem. The lizard simply moves to a shadier spot. This behavior explains how ectotherms interact with their external environment to control their internal body temperature.

Maintaining a balanced internal state, or homeostasis, is critical to the health and functioning of an organism. When your internal temperature is below a normal temperature of 37 °C (98.6 °F), your body responds by shivering to produce heat. This is a biological response to an internal stimulus. Behavioral responses to the environment also help organisms maintain homeostasis. These responses are often movements or reactions that will help support a balanced state, increasing the chance of survival.

Cause and Effect

FIGURE 3: Red crabs migrate during mating season.

Migration

To survive and reproduce, animals need water, food, and shelter. For many species, this requires individuals to move from one location to another or migrate. Each species has one or more triggers that cue migration. Certain species of birds often migrate from one area to another in a seasonal pattern. Each season brings changes in temperature, availability of food, and length of day.

Some migration cues are biological. In some species, depletion of energy reserves may signal a need to travel to available food sources. In others, changes in hormone levels or reproductive life cycles trigger mass movements. The breeding ritual of the red crabs of Christmas Island starts at the beginning of the rainy season. The crabs must migrate at this time because their eggs must be released in the sea before sunrise during the last quarter phase of the moon.

Predict According to what you know about natural selection and evolution, how does a behavior evolve, such as mass migration of a species, where all individuals respond in the same way at the same time?

FIGURE 4: A Swarm of Locusts

Weighing the Costs of Behavior

Every behavior has benefits and costs. A swarm is a large, dense group of animals, such as insects or birds. A swarm offers many advantages to living and traveling. Swarms confuse predators, which protects individual members. A swarm also may be better at finding food than an individual.

A swarm has disadvantages too. The size of a swarm can actually attract predators, leaving individuals on the outer edges of the swarm particularly at risk. A group with more individuals requires greater resources, which must be shared.

Gather Evidence When would swarming behavior be beneficial and when would it be too costly? How might a behavior such as swarming evolve among species?

Costs of Behavior

Behavioral costs can be measured in terms of energy, risk, and opportunity.

Energy costs describe the difference between the energy used in carrying out an activity and the energy used if the individual had done nothing. For example, it takes energy for a lizard to move from a shady spot to a sunny spot. However, it is worth that energy cost in order to maintain body temperature.

Risk costs are the increased chance of being injured or killed by carrying out a certain behavior versus doing nothing. Consider the wolves in Figure 5. Wolves risk injury or even death by fighting with other wolves. However, they may win access to mates or better territory if they win. Sometimes, the benefits outweigh the risks.

Opportunity costs result when an animal spends time doing one behavior and loses an opportunity to do a different behavior. For example, when a songbird defends its territory from rivals, it is using time that could have been spent foraging or mating.

FIGURE 5: Fighting can result in serious injury or even death.

Benefits of Behavior

If a predator approaches an animal suddenly, the stimulus elicits an involuntary, or innate, behavior such as running that is meant to protect the animal. One of the main benefits of an innate behavior is that it increases survivorship, or the number of individuals that survive from one year to the next. This will in turn increase an animal's fitness by natural selection. A behavior will be expressed if its benefits outweigh its costs. So, the benefit of maintaining homeostasis by basking in the sun outweighs the risk cost of a lizard exposing itself to predators. Behaviors that improve an individual's fitness will be passed on to future generations.

Analyze Some spiders build webs that include visible zigzag lines. But more visible webs catch fewer insects than do less visible webs. What benefits do you think the spider gets by building such a visible web?

All organisms require food to survive. At times it is more beneficial for an individual to gather food alone. A solitary hunter only needs to find enough food for itself or its young. In other species, such as lions, group hunting is more beneficial. The division of labor reduces the energy cost and risk cost per individual. Group hunts increase the potential to take down bigger or more prey and the group has greater protection. However, a group must find more food and there is more competition for that food.

In some group hunts, the pack works together to pursue and take down the prey. In other groups, such as bottlenose dolphins, individuals have specific roles. Bottlenose dolphins forage in groups of three to six, with one individual acting as the driver to herd the fish toward other dolphins lined up as barriers to prevent the fish from escaping. The driver slaps its tail, causing the fish to leap into the air. This makes it easier for the dolphins to catch the fish. Clearly the energy cost per individual and risk from predators is less for the group, which gathers far more fish than a solitary hunter.

FIGURE 6: Lions hunt in a group.

Murmurations

Murmurations are a form of group behavior in which thousands of starlings flock together as shape-shifting clouds. The birds fly together as one, creating incredible patterns as the flock twists and turns in the sky. Murmurations are often triggered by the presence of a predator, which is outmaneuvered by the rapid pattern changes.

Explain Murmurations require a great deal of energy expenditure. Explain the function of this behavior and the cost-benefit relationship. Does the benefit derived from the behavior outweigh the cost?

EXPLORATION 2

Social Interactions

FIGURE 7: When a predator is near, individuals in a group will move in unison for protection.

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Similar to flocking of birds, schooling in fish is a group activity that benefits the individual members. Fish school for several reasons, including foraging for food, defending themselves from predators, and reproducing. Swimming in a group also may improve hydrodynamics, or the dynamics of fluids, and reduce the energy cost associated with traveling through water. In the absence of predators, schools will often break apart, or the fish will take cover when in danger.

Analyze How do you think schooling behavior evolved over time? How does it increase the fitness of individuals in the school?

FIGURE 8: Springbok Pronking

Living in a Group

Sometimes, springboks hop on all four legs rather than run away when they spot a predator. This behavior, called *pronking*, alarms the rest of the herd but makes the individual visible to predators. Pronking gives the herd enough time to escape and signals to the predator that the herd already spotted it. Social behaviors include any and all interactions between individuals of the same species. Social groups interact in many ways, such as through communication, mate selection, and defense.

Explain Pronking carries with it a high energy costs and high risk costs. Why would an individual put itself at risk to alert and protect the rest of the group? What are the potential benefits?

Explore Online

FIGURE 9: Chimpanzee Pant-hooting

Communication

Communication is the sharing or exchange of information and is critical to the survival of individuals and groups, as well as for the species itself. Vocalizations, plumage, songs, mutual grooming, and pheromone trails are all forms of animal communication.

Chimpanzees live in dense tropical rain forests where it is easy to lose sight of others. They use a variety of vocalizations to stay in touch and let each other know where they are located. Other vocalizations are used to show excitement, greet group members, and alert the group to predators. Chimpanzees also communicate through facial expressions and body postures.

Mate Selection

Courtship displays are behaviors most often used by male members of a species to attract females. Scientists theorize that females use courtship displays to judge the condition of their potential mate or the quality of his genes. For example, as shown in Figure 10, blue-footed boobies high step and strut to show off their blue feet to potential partners. The pigment that gives the blue-footed booby its bright blue feet comes from its food. So an individual that is more successful at finding food will have brighter feet. The courtship "dance" helps females find the most fit partner.

Explore Online

FIGURE 10: Blue-Footed Booby

Defense

Defensive behaviors are responses to threatening stimuli from the environment. These various behaviors are meant to reduce harm to the individual. Animals will often put themselves in harm's way to protect their young as well. For example, the adult penguins in Figure 11 put themselves between their young and a petrel, who will eat young penguins. Groups of animals also will warn each other of danger with different vocalizations. Vervet monkeys, for example, use one call to indicate that a predator is a snake and another to indicate that it is a large cat or bird. This tells group members where to look and where to escape.

Explore Online

FIGURE 11: Penguins protecting their young from a petrel.

Model Make a model that explains how different types of behavior benefit the individual, and thereby the group. For each type of behavior, include elements that explain how this trait evolved over time.

Cooperation

Lions hunt together in packs, called *prides*, to increase their chances of success. Most prey can outrun a single lion but not an entire hunting group. The group works together to stalk the prey and make a barrier to prevent its escape. They then pounce together to take down the prey. This behavior is an example of *cooperation*, which involves behaviors that improve the fitness of the individuals involved.

Reciprocity

Vampire bats live together in tightly knit communities, providing protection and warmth to each other. A female vampire bat will donate food that she has collected from her hunt to a bat that is unable to hunt for its own food, voluntarily regurgitating and sharing part of its meal. This comes at a cost to the donor bat, because it has used energy to gather the food and is losing some energy by sharing.

Vampire bats keep track of which bats share food and, in turn, will share food with those bats. This is an example of reciprocity, another form of cooperative behavior among animals. The idea is that one action, such as sharing food, will result in a future beneficial response, such as being the recipient of shared food. Research has shown that bats in need of food received more donations if they had previously shared food with other bats.

FIGURE 12: Vampire bats share food with other bats.

Gather Evidence Which individuals within a larger community of bats would be most beneficial to feed after missing a meal or two?

Explore Online

FIGURE 13: Meerkats show altruistic behaviors.

Altruism

Meerkats, such as those shown in Figure 13, stand and watch for predators. When an individual sees a predator, it raises an alarm to the group. This signaling brings attention to itself and increases its own risk of being attacked but may save other individuals. This type of behavior is known as *altruism*. **Altruism** is a kind of behavior in which an animal reduces its own fitness to help other members of its social group. In other words, the animal appears to sacrifice itself for the good of the group.

Model Explain how you could model the cost-benefit relationship exhibited in altruistic behaviors.

How can we explain the evolution of altruism if behavior is supposed to increase fitness? British evolutionary biologist William Hamilton realized that alleles can be transmitted and therefore spread in a population in two ways, either directly from an individual to its offspring or indirectly by helping close relatives survive.

When an animal reproduces, its offspring gets half of its alleles. But its relatives also share some of the same alleles, in the following proportions:

- Parents and siblings share 50 percent of the animal's alleles.
- Nephews and nieces share 25 percent of its alleles.
- First cousins share 12.5 percent of its alleles.

The total number of genes an animal and its relatives contribute to the next generation is called **inclusive fitness**. It includes both direct fitness from reproduction and indirect fitness from helping kin survive. When natural selection acts on alleles that favor the survival of close relatives, it is called **kin selection**.

Eusocial Behavior

FIGURE 14: Weaver ants work together in eusocial colonies.

Analyze How is it possible for a behavior to evolve when there is only one reproductive female and the rest of the colony never reproduces?

Among colonies of insects, such as wasps, bees, and ants, only a small number of reproductive females exist. In honeybee colonies, one queen produces a few male offspring along with thousands of sterile female workers. These worker bees are incapable of reproduction and spend their short lives maintaining and protecting the hive, gathering food, producing wax and honey, and feeding the young. The workers live for about six weeks during the summer, while the queen can live for several years. Female offspring that will one day take the queen's place are raised in a separate cell and are fed a special diet.

If you were to look across many **eusocial** colonies, you would find that they share a common feature, haplodiploidy. This means their sex is determined by the number of chromosome sets in an individual. Males are haploid and females are diploid. Female social insects produce daughters through eggs fertilized by sperm. Unfertilized eggs produce sons. In these animals, daughters share half of their mother's alleles but all of their father's alleles. Sisters therefore share up to 75 percent of their alleles overall with one another, compared with 50 percent in humans and most other animals. The close relationship between sisters in a colony may influence the evolution of eusociality.

Explain Compare and contrast individual behaviors and group behaviors. What requirements are there for these behaviors to evolve?

Learned Behaviors

Young chimpanzees learn how to perform many tasks, some requiring the use of tools. Chimpanzees can learn to use leaves to drink water or to use rocks to crack open hard-shelled nuts and fruits. The chimpanzee in Figure 15 is using a twig to fish termites out of a mound. These are all examples of behaviors that must be learned. Chimpanzees are not born knowing how to use tools. They learn by watching and trying to imitate the behavior from their mother or other individuals in their social group.

Explore Online

FIGURE 15: A chimpanzee termite fishing.

Gather Evidence Why might some animals need to learn behaviors? What are some advantages of learned behaviors over those that are part of genetics?

Learning

Some aspects of behavior are influenced by genes, but many can be modified by experience. Learned behaviors are actions that change with experience. Learning takes many forms, ranging from changes in behaviors that are largely innate to problem-solving in new situations. In each case, learning involves the strengthening of nerve pathways. Most behaviors are not simple reactions to stimuli using preset pathways in the animal's brain. Instead, they represent a combination of innate tendencies influenced by learning and experience. Learning allows animals to quickly adapt to changes in their environment, increasing their ability to survive and reproduce.

Analyze Is learning genetically controlled? Consider the example of the chimpanzee learning to use tools. Can the chimpanzee pass on what it has learned? Can the chimpanzee pass on the ability to learn? Use evidence to support you claims.

Cultural Behavior

Cultural behavior is behavior that is spread through a population largely through learning, rather than selection. The key to cultural behavior is that the behavior is taught to one generation by another, known as *cultural transmission*.

Explore Online

FIGURE 16: Orcas learn to hunt through cultural transmission.

For example, the orca shown in Figure 16 intentionally beaches itself to hunt seals in the shallow waters. Only orcas in certain parts of the world, and only certain groups, exhibit this behavior. Orcas learn this from their mothers and other members in their group and will teach it to their offspring as long as the behavior is advantageous.

The development of cultural behavior does not require living in complex societies. The transmission of birdsong in some taxonomic groups of birds is an example of cultural behavior. However, living close together in social groups may help to enhance the transmission and expression of cultural behaviors.

Explain Construct an explanation as to how learned and cultural behaviors can increase an individual's fitness.

Language Arts Connection

The Evolution of Play Behavior

The polar bear cubs in Figure 17 may look like they are fighting, but they are actually just playing. Play fighting, also known as *rough-and-tumble play*, carries the risk of injury and uses energy. Why risk so much to play?

FIGURE 17: Play is often a juvenile form of adult behavior such as hunting or fighting.

Determining what play behavior is can be tricky, as there is sometimes a fine line between what is play and what is genuine fighting. According to researchers, play involves behaviors that are an adaptation of normal behaviors, such as fighting, fleeing, or feeding. It also involves communications, such as postures or facial expressions, to let other individuals know that this is play.

Although play is fun, it is hypothesized that this activity also builds skills among juveniles that will be beneficial to them as adults. Play is observed in many forms; however, researchers classify it into three categories—play as physical training, social training, and cognitive development. Cognition is the mental process of knowing through perception or reasoning.

Many young mammals engage in physical play as they wrestle and nip at each other with juvenile teeth. This physical play strengthens growing muscles and is thought to develop skills that may be needed later for hunting or protecting themselves or their own offspring as adults.

Social training involves learning from others. Think about behaviors that may be familiar in animals, such as interactions between wolves. Different postures signal different messages. One signal may be described as a "play bow," which sends a message that the wolves want to play. As juveniles, play provides the opportunity to learn social signals that may be used for other purposes, such as gaining attention, courting, or showing aggression. Cognitive development occurs as playful peers learn from one another.

Scientists are still researching why animals play and how the behavior evolved. They do know that the benefits of play, like those of other animal behaviors, outweigh the associated risks.

Language Arts Connection
Write an explanatory blog post that supports the claim that play behavior has evolved because it benefits the individual by giving them practice for events later in life. What evidence is there that play has evolved for these reasons? As you write your argument, consider following these steps:

- Introduce your claim, or the point your argument makes.
- Develop your claim by providing strong, logical reasons and evidence.
- Link ideas to show how your reasons relate to your claim.
- End with a conclusion that wraps up your argument.

EXAMPLES OF ANIMAL BEHAVIOR | USING AN ETHOGRAM | CAREER: ANIMAL BEHAVIORIST | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 18: Naked mole rats live in a eusocial colony.

Naked mole rats live underground, as moles do. Each solitary, underground colony typically has only one reproductive female, the queen, and a few breeding males. The remainder of the colony consists of non-reproducing individuals that spend their entire lives as workers, maintaining and protecting the colony, gathering food, and taking care of the queen's offspring.

Explain Refer to the notes in your Evidence Notebook to explain why animals, such as naked mole rat workers, evolved not to reproduce.

Many of the eusocial insects investigated in this lesson are haplodiploid. Naked mole rats, however, are diploid animals. Their colonies, though, are still made up of closely related animals. These animals often live in areas where it is difficult for individuals to survive on their own. For example, naked mole rats live in colonies of 70 to 80 individuals. Most of the colony are the queen's siblings or offspring. Non-reproducing adults are either soldiers or workers. Soldiers defend the colony, while workers work together as a chain gang to dig through the soil to find edible tubers.

This eusocial behavior may have evolved due to the amount of work needed to find food. If leaving the colony leads to starvation, kin selection may favor staying in the burrow to work together as a group instead.

CHECKPOINTS

Check Your Understanding

1. How does a behavior that actually increases risk to an individual, such as pronking in springboks, ensure that genes will be passed along to offspring? Select all correct answers.
   a. The behavior draws attention to the herd.
   b. The behavior alerts the herd.
   c. The behavior confuses predators.
   d. The behavior uses energy.
   e. The behavior decreases opportunity costs.

2. Classify each behavior as innate or learned.
   a. Chimpanzees use tools to fish for termites.
   b. Newly hatched sea turtles crawl into the sea.
   c. Bats fly out of caves at night to eat mosquitoes.
   d. Bears fish for salmon out of a running stream.
   e. Birds avoid eating monarch butterflies because they taste bad.
   f. Penguins dance ecstatically to attract a mate.
   g. Honeybees associate certain colors and fragrances with nectar.
   h. Cockroaches run for dark spaces when lights are turned on.

3. Which of the following best explains how behaviors, such as swarming and flocking, help protect organisms?
   a. Individuals in swarms or flocks act as decoys to distract predators.
   b. Working together in swarms or flocks requires less energy.
   c. The movement and size of the swarm or flock confuses predators.
   d. Swarms and flocks can overtake larger predators.

4. Which of the following characteristics is the best criteria for classifying a colony as eusocial?
   a. Female workers engage in group foraging.
   b. Opportunistic mating occurs randomly between males and females.
   c. Within the colony there are only a few breeding females.
   d. The colony is characterized by the defensive behavior of females.

5. A female ground squirrel may send out a call warning her offspring that a predator is near. Often, the mother sacrifices her own life since the predator can more easily locate her from the call. Even though this behavior results in death, it is beneficial to her in that:
   a. half of her alleles are preserved in each offspring.
   b. all of her alleles are preserved in each offspring.
   c. the predator may be less likely to attack the population again.
   d. the alleles that caused her behavior will no longer be in the gene pool.

6. How does cooperative behavior contribute to the survival of animals?
   a. Cooperative behavior puts one individual at risk for the survival of the whole group.
   b. Cooperative behavior benefits one individual, which will be reciprocated in the future.
   c. Cooperative behavior enables individuals to work together toward a common goal that will benefit the group.
   d. Cooperative behavior engages all members of a group to work together for the benefit of a few.

7. Use the following terms to classify each type of behavior: *communication, reciprocity, altruism, defensiveness, migration*. You may use each response more than once.
   a. A bat shares a part of its food with another.
   b. A monkey brings attention to itself when sounding an alarm to the group.
   c. Bison respond to a threat stimuli from the environment.
   d. Ants leave a pheromone trail to food.
   e. Black bears leave an established territory to find new sources of food.
   f. Nonbreeding female workers care for the queen's offspring.
   g. A male peacock fans its feathers and struts.

8. Identify the most likely costs of each behavior using the following terms: *opportunity costs, risk costs, energy costs*.
   a. A group of bats tend to their young rather than flying out to gather food.
   b. Two worker termites guard the entrance to the mound.
   c. A leopard chases down a gazelle in an attempt to eat it.

9. An antelope is grazing on the savanna and feels thirsty. It takes a drink from a nearby watering hole. As the antelope drinks, another antelope in the herd signals danger. The antelope and herd members sprint away. After running, the antelope feels hot and goes to lie in the shade.

   Identify each of the following as a stimulus or a response. If you identify it as a stimulus, decide if it is an internal or external stimulus.
   a. feels thirsty
   b. drinks water
   c. sprints away
   d. lies in shade
   e. feels hot

10. Two separate groups of chimpanzees, living in separate regions, both use tools to gather honey. One group uses long sticks as tools to gather honey from a log and the other uses chewed leaves to collect the honey. Which of the following would best explain these two behaviors used for the same purpose?
   a. cultural transmission
   b. cooperation
   c. transitive behavior
   d. migratory behavior

11. Which of the following best explains how a certain behavior may be more likely to be selected for and evolve as an innate behavior?
   a. The behavior is easily learned.
   b. The behavior has very low risk and opportunity costs.
   c. The benefits of the behavior for survival outweigh the costs.
   d. The behavior is in response to a stimulus.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

A behavior is anything an organism does in response to a stimulus and helps the organism maintain homeostasis in a changing environment.

A behavior is selected for if the benefit of the behavior outweighs the cost or risk.

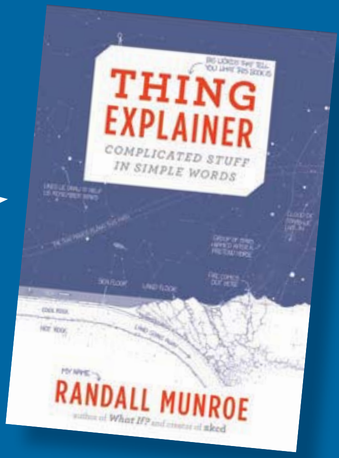
Behaviors may be classified as innate or learned. Innate behaviors are those that are instinctive and are heritable. Learned behaviors are acquired through observation, practice, and experience and may be culturally specific.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how any behavior that increases the survival of an individual or its reproductive success will likely be passed from one generation to the next.

A BOOK EXPLAINING COMPLEX IDEAS USING ONLY THE 1,000 MOST COMMON WORDS

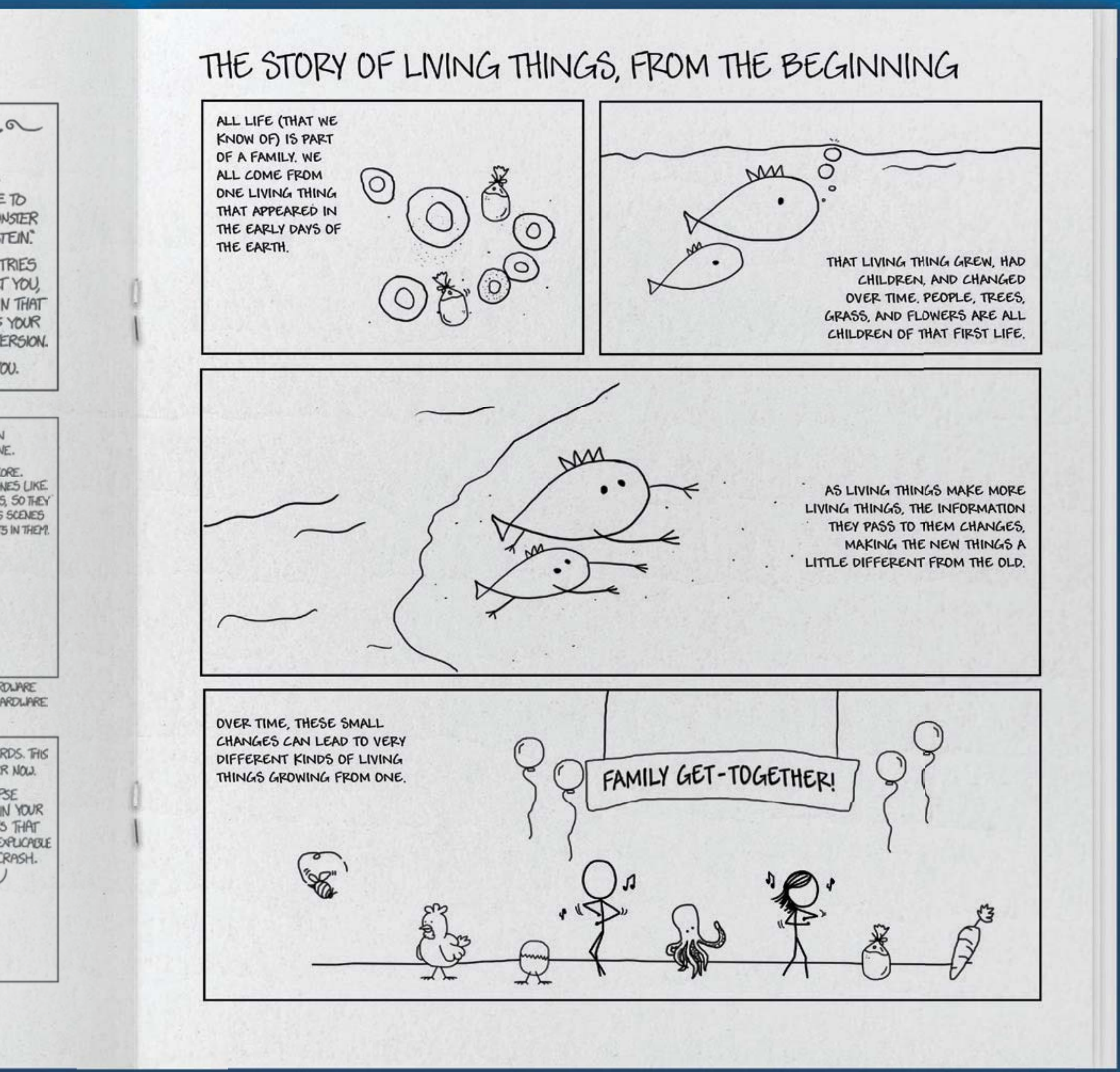


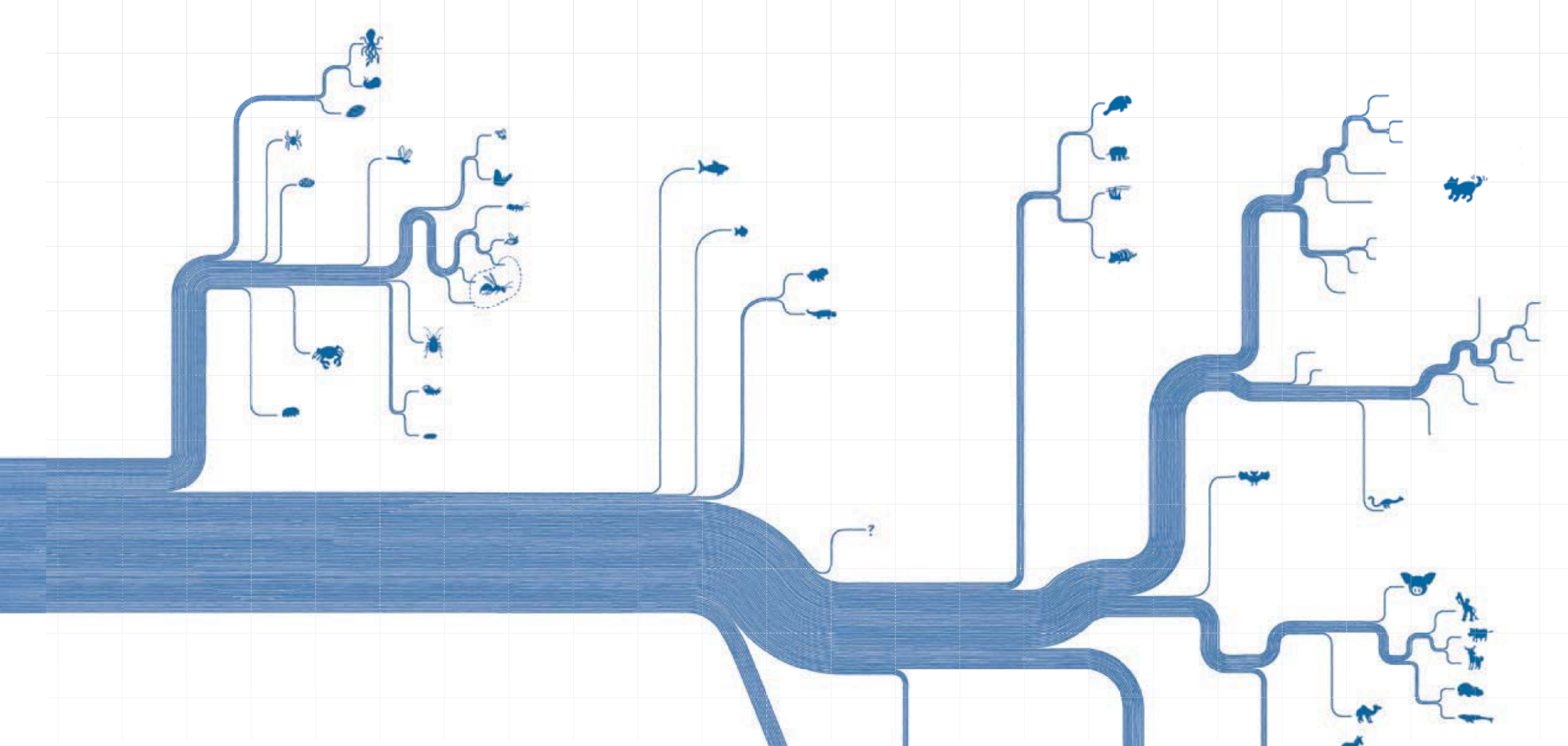
RANDALL MUNROE
XKCD.COM

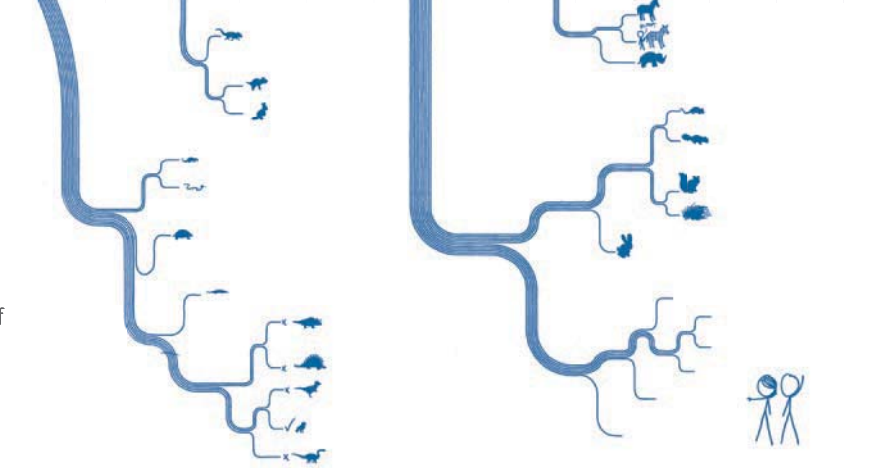
TREE OF LIFE

All living things as part of the same family

You've learned that organisms can be classified based on physical and genetic characteristics, which reveal their evolutionary relationships. Tree diagrams are used to describe the relationships between organisms, both living and extinct. Here's one that uses easy-to-understand language.







This tree shows how different kinds of life branched off from one another.

This tree doesn't show all living things, or even most of them. It just shows some of the living things you might know, along with which branch of life's family they're in.

This is just a tiny part of the tree of life. The whole tree is too big to fit in any single picture, and there are too many kinds of life for anyone to give names to all of them—no matter what kind of words they use.

And really, a true tree of life wouldn't just have a line for every *kind* of life. It would have a line for each living thing that ever was, every one of them crossing and joining and winding across the page, slowly changing from one kind of life to another, in a path that reaches all the way back, without a single break, to that very first life.

No one really knows how many living things there are in the world, but we can make some guesses, and they're big. Not only can we never find enough words to talk about all those lives, we have a hard time talking about the number itself.

Here's one way to think about how many things have lived on Earth: The world is covered in seas that are ringed with beaches of sand. One day, when you're walking on a beach, pick up some sand and look at it. Imagine that every tiny piece of sand under your feet is a whole world of its own, each one with its own seas and beaches, just like Earth.

The full tree of life has as many living things as there are bits of sand on all those beaches on all those tiny sand worlds put together.

Next to the world we're talking about, all our words are small.

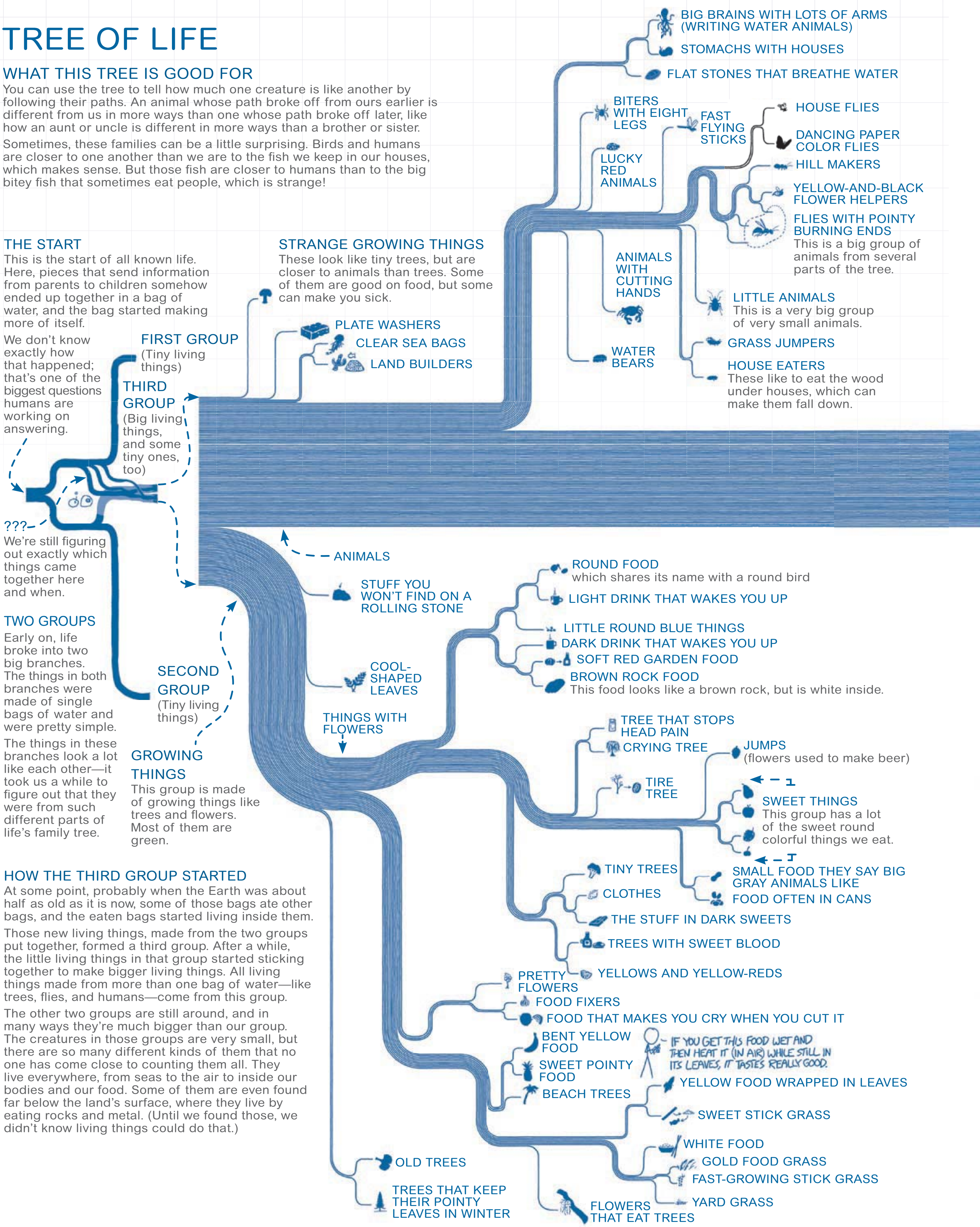
ANIMAL THAT LIVES DEEP IN THE SEA AND HAS BEEN ON EARTH FOR A VERY LONG TIME

TREE OF LIFE

WHAT THIS TREE IS GOOD FOR

You can use the tree to tell how much one creature is like another by following their paths. An animal whose path broke off from ours earlier is different from us in more ways than one whose path broke off later, like how an aunt or uncle is different in more ways than a brother or sister.

Sometimes, these families can be a little surprising. Birds and humans are closer to one another than we are to the fish we keep in our houses, which makes sense. But those fish are closer to humans than to the big bitey fish that sometimes eat people, which is strange!



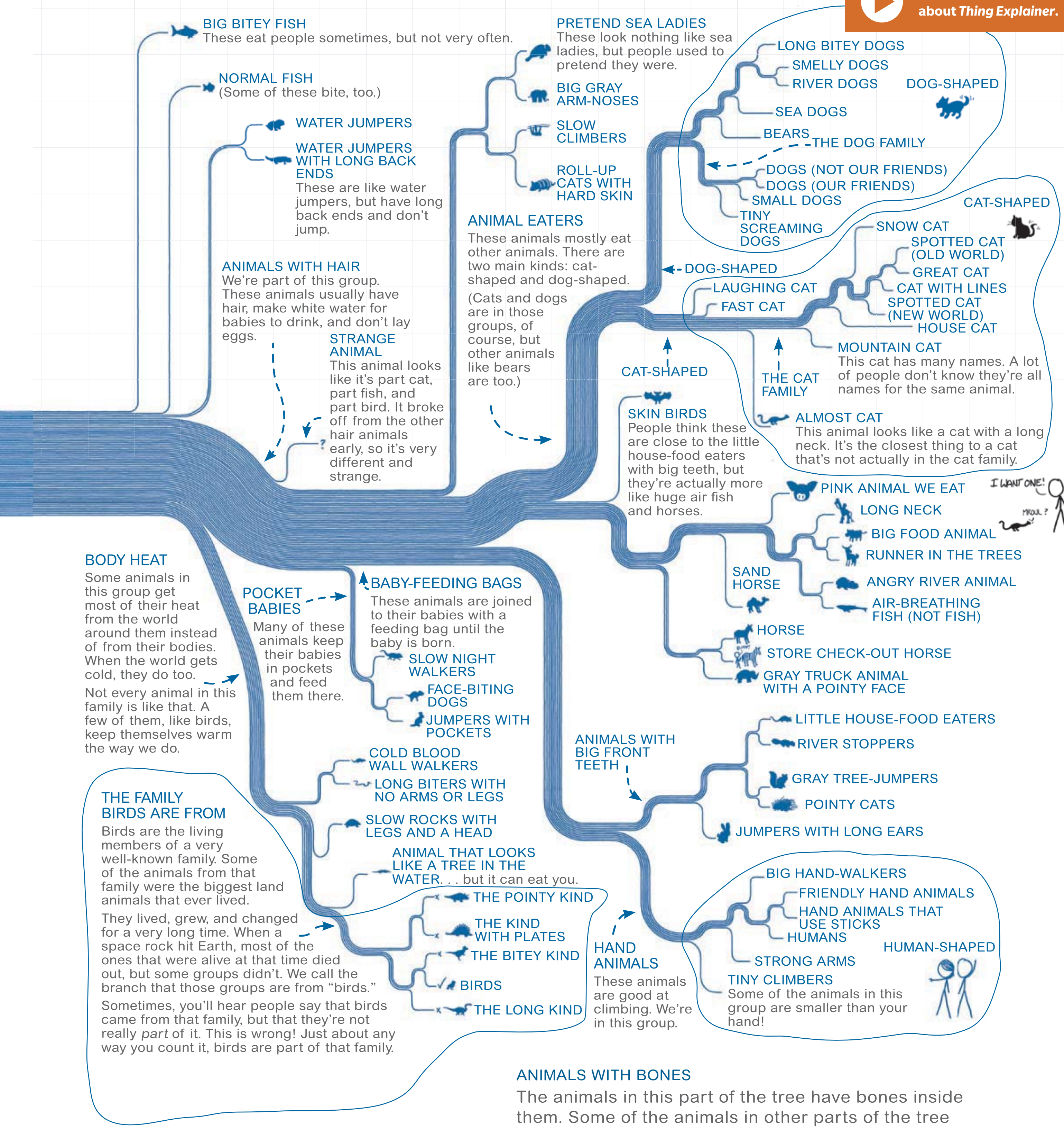
HOW THE THIRD GROUP STARTED

At some point, probably when the Earth was about half as old as it is now, some of those bags ate other bags, and the eaten bags started living inside them.

Those new living things, made from the two groups put together, formed a third group. After a while, the little living things in that group started sticking together to make bigger living things. All living things made from more than one bag of water—like trees, flies, and humans—come from this group.

The other two groups are still around, and in many ways they're much bigger than our group. The creatures in those groups are very small, but there are so many different kinds of them that no one has come close to counting them all. They live everywhere, from seas to the air to inside our bodies and our food. Some of them are even found far below the land's surface, where they live by eating rocks and metal. (Until we found those, we didn't know living things could do that.)

Go online for more about *Thing Explainer*.



ANIMALS WITH BONES

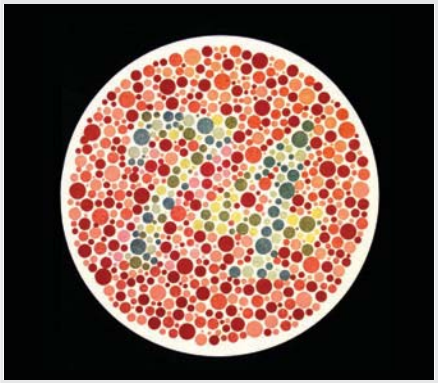
The animals in this part of the tree have bones inside them. Some of the animals in other parts of the tree have hard body parts, but they usually have them on the outside. The animals in this part have bones on the inside, with the soft parts hanging from them.

Earth Science Connection

Color blindness on Pingelap Catastrophic weather events can have significant impacts on populations, sometimes for generations to come. In 1775, Typhoon Lengkieki struck the Micronesian atoll of Pingelap. Today, roughly 1 in 10 residents of Pingelap are entirely colorblind, compared with a rate of 1 in 40,000 individuals worldwide.

Using library and Internet resources, research the link between color blindness in the residents of Pingelap and Typhoon Lengkieki. Prepare a report discussing your findings, including factors such as founder effect or genetic drift that may have contributed to the phenomenon.

FIGURE 1: Colorblind individuals may have difficulty distinguishing colors.



Humanities Connection

Evolution of Fashion Changes and adaptations in culture occur in human populations—though mostly due to pressures different than those that drive biological evolution. Fashion, for instance, has "evolved" in nearly every human society as social norms, artistic trends, climate conditions, and other factors develop and change. Many aspects of a society are reflected in the fashion preferences of its people, and some fashion trends are uniquely representative of a particular time and place.

Using library and Internet resources, research the evolution of fashion trends over time in a particular society. Write a blog post about a specific change in fashion, and describe some of the societal changes that may have led to this fashion evolution. Be sure to include representative pictures to illustrate your findings.

FIGURE 2: Trends in fashion change over time in most societies.

Engineering Connection

Animal Influence in Robot Design Research focused on the ways that animals behave, react, and move has led to potential improvements in robotic design. Engineers often use strategies evolved in animal species when developing robots. For example, engineers have developed robots that climb using technology modeled on how gecko feet "stick" to surfaces. Robotics engineers have also found a way to add stability to robots based on studies of how fish use their tails to swim.

Using library and Internet resources, research the design and function of a robot that has been influenced by animal behavior or movement. What specific characteristics or strategies were "borrowed" from the animal in the robot's design? What other characteristics of the animal that inspired the design might be useful for the robot's function? Write a report detailing your findings and suggestions, and present it to the class.

FIGURE 3: Many robotic designs are influenced and inspired by adaptations in animals.

SYNTHESIZE THE UNIT

In your Evidence Notebook, make a concept map, graphic organizer, or outline using the Study Guides you made for each lesson in this unit. Be sure to use evidence to support your claims.

When synthesizing individual information, remember to follow these general steps:

- Find the central idea of each piece of information.
- Think about the relationships between the central ideas.
- Combine the ideas to come up with a new understanding.

DRIVING QUESTIONS

Look back to the Driving Questions from the opening section of this unit. In your Evidence Notebook, review and revise your previous answers to those questions. Use the evidence you gathered and other observations you made throughout the unit to support your claims.

PRACTICE AND REVIEW

1. In a certain species of sea snake, a single gene controls tongue shape. The forked-tongue allele (*T*) is dominant, while the non-forked-tongue allele (*t*) is recessive. In this population, 16 individuals are homozygous recessive, 36 individuals are homozygous dominant, and 48 individuals are heterozygous. Using this information, answer the following questions:

a. How many total alleles for tongue shape are in this population?

b. How many *T* alleles are in the population?

c. How many *t* alleles are in the population?

d. What is the frequency of the *T* allele? Express your answer as a percentage.

e. What is the frequency of the *t* allele? Express your answer as a percentage.

2. Bright green tree frogs are generally more common in tropical rain forests than in temperate areas, where leaf colors change with the season. Why might this be true?

a. The frogs' numbers are similar in both environments but are easier to spot in green tropical rain forests.

b. The frogs' coloration provides better camouflage in temperate forests, where leaves may turn brown or other colors, than in green tropical rain forests.

c. The frogs' coloration helps them stand out better in green tropical rain forests, compared with temperate forests, where leaves may turn brown or other colors.

d. The frogs' coloration provides better camouflage in green tropical rain forests than in temperate forests, where leaves may turn brown or other colors.

3. Some individuals in a particular species of butterfly display coloration that mimics that of a different, poisonous butterfly species living in the same habitat. Place the elements in order to model what may happen to the first butterfly species if the poisonous butterfly species is removed from the habitat.

a. Predators will eat butterflies with mimicking coloration more often than before.

b. The proportion of individuals in the population with mimicking coloration will decrease.

c. The pressure on predators to avoid eating poisonous butterflies will decrease.

d. The survival advantage for mimicking butterflies will decrease.

4. In clam species, a thick shell can discourage potential predators such as sea otters who crack open the shells to eat the clams. In a habitat where sea otters are tending to grow larger and stronger, which type of evolution might be observed in local clams, in terms of shell thickness?

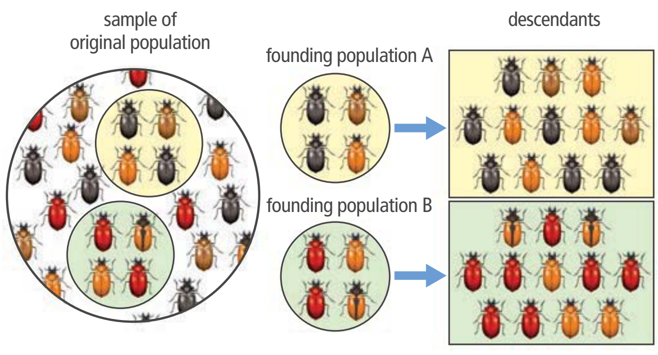
a. disruptive evolution, with the thickest and thinnest shells becoming more prevalent

b. stabilizing evolution, with shells around the average thickness becoming more prevalent

c. directional evolution, with the average tending toward thicker shells across the clam population

d. directional evolution, with the average tending toward thinner shells across the clam population

FIGURE 4: Founder effect in beetle populations.



5. Examine the image of founding beetle populations in Figure 4. What may be observed in the descendant populations that arise from a small number of founding individuals? Select all correct answers.
   a. Individuals in descendant populations are all heterozygous for traits.
   b. Allele frequencies in one descendant population may be very different from those in another descendant population.
   c. Some alleles may be completely lost in one or more descendant populations.
   d. The genetic variation of the descendant population is usually lower than in the original population.

6. Individuals from two different species of firefly, species A and species B, are brought together. It is determined that the females from species A do not recognize the mating signals flashed by males of species B, and females from species B do not recognize signals from males of species A. Based on this finding, what past phenomenon may have led to speciation in these fireflies?
   a. sexual isolation
   b. temporal isolation
   c. behavioral isolation
   d. geographic isolation

7. Cichlids are a group of more than 2,000 species of fish that live in African lakes and are thought to have evolved from adaptive radiation. Explain how so many species may have evolved from a common ancestor.

8. Explain a phenomenon related to climate change and how it can have negative impacts on species, and even directly lead to species extinction. Use a specific example to support your claims.

9. Herring are small ocean fish that often swim together in large schools. Though this behavior uses significant energy and can increase competition for resources, what advantages might the evolution of schooling behavior provide for herring? Select all correct answers.
   a. the ability for many individuals to spot predators
   b. the possibility of diving deeper as a school
   c. greater efficiency in searching for food together
   d. confusing potential predators by appearing to be one large animal

10. African wild dogs practice cooperative hunting, forming packs to hunt animals such as antelopes, warthogs, and wildebeest. Explain some of the advantages and disadvantages of group hunting.

UNIT PROJECT

Return to your unit project. Prepare your research and materials into a presentation to share with the class. In your final presentation, evaluate the strength of your analysis and conclusions.

Remember these tips while evaluating:

- Look at the empirical evidence—evidence based on observations and data. Does the evidence support the explanation?
- Consider if the explanation is logical. Does it contradict any evidence you have seen?
- Think of tests you could do to support and contradict the ideas.

Genetic Diversity in Cheetahs

Today, there are fewer than 20,000 African cheetahs (*Acinonyx jubatus*). Before the last ice age, cheetah species could be found in North America, Europe, Asia, and Africa. Around 10,000 to 12,000 years ago, a mass extinction event occurred that caused the extinction of almost 75 percent of the world's large mammals. A single cheetah species survived this extinction event, with a range limited to parts of eastern, central, and southern Africa. What effect did this mass extinction event have on cheetah diversity?

1. DEFINE THE PROBLEM

With your team, write a statement outlining the problem you've been asked to solve. Record any questions you have on the problem and the information you need to solve it.

2. ANALYZE DATA

With your team, analyze the graph of genetic variation and population size shown in Figure 5. What effect does a sudden decrease in population size have on genetic variation? Does genetic variation within a species recover as the species' population recovers?

3. CONDUCT RESEARCH

On your own, use library and Internet resources to research how the mass extinction event affected genetic variation in cheetahs. How does a change in genetic variation affect modern-day cheetah populations?

4. CONSTRUCT AN EXPLANATION

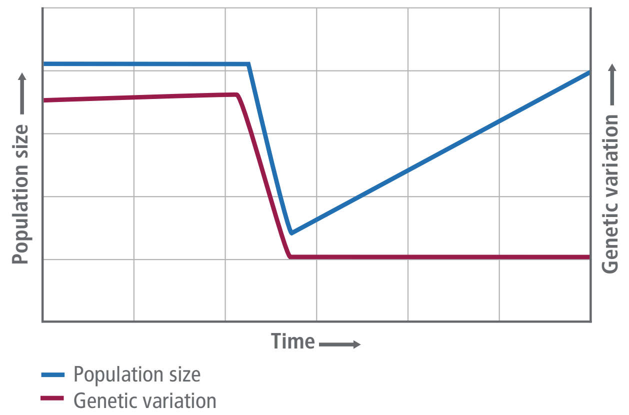
Write an explanation of the evolutionary mechanism that affected genetic diversity in cheetah populations. Can cheetah populations recover lost genetic diversity?

5. COMMUNICATE

Write a report detailing your analysis and your predictions for what will happen to genetic variation in cheetah populations in the future.

Changes in Population Size and Genetic Variation

FIGURE 5: Genetic variation and population size



Source: "Low genetic variation." Understanding Evolution. University of California Museum of Paleontology. 8 December 2016 <http://evolution.berkeley.edu/evolibrary/article/conservation_04>.

CHECK YOUR WORK

A complete report should include the following information:

- a clearly defined problem with supporting questions that are answered in the final presentation
- an analysis of the mass extinction event that affected genetic variation in cheetahs and how that event continues to impact modern-day cheetah populations
- an explanation of the evolutionary mechanism that led to a change in genetic variation in cheetahs
- predictions about future changes in genetic variation in cheetah populations