Evolution of Populations

Q: How can populations evolve to form new species?

Poised on a flower, the two common blue butterflies (Polyommatus icarus) appear identical. However, if you look closely, you can see that the patterns on their wings are slightly different. Variations among individual members of a population provide the raw material for evolution and sometimes for the formation of new species.

Chapter 17 advances students’ comprehension of the Enduring Understanding for Unit 5: *The diversity of life is the result of ongoing evolutionary change. Species alive today have evolved from ancient common ancestors.* The graphic organizer at the right shows how chapter content frames their explanation of this Enduring Understanding.

**UNDERSTANDING by DESIGN**

Chapter 17 advances students’ comprehension of the Enduring Understanding for Unit 5: *The diversity of life is the result of ongoing evolutionary change. Species alive today have evolved from ancient common ancestors.* The graphic organizer at the right shows how chapter content frames their explanation of this Enduring Understanding.

**PERFORMANCE GOALS**

In Chapter 17, students will use models, graphs, and data to learn how changes in allele frequencies lead to speciation. The Chapter Mystery provides a real-world example of evolution: the evolution of new strains of flu viruses. At the end of the chapter, students will create a poster to illustrate how evolution leads to diversity of life through speciation.
In 1918, an epidemic began that would go on to kill more than 40 million people. A doctor wrote: “Dead bodies are stacked about the morgue like cordwood.”

What was this terrible disease? It was a variety of the same influenza virus that causes “the flu” you catch again and again. How did this strain of a common virus become so deadly? And could that kind of deadly flu epidemic happen again?

The answers to those questions explain why we can’t make a permanent vaccine against the flu, as we can against measles or smallpox. They also explain why public health officials worry so much about something you may have heard referred to as “bird flu.” As you read this chapter, look for evolutionary processes that might help explain how new strains of influenza virus appear all the time. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the epidemic mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

What’s Online
Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
The mystery of the 1918 flu epidemic allows students to investigate how mutations and other evolutionary processes lead to new strains of flu virus.

UNTAMED SCIENCE VIDEO
Students explore speciation mechanisms in Hawaii, where geographic isolation contributes to evolutionary patterns similar to those in Darwin’s finches.

ART REVIEW
Drag-and-drop labels give students a chance to apply the concepts of dominance and allele frequency to additional gene pools.

ART IN MOTION
Students explore how the composition of a population changes under different types of natural selection pressure.

DATA ANALYSIS
Students can analyze data from the Grants’ study of Darwin’s finches.

TUTOR TUBE
The tutorial shows students how to use a concept map to distinguish the concepts of selection, adaptation, speciation, and evolution.
**Getting Started**

**Objectives**

17.1.1 Define evolution in genetic terms.
17.1.2 Identify the main sources of genetic variation in a population.
17.1.3 State what determines the number of phenotypes for a trait.

**Student Resources**

Study Workbooks A and B, 17.1 Worksheets
Spanish Study Workbook, 17.1 Worksheets

**Activate Prior Knowledge**

Make a T-Chart on the board, and label one column Genotype and the other column Phenotype. Have each student add a descriptive term, fact, or example to the chart under one of the headings. Discuss the finished chart as a class. Make sure students understand how genotype and phenotype are related.

Study Wkbks A/B, Appendix S30, T-Chart.
Transparencies, GO15.

**UNIFYING CONCEPTS AND PROCESSES**

I, II, III, IV

**CONTENT**

C.2.a, C.2.b, C.2.c, C.3.a

**INQUIRY**

A.2.d

**Genes and Variation**

**Key Questions**

- How is evolution defined in genetic terms?
- What are the sources of genetic variation?
- What determines the number of phenotypes for a given trait?

**Vocabulary**

- gene pool
- allele frequency
- single-gene trait
- polygenic trait

**Taking Notes**

Concept Map As you read about sources of genetic variation, construct a concept map to describe the sources.

**THINK ABOUT IT**

Darwin developed his theory of natural selection without knowing how heredity worked. Mendel’s studies on inheritance in peas were published during Darwin’s lifetime, but no one (including Darwin) realized how important that work was. So Darwin had no idea how heritable traits pass from one generation to the next.

What’s more, although Darwin based his theory on heritable variation, he had no idea where that variation came from. What would happen when genetics answered those questions?

**Genetics Joins Evolutionary Theory**

**How is evolution defined in genetic terms?**

After Mendel’s work was rediscovered around 1900, genetics took off like a rocket. Researchers discovered that heritable traits are controlled by genes that are carried on chromosomes. They learned how changes in genes and chromosomes generate variation.

All these discoveries in genetics fit perfectly into evolutionary theory. Variation is the raw material for natural selection, and finally scientists could study how and why variation occurs. Today, techniques of molecular genetics are used to form and test many hypotheses about heritable variation and natural selection. Modern genetics enables us to understand, better than Darwin ever could, how evolution works.

**Genotype and Phenotype in Evolution**

Typical plants and animals contain two sets of genes, one contributed by each parent. Specific forms of a gene, called alleles, may vary from individual to individual. An organism’s genotype is the particular combination of alleles it carries. An individual’s genotype, together with environmental conditions, produces its phenotype. Phenotype includes all physical, physiological, and behavioral characteristics of an organism, such as eye color or height. Natural selection acts directly on phenotype, not genotype. In other words, natural selection acts on an organism’s characteristics, not directly on its alleles.

**FIGURE 17–1 Genes and Variation**

Why do biological family members resemble each other, yet also look so different? Similarities come from shared genes. Most differences come from gene shuffling during reproduction and environmental influences. A few differences may be caused by random mutations.

**Teach for Understanding**

**ENDURING UNDERSTANDING**

The diversity of life is the result of ongoing evolutionary change. Species alive today have evolved from ancient common ancestors.

**GUIDING QUESTION**

How do genes make evolution possible?

**EVIDENCE OF UNDERSTANDING**

After completing the lesson, give students the following assessment to show they understand that evolution is a change in the relative frequency of alleles in a population’s gene pool. Provide small groups of students with scissors and sheets of paper of different colors. Tell students to cut the paper into small squares to represent alleles. Then have groups use their squares to model how evolution occurs in genetic terms. Give each group a chance to explain its model to the class.
How does that work? In any population, some individuals have phenotypes that are better suited to their environment than are the phenotypes of other individuals. The better-suited individuals produce more offspring than the less fit individuals do. Therefore, organisms with higher fitness pass more copies of their genes to the next generation.

Natural selection never acts directly on genes. Why? Because it is an entire organism—not a single gene—that either survives and reproduces or dies without reproducing.

**In Your Notebook** Describe how natural selection affects genotypes by acting on phenotypes.

![Sample Population Diagram](image)

**Populations and Gene Pools** Genetic variation and evolution are both studied in populations. A population is a group of individuals of the same species that mate and produce offspring. Because members of a population interbreed, they share a common group of genes called a gene pool. A gene pool consists of all the genes, including all the different alleles for each gene, that are present in a population.

Researchers study gene pools by examining the numbers of different alleles they contain. Allele frequency is the number of times an allele occurs in a gene pool, compared to the total number of alleles in that pool for the same gene. For example, in the mouse population in Figure 17–2, the allele frequency of the dominant B allele (black fur) is 40 percent, and the allele frequency of the recessive b allele (brown fur) is 60 percent. The allele frequency of an allele has nothing to do with whether the allele is dominant or recessive. In this mouse population, the recessive allele occurs more frequently than the dominant allele.

Evolution, in genetic terms, involves a change in the frequency of alleles in a population over time. For example, if the frequency of the B allele in Figure 17–2 drops to 30 percent, the population is evolving. It's important to note that populations, not individuals, evolve. Natural selection operates on individual organisms, but the changes it causes in allele frequency show up in the population as a whole.

![Frequency of Alleles Table](image)

**BUILD Vocabulary**

**MULTIPLE MEANINGS** Perhaps the most common definition of the noun pool is a large man-made body of water in which you can swim. However, a pool can also refer to an available supply of a resource. In the case of a gene pool, the resource is genetic information.

**Use Visuals**

Use Figure 17–2 to help students see how a population's genotype frequencies relate to allele frequencies in its gene pool. Ask students to calculate the number of mice with each genotype, assuming that there are 25 individuals in the population, since Figure 17–2 shows a total of 50 alleles. (heterozygous black—12; homozygous black—4; homozygous brown—9) Then, ask students to calculate the number of B and b alleles each genotype contributes to the gene pool. (heterozygous black—12 B, 12 b; homozygous black—8 B; homozygous brown—18 b) Have students add the numbers of each type of allele and check that the totals match the number of allele icons in the matrix.

**Ask** If the current generation of homozygous brown mice had no offspring, how would this affect the allele frequency of the b allele in the next generation? (The frequency would decline.)

**DIFFERENTIATED INSTRUCTION**

**l** **Special Needs** Give students 20 pennies and 30 paper clips to represent the B and b alleles, respectively, in the mouse gene pool in Figure 17–2. Challenge students to arrange the items in groups of two to represent the numbers of genotypes in the mouse population.

**Art Review: Frequency and Dominance** students can use drag-and-drop labels and representations of alleles to help them distinguish between allele dominance and allele frequency.

**Answers**

**FIGURE 17–2** In a total of 100 alleles, 40 alleles would be B (black) and 60 alleles would be b (brown).

**IN YOUR NOTEBOOK** Genotype largely determines phenotype. Phenotype directly affects how an organism interacts with its environment. Organisms with adaptive phenotypes are more likely to pass their alleles, and therefore their genotypes, on to the next generation.
LESSON 17.1

Sources of Genetic Variation

What are the sources of genetic variation?

Genetics enables us to understand how heritable variation is produced.

Three sources of genetic variation are mutation, genetic recombination during sexual reproduction, and lateral gene transfer.

Mutations

A mutation is any change in the genetic material of a cell. Some mutations involve changes within individual genes. Other mutations involve changes in larger pieces of chromosomes. Some mutations—called neutral mutations—do not change an organism’s phenotype.

Mutations that produce changes in phenotype may or may not affect fitness. Some mutations, such as those that cause genetic diseases, may be lethal. Other mutations may lower fitness by decreasing an individual’s ability to survive and reproduce. Still other mutations may improve an individual’s ability to survive and reproduce.

How common are mutations? Recent estimates suggest that each of us is born with roughly 300 mutations that make parts of our DNA different from that of our parents. Most of those mutations are neutral. One or two are potentially harmful. A few may be beneficial.

Note that mutations matter in evolution only if they can be passed from generation to generation. For that to happen, mutations must occur in the germ line cells that produce either eggs or sperm. A mutation in skin cells that produces a nonlethal skin cancer, for example, will not be passed to the next generation.

Genetic Recombination in Sexual Reproduction

Mutations are not the only source of heritable variation. You do not look exactly like your biological parents, even though they gave you all your genes. You probably look even less like any brothers or sisters you may have. Yet no matter how you feel about your relatives, mutant genes are not primarily what makes them look so different from you. Most heritable differences are due not to mutations, but to genetic recombination during sexual reproduction. Remember that each chromosome in a pair moves independently during meiosis. In humans, who have 23 pairs of chromosomes, this process can produce 8.4 million gene combinations!

Crossing-over is another way in which genes are recombined. Recall that crossing-over occurs during meiosis. In this process, paired chromosomes often swap lengths of DNA at random. Crossing-over further increases the number of new genotypes created in each generation. You can now understand why, in species that reproduce sexually, no two siblings (except identical twins) ever look exactly alike. With all that independent assortment and crossing-over, you can easily end up with your mother’s eyes, your father’s nose, and hair that combines qualities from both your parents. You can also now understand why, as Darwin noted, individual members of a species differ from one another.

In Your Notebook Which source of variation brings more diversity into a gene pool—mutation or sexual reproduction? Explain.

Address Misconceptions

Mutations Students may hold the misconception that all mutations are harmful, making it hard for them to understand why mutations are needed for evolution. Address this misconception by giving them examples of mutations that are beneficial to the organisms in which they occur, such as those that let bacteria resist antibiotics and adult humans digest lactose.

Answers

In Your Notebook Most diversity in a gene pool is due to sexual reproduction, not mutations, because millions of gene combinations can be produced through independent assortment and crossing-over.

Hand Signals

Check for Understanding

Hand Signals

Ask students the following questions about sources of genetic variation. For each question, have them respond with a thumbs-up sign if they understand, a thumbs-down sign if they do not understand, and a waving-hand sign if they are uncertain.

- Why must mutations occur in germ line cells to affect evolution?
- How does sexual reproduction increase genetic variation?
- How does lateral gene transfer increase genetic variation?

Adjust Instruction

For any question students do not understand, have them reread the relevant text and then prepare a brief written answer. Call on volunteers to read their answers to the class. If any answers are incorrect, explain the correct answers in detail.
**Lateral Gene Transfer**

Most of the time, in most eukaryotic organisms, genes are passed only from parents to offspring (during sexual or asexual reproduction). Some organisms, however, pass genes from one individual to another, or even from individuals of one species to another. Recall, for example, that many bacteria swap genes on plasmids as though the genes were trading cards. This passing of genes from one organism to another organism that is not its offspring is called lateral gene transfer. Lateral gene transfer can occur between organisms of the same species or organisms of different species.

Lateral gene transfer can increase genetic variation in any species that picks up the “new” genes. This process is important in the evolution of antibiotic resistance in bacteria. Lateral gene transfer has been common, and important, in single-celled organisms during the history of life.

**Single-Gene and Polygenic Traits**

**What determines the number of phenotypes for a given trait?**

Genes control phenotype in different ways. In some cases, a single gene controls a trait. Other times, several genes interact to control a trait. **The number of phenotypes produced for a trait depends on how many genes control the trait.**

**Single-Gene Traits**

In the species of snail shown below, some snails have dark bands on their shells, and other snails don’t. The presence or absence of dark bands is a single-gene trait—a trait controlled by only one gene. The gene that controls shell banding has two alleles. The allele for a shell without bands is dominant over the allele for a shell with dark bands. All genotypes for this trait have one of two phenotypes—shells with bands or shells without bands. Single-gene traits may have just two or three distinct phenotypes.

The bar graph in Figure 17–4 shows the relative frequency of phenotypes for this single gene in one population of snails. This graph shows that the presence of dark bands on the shells may be more common in a population than the absence of bands. This is true even though the allele for shells without bands is the dominant form. In populations, phenotypic ratios are determined by the frequency of alleles in the population as well as by whether the alleles are dominant or recessive.

**Use Models**

Help students appreciate how many more genotypes are possible for polygenic traits than single-gene traits by having groups of students model the possible genotypes for a single-gene trait and a two-gene (polygenic) trait. All genes should have two alleles. Students can represent alleles with letters or small objects such as coins or slips of paper. Ask groups to compare their models. Did they all arrive at the correct number of genotypes? (3 for the single-gene trait, 9 for the two-gene trait) Tell students that 64 genotypes are possible for a three-gene trait with two alleles per gene.

**Ask** How would the number of genotypes be affected if each gene had more than two alleles? (It would be much greater.)

**DIFFERENTIATED INSTRUCTION**

**ELL Less Proficient Readers**

Graphs can be thought of as models that show trends. Use the graphs in Figure 17–4 and Figure 17–5 to help less proficient readers differentiate the number of phenotypes for single-gene and polygenic traits. Call students’ attention to the patterns shown by the two graphs.

**Ask** What is the graph for the single-gene trait like? (two distinct bars of different heights) What is the graph for the polygenic trait like? (a curve) What does this tell you about the difference between single-gene and polygenic phenotypes? (For single-gene traits, there are often only two distinct phenotypes. For polygenic traits, there is usually a range of phenotypes.)

**ELL Focus on ELL:**

**Access Content**

**ALL SPEAKERS** Ask students to create a T-Chart of lesson vocabulary terms. On the left side of the chart, have them list the terms. On the right side, have them list characteristics of each term and a symbol that will help them remember the term. Have intermediate speakers also add a sentence that will help them remember each term. Advanced speakers can write two or more sentences that define each term, using information from the text.

When students have finished their charts, pair advanced and advanced high speakers with intermediate and beginning speakers. Members of each pair should compare their charts. Advanced speakers should help beginning and intermediate speakers understand the meanings of the vocabulary terms.

**Study Wkbks A/B, Appendix S30, T-Chart. Transparencies, G015.**

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**Biology In-Depth**

**SOURCES OF LATERAL GENE TRANSFER**

Bacterial transformation by horizontal gene transfer is a primary factor in the spread of antibiotic resistance. Bacteria with antibiotic resistance can easily transfer the gene from organism to organism, quickly spreading the trait. Over the history of life there have been other sources of lateral gene transfer. One prominent source is endosymbiosis. (The endosymbiotic origin of mitochondria and possibly other organelles is discussed in Chapter 19.) Endosymbiosis occurred at least once in the evolution of eukaryotic cells. It probably occurred several other times during the evolution of plants, accounting for different types of chloroplasts in various groups of algae and in green plants.
Assess and RemEDIATE

EVALUATE UNDERSTANDING

Call on students to explain why populations, rather than individuals, evolve. (Evolution occurs due to the change of the relative frequency of alleles in a population over time. The alleles in an individual organism do not change during the organism’s lifetime.) Then, have students complete the 17.1 Assessment.

REMEDICATION SUGGESTION

Less Proficient Readers If students have trouble with Question 3c, have them compare the graphs in Figure 17–4 and Figure 17–5. Ask how many phenotypes are shown in each graph. Then, ask how many different phenotypes are described in Question 3c.

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Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Answers

FIGURE 17–5 The shape of the graph indicates that there is a range of heights in the population. Few people are very short or very tall—most are in the middle of the range.

Assessment Answers

1a. A gene pool consists of all the genes, including all the different alleles for each gene, that are present in a population. The allele frequency is the number of times that the allele occurs in a gene pool, compared with the number of times other alleles for the same gene occur.

1b. change in the relative frequency of alleles in the population’s gene pool over time

1c. The frequency would probably decrease.

2a. mutations, genetic recombination in sexual reproduction, and lateral gene transfer

2b. Gene shuffling results in different combinations of genes and alleles through independent assortment and crossing over.

2c. Sexual reproduction combines alleles from different parents to produce offspring with different genotypes than the parents. Asexual reproduction produces offspring with the same genotype as the parent.

3a. A single-gene trait is a trait controlled by only one gene. A polygenic trait is a trait controlled by two or more genes.

3b. Single-gene traits have just a few distinct phenotypes. Polygenic traits have many possible phenotypes, which often are not clearly distinct from one another.

3c. It is probably a single-gene trait because it has two distinct phenotypes. If it were a polygenic trait, the offspring’s coat color would have more variation.

WRITE ABOUT SCIENCE

4. Mutations are a source of genetic variation in gene pools. Genetic variation is needed for biological evolution to occur. There must be variation in order for some organisms to be better-suited to their environment and thereby pass on more copies of their genes.
Evolution as Genetic Change in Populations

THINK ABOUT IT: Ever since humans began farming, they have battled insects that eat crops. Many farmers now use chemicals called pesticides to kill crop-destroying insects. When farmers first used modern pesticides such as DDT, the chemicals killed most insects. But after a few years, many pesticides stopped working. Today, farmers fight an ongoing “arms race” with insects. Scientists constantly search for new chemicals to control pests that old chemicals no longer control. How do insects fight back? By evolving.

At first, individual pesticides kill almost all insects exposed to them. But a few individual insects usually survive. Why? Because insect populations often contain enough genetic variation that a few individuals, just by chance, are resistant to a particular pesticide. By killing most of the susceptible individuals, farmers increase the relative fitness of the few individuals that can resist the poison. Those insects survive and reproduce, passing their resistance on to their offspring. After a few generations, the descendants of the original, resistant individuals dominate the population.

To understand completely how pesticide resistance develops, you need to know the relationship between natural selection and genetics.

How Natural Selection Works

How does natural selection affect single-gene and polygenic traits?

Pesticide-resistant insects have a kind of fitness that protects them from a harmful chemical. In genetic terms, what does fitness mean? Each time an organism reproduces, it passes copies of its genes on to its offspring. We can, therefore, view evolutionary fitness as success in passing genes to the next generation. In the same way, we can view an evolutionary adaptation as any genetically controlled trait that increases an individual’s ability to pass along its alleles.

Key Questions

How does natural selection affect single-gene and polygenic traits?

What is genetic drift?

What conditions are required to maintain genetic equilibrium?

Vocabulary:
- directional selection
- stabilizing selection
- disruptive selection
- genetic drift
- bottleneck effect
- founder effect
- genetic equilibrium
- Hardy-Weinberg principle
- sexual selection

Taking Notes

Preview Visuals: Before you read, look at Figure 17–6. What evolutionary trend does it seem to show?

Getting Started

Objectives

17.2.1 Explain how natural selection affects single-gene and polygenic traits.

17.2.2 Describe genetic drift.

17.2.3 Explain how different factors affect genetic equilibrium.

Student Resources

Study Workbooks A and B, 17.2 Worksheets
Spanish Study Workbook, 17.2 Worksheets
Lab Manual B, 17.2 Data Analysis Worksheet, Hands-On Activity Worksheet

For corresponding lesson in the Foundation Edition, see pages 409–413.

Activate Prior Knowledge

Based on what they learned in Chapter 16 about Darwin’s theory of evolution, have several students in turn state a fact about, or give an example of, natural selection.

Ask: If Darwin had known what you know about genes, how do you think he would have defined fitness? (Sample answers: possession of genes that enhance survivability; ability of an individual to pass copies of its genes to its offspring)

Teach for Understanding

ENDURING UNDERSTANDING The diversity of life is the result of ongoing evolutionary change. Species alive today have evolved from ancient common ancestors.

GUIDING QUESTION What causes a population’s gene pool to change?

EVIDENCE OF UNDERSTANDING After the lesson, give students the following assessment to determine whether they understand the role of chance events in the evolution of small populations. Have pairs of students use coin tosses to simulate the effects of chance on the allele frequencies in a population of 10 individuals. In the first generation, there are 10 “heads” alleles and 10 “tails” alleles. Students should assume that there are 10 individuals in the next generation. Students should toss the coin twice for each individual in the next generation and record the outcomes of the tosses. After pairs compare their new allele frequencies, have each student write a brief explanation of whether genetic drift has occurred.

UNIFYING CONCEPTS AND PROCESSES

I, II, III, IV

CONTENT

C.2.c, C.3.a, C.3.b, C.3.c

INQUIRY

A.1.b, A.1.c, A.2.a, A.2.d
LESSON 17.2

Natural Selection on Single-Gene Traits

Recall that evolution is any change over time in the allele frequency in a population. This process works somewhat differently for single-gene traits than for polygenic traits.

Limitation on single-gene traits can lead to changes in allele frequencies and, thus, to changes in phenotype frequencies. For example, imagine that a population of lizards experiences mutations in one gene that determines body color. The normal color of the lizards is brown. The mutations produce red and black forms, as shown in Figure 17–6. What happens to the new alleles? If red lizards are more visible to predators, they might be less likely to survive and reproduce. Therefore, the allele for red coloring might not become common.

Black lizards, on the other hand, might absorb more sunlight and warm up faster on cold days. If high body temperature allows the lizards to move faster to feed and avoid predators, they might produce more offspring than brown forms produce. The allele for black color might increase in frequency. The black phenotype would then increase in frequency. If color change has no effect on fitness, the allele that produces it will not be under pressure from natural selection.

Answers

FIGURE 17–6 Red lizards have been selected against because they are more visible to predators, while black lizards have been selected for because they can move faster and avoid predators. As a result, red lizards have been eliminated and black lizards have become more common.

IN YOUR NOTEBOOK Directional selection shifts the range of phenotypes toward one end of the curve because phenotypes at this end are more fit. Stabilizing selection narrows the curve without shifting it from the center because phenotypes at the center of the curve are more fit. Disruptive selection causes the curve to split into a higher and lower peak because phenotypes at both ends of the curve are more fit.

Natural Selection on Polygenic Traits

When traits are controlled by more than one gene, the effects of natural selection are more complex. As you saw earlier, polygenic traits such as height often display a range of phenotypes that form a bell curve. The fitness of individuals may vary from one end of such a curve to the other. Where fitness varies, natural selection can act.

Natural selection on polygenic traits can affect the relative fitness of phenotypes and thereby produce one of three types of selection: directional selection, stabilizing selection, or disruptive selection. These types of selection are shown in Figure 17–7.
**Directional Selection** When individuals at one end of the curve have higher fitness than individuals in the middle or at the other end, directional selection occurs. The range of phenotypes shifts because some individuals are more successful at surviving and reproducing than are others.

Consider how limited resources, such as food, can affect individuals’ fitness. Among seed-eating birds such as Darwin’s finches, birds with bigger, thicker beaks can feed more easily on larger, harder, thicker-shelled seeds. Suppose the supply of small and medium-size seeds runs low, leaving only larger seeds. Birds with larger beaks would have an easier time feeding than would small-beaked birds. Big-beaked birds would therefore be more successful in surviving and passing genes to the next generation. Over time, the average beak size of the population would probably increase.

**Stabilizing Selection** When individuals near the center of the curve have higher fitness than individuals at either end, stabilizing selection takes place. This situation keeps the center of the curve at its current position, but it narrows the curve overall.

For example, the mass of human infants at birth is under the influence of stabilizing selection. Very small babies are likely to be less healthy and, thus, less likely to survive. Babies who are much larger than average are likely to have difficulty being born. The fitness of these smaller or larger babies is, therefore, lower than that of more average-size individuals.

**Disruptive Selection** When individuals at the outer ends of the curve have higher fitness than individuals near the middle of the curve, disruptive selection occurs. Disruptive selection acts against individuals of an intermediate type. If the pressure of natural selection is strong and lasts long enough, this situation can cause the single curve to split into two. In other words, disruptive selection creates two distinct phenotypes.

Suppose a bird population lives in an area where medium-size seeds become less common and large and small seeds become more common. Birds with unusually small or large beaks would have higher fitness. As shown in the graph, the population might split into two groups: one with smaller beaks and one with larger beaks.

Use Visuals

After students have studied the three graphs in Figure 17–7, ask them to describe how each graph would look if fitness parameters changed. This will require students to apply what they learned about selection on polygenic traits.

**Ask** If large seeds became scarce and there were more small seeds available, how would this affect the curve for directional selection? *(The curve would probably shift to the left.)*

**Ask** If medical advances led to large babies having a better chance of surviving, how would this affect the curve for stabilizing selection? *(The curve would shift to the right.)*

**Ask** If more medium-sized seeds became available and small and large seeds became scarce, how would this affect the curve for disruptive selection? *(The curve would shift back to having one central peak.)*

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** To help students differentiate between the three types of selection, carefully go over each graph with them. Make sure that students understand how to interpret the different lines and the graph axes. Call attention to the key at the top of Figure 17–7.

**Ask** What does the dashed line show? *(the original distribution of phenotypes)* What does the solid line show? *(the distribution that resulted from selection)*

Then discuss what the horizontal and vertical axes show in each graph.

**Ask** In each of the graphs, what does the arrow along the horizontal axis indicate? *(an increase in size)*

Students can see how directional, stabilizing, and disruptive selection change the distribution of phenotypes for a polygenic trait over time in *Art in Motion: Natural Selection.*
LESSON 17.2

Connect to Environmental Science

Explain that the founder effect may be especially likely to occur following a major change in the environment, such as a forest fire, landslide, volcanic eruption, or human destruction of a habitat. Challenge students to describe a scenario in which an environmental change such as this leads to the founder effect. (Sample answer: a fire might isolate a few mice in a small remnant of forest.)

DIFFERENTIATED INSTRUCTION

Special Needs Adapt the Connect to Environmental Science activity for hearing-impaired students. Write the examples of environmental change on the board or show pictures to illustrate them. When you discuss the disasters and ask students to describe how they might lead to the founder effect, be sure to face students when you speak. For example, don’t speak as you are writing on the board. Also avoid standing with your back to a window so your face is not in shadow. Give students the option of putting their descriptions in writing.

Address Misconceptions

Mechanisms of Evolution A common misconception about natural selection is that it is the only mechanism of evolution. Be sure to clear up this misconception, or students might not appreciate that genetic drift can also be a potent force of evolution. Make certain students understand that genetic drift can lead to evolution of a population entirely independent of natural selection.

Answers

FIGURE 17–8 The two populations of descendants are different because they were founded by small subgroups of the original population that were, by chance, genetically very different from one another.

Genetic Drift

What is genetic drift?

Natural selection is not the only source of evolutionary change. In small populations, an allele can become more or less common simply by chance. In small populations, individuals that carry a particular allele may leave more descendants than other individuals leave, just by chance. Over time, a series of chance occurrences can cause an allele to become more or less common in a population. This kind of random change in allele frequency is called genetic drift.

Genetic Bottlenecks Sometimes, a disaster, such as disease, can kill many individuals in a population. Just by chance, the smaller population’s gene pool may have allele frequencies that are different from those of the original gene pool. If the reduced population later grows, its alleles will be different in frequency from the original population’s. The bottleneck effect is a change in allele frequency following a dramatic reduction in the size of a population. A severe bottleneck effect can sharply reduce a population’s genetic diversity.

The Founder Effect Genetic drift may also occur when a few individuals colonize a new habitat. These founding individuals may carry alleles that differ in relative frequencies from those of the main population, just by chance. The new gene pool may therefore start out with allele frequencies different from those of the parent gene pool, as shown in Figure 17–8. This situation, in which allele frequencies change as a result of the migration of a small subgroup of a population, is known as the founder effect.

One example of the founder effect is the evolution of several hundred species of fruit flies on different Hawaiian islands. All those species descended from the same mainland fruit fly population. However, species on different islands have allele frequencies that are different from those of the original species.

Quick Facts

TRISTAN DA CUNHA

The tiny island of Tristan da Cunha in the South Atlantic provides an interesting example of the founder effect in humans. The island was originally settled by about 15 English immigrants in the early 1800s, and only a small number of people immigrated to the island after that. Today, the island has a population of about 250 people, and virtually all of them are related to one another, as evidenced by the fact that there are only seven different surnames on the island. One of the founders of the population apparently carried a recessive allele for a type of blindness called retinitis pigmentosa. This genetic disease is very rare in the English parent population but has a relatively high frequency in the population of Tristan da Cunha. This shows how the founder effect can lead to major changes in allele frequencies.
Allele Frequency

The Hardy-Weinberg principle can be used to predict the frequencies of certain genotypes if you know the frequency of other genotypes. Imagine, for example, that you know of a genetic condition, controlled by two alleles S and s, which follow the rule of simple dominance at a single locus. The condition affects only homozygous recessive individuals. (The heterozygous phenotype shows no symptoms.) The population you are studying has a population size of 10,000 and there are 36 individuals affected by the condition. Based on this information, use the Hardy-Weinberg equations to answer the following questions.

Evolution Versus Genetic Equilibrium

What conditions are required to maintain genetic equilibrium?

One way to understand how and why populations evolve is to imagine a model of a hypothetical population that does not evolve. If a population is not evolving, allele frequencies in its gene pool do not change, which means that the population is in genetic equilibrium.

Sexual Reproduction and Allele Frequency

Gene shuffling during sexual reproduction produces many gene combinations. But a century ago, researchers realized that meiosis and fertilization, by themselves, do not change allele frequencies. So hypothetically, a population of sexually reproducing organisms could remain in genetic equilibrium.

The Hardy-Weinberg Principle

The Hardy-Weinberg principle states that allele frequencies in a population should remain constant unless one or more factors cause those frequencies to change. The Hardy-Weinberg principle makes predictions like Punnett squares—but for populations, not individuals. Here’s how it works. Suppose that there are two alleles for a gene: A (dominant) and a (recessive). A cross of these alleles can produce three possible genotypes: AA, Aa, and aa. The frequencies of genotypes in the population can be predicted by these equations, where p and q are the frequencies of the dominant and recessive alleles:

In symbols:

\[ p^2 + 2pq + q^2 = 1 \text{ and } p + q = 1 \]

In words:

\[
\text{(frequency of AA) + (frequency of Aa) + (frequency of aa)}
= 100\% \text{ and } \left(\text{frequency of } A\right) + \left(\text{frequency of } a\right) = 100\%.
\]

Suppose that, in one generation, the frequency of the A allele is 40 percent (\(p = 0.40\)) and the frequency of the a allele is 60 percent (\(q = 0.60\)).

ANSWERS

1. frequency of \(S = p = 94\% = 0.94\); frequency of \(s = q = 6\% = 0.06\)  
2. \(SS\) frequency = \(p^2 = 0.8836 = 88.36\%\)  
   \(Ss\) frequency = \(2pq = 0.1128 = 11.28\%\)  
   \(ss\) frequency = \(q^2 = 0.0036 = 0.36\%\)  
3. Percentage of people carrying the allele = percentage of asymptomatic carriers (heterozygotes) + percentage of homozygotes = \(2pq + q^2 = 11.64\%\).  

Expand Vocabulary

Genetic equilibrium is an important concept in evolution, so students should have a good understanding of the term. Begin with the word equilibrium. Tell students that the prefix equi- means “equal,” and the rest of the term comes from the Latin word libra, which means “weight.” Have students make a Cause and Effect Diagram to show the five conditions that lead to genetic equilibrium, or no change in allele frequencies.

Study Wkbks A/B, Appendix S18, Cause and Effect Diagram. Transparencies, GO1.

DIFFERENTIATED INSTRUCTION

Struggling Students

To help students understand the concept of genetic equilibrium, draw a seesaw with a child at each end. Point out that if the children are equal in weight, the seesaw will be balanced. Ask students to volunteer a definition of equilibrium based on this analogy. (state of balance) Then ask them what the term genetic equilibrium means. (state in which the allele frequencies in a population are in balance) Have students compare their definitions with the definition in the text.
Assess and Remediate

LESSON 17.2

Assessment Answers

1a. Natural selection can lead to changes in the frequencies of the alleles for a single-gene trait and, thus, to changes in phenotype frequencies.

1b. Directional selection shifts the distribution of phenotypes toward one end of the range because phenotypes at this end are most fit. Disruptive selection results when phenotypes at both ends of the range are more fit than phenotypes in the middle, or average, range.

2a. Genetic drift is a random change in allele frequency that occurs in small populations due to chance occurrences.

2b. A small number of individuals from a parent population may found a new population. Just by chance, these individuals may carry alleles in different relative frequencies than the parent population. The new gene pool will start out with different allele frequencies from the parent gene pool.

3a. The population must be very large; there can be no mutations; there must be random mating; there can be no movement into or out of the population; there can be no natural selection.

3b. Actual populations are unlikely to meet all five conditions that are required to maintain genetic equilibrium.

4. No, because under new environmental conditions, organisms with different characteristics will be more likely to survive and reproduce. The frequency of the alleles that produce these traits will likely increase.

b. Infer Why is genetic equilibrium uncommon in actual populations?

Evolution

4. Do you think populations stay in genetic equilibrium after the environment has changed significantly? Explain your answer.

The Hardy-Weinberg principle predicts that five conditions can disturb genetic equilibrium and cause evolution to occur: (1) nonrandom mating; (2) small population size; and (3) immigration or emigration; (4) mutations; or (5) natural selection.

Nonrandom Mating In genetic equilibrium, individuals must mate with other individuals at random. But in many species, individuals select mates based on heritable traits, such as size, strength, or coloration, a practice known as sexual selection. When sexual selection is at work, genes for the traits selected for or against are not in equilibrium.

Small Population Size Genetic drift does not usually have major effects in large populations, but can affect small populations strongly. Evolutionary change due to genetic drift thus happens more easily in small populations.

Immigration or Emigration Individuals who join a population may introduce new alleles into the gene pool, and individuals who leave may remove alleles. Thus, any movement of individuals into or out of a population can disrupt genetic equilibrium.

Mutations Mutations can introduce new alleles into a gene pool, thereby changing allele frequencies and causing evolution to occur.

Natural Selection If different genotypes have different fitness, genetic equilibrium will be disrupted, and evolution will occur.

Note that one or more of these conditions usually holds for real populations. This means that, in most species, most of the time, evolution happens.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.
Biology & Society

Should Antibiotic Use Be Restricted?

Natural selection and evolution aren’t just about fossils and finches. Many disease-causing bacteria are evolving resistance to antibiotics—drugs intended to kill them or interfere with their growth.

During your lifetime, antibiotics have always been available and effective. So it is probably hard for you to imagine what life was like before antibiotics were discovered. It wasn’t pleasant. During the 1930s, it was not unusual for half of all children in a family to die from bacterial infections that are considered trivial today.

When antibiotics were developed, they rapidly became one of medicine’s greatest weapons. Antibiotics saved thousands of lives during World War II by controlling bacterial infections among wounded soldiers. Soon, many bacterial diseases, such as pneumonia, posed much less of a threat. That’s why antibiotics were called “magic bullets” and “wonder drugs.” But the magic is fading as bacteria evolve.

Bacterial populations have always contained a few individuals with mutations that enabled them to destroy, inactivate, or eliminate antibiotics. But those individuals didn’t have higher fitness, so those mutant alleles didn’t become common.

Then, doctors began prescribing antibiotics widely, and farmers started feeding antibiotics to farm animals to prevent infections. As a result, antibiotics have become a regular part of the environment for bacteria.

In this new environment, individuals with resistance alleles have higher fitness, so the resistance alleles increase in frequency. Also, resistance alleles can be transferred from one bacterial species to another on plasmids. Thus, disease-causing bacteria can pick up resistance from harmless strains.

Many bacteria, including those that cause tuberculosis and certain forms of staph infections, are evolving resistance to not just one antibiotic, but to almost all medicines known. Many doctors are terrified. They fear the loss of one of the vital weapons against bacterial disease. Given this problem, should government agencies restrict antibiotic use?

The Viewpoints

Restrict Antibiotic Use Some people think that the danger of an incurable bacterial epidemic is so high that the government must take action. Doctors overuse antibiotics because patients demand them. The livestock industry likes using antibiotics and will not change their practice unless forced to do so.

Don’t Restrict Use Other people think that the doctors and the livestock industry need the freedom to find solutions that work best for them. Researchers are constantly developing new drugs. Some of these drugs can be reserved for human use only.

Research and Decide

1. Analyze the Viewpoints Learn more about this issue by consulting library and Internet resources. Then, list the advantages and disadvantages of restricting antibiotic use.

2. Form Your Opinion Should antibiotics be restricted? Would regulations be more appropriate in some situations than in others?

Quick Facts

MRSA

You have probably heard about MRSA in the news. It stands for methicillin-resistant Staphylococcus aureus, a strain of bacteria that has evolved resistance to most antibiotics. MRSA causes serious skin infections. It may also cause pneumonia or infections of other vital organs besides the lungs, with a high fatality rate. Until recently, most MRSA infections occurred in hospitals and nursing homes, but infections outside of these settings are becoming increasingly common. In community settings, young children and people who play contact sports are at greatest risk.

Teach

Lead a Discussion

Show students an example of the label that is always affixed to antibiotic prescription bottles, warning patients to take all of the medication. Tell students that, despite these warning labels, patients often discontinue antibiotics when they start feeling better.

Ask How might this practice help bacteria evolve antibiotic resistance? (Some bacteria survive in the patient’s body even after the patient stops taking the medicine and may evolve into a new, antibiotic-resistant strain.)

Ask How can patients help prevent antibiotic resistance from becoming more prevalent? (by finishing any antibiotics that are prescribed for them)

Answers

RESEARCH AND DECIDE

1. Advantages of restricting antibiotic use include a reduced risk of bacteria becoming resistant to antibiotics and therefore less danger of people succumbing to a disease caused by antibiotic-resistant bacteria or of epidemics of diseases caused by antibiotic-resistant bacteria. Disadvantages include a possible reduction in the food supply because of an increase in infections in farm animals, and a decrease in the options that doctors and farmers have to treat and prevent disease.

2. Accept any answers that are supported by facts and logical opinions.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP IV
CONTENT C.2.c, C.3.a, G.1
INQUIRY A.1.f
Getting Started

Objectives

17.3.1 Identify the types of isolation that can lead to the formation of new species.
17.3.2 Describe the current hypothesis about Galápagos finch speciation.

Student Resources

Study Workbooks A and B, 17.3 Worksheets
Spanish Study Workbook, 17.3 Worksheets
Biology.com: Lesson Overview • Lesson Notes • Activities: Data Analysis, Tutor Tube • Assessment: Self-Test, Lesson Assessment


Activate Prior Knowledge

Remind students of some of the techniques for selective breeding and increasing genetic variation they learned about in Lesson 15.1. Many of the steps in these processes, such as preventing particular organisms from breeding and introducing mutations, are similar to what occurs naturally during the process of speciation.

Students may infer that the isolation might lead to the emergence of new virus strains. Students can go online to Biology.com to gather their evidence.

UNIFYING CONCEPTS AND PROCESSES

II, III, IV, V

CONTENT

C.2.c, C.3.a, C.3.b, C.3.d, C.6.c, G.1

INQUIRY

A.2.a, A.2.b, A.2.e, A.2.f

Think About It

How does one species become two? Natural selection and genetic drift can change allele frequencies, causing a population to evolve. But a change in allele frequency by itself does not lead to the development of a new species.

Isolating Mechanisms

What types of isolation lead to the formation of new species?

Biologists define a species as a population or group of populations whose members can interbreed and produce fertile offspring. Given this genetic definition of species, what must happen for one species to divide or give rise to a new species? The formation of a new species is called speciation.

Interbreeding links members of a species genetically. Any genetic changes can spread throughout the population over time. But what happens if some members of a population stop breeding with other members? The gene pool can split. Once a population has thus split into two groups, changes in one of those gene pools cannot spread to the other. Because these two populations no longer interbreed, reproductive isolation has occurred. When populations become reproductively isolated, they can evolve into two separate species. Reproductive isolation can develop in a variety of ways, including behavioral isolation, geographic isolation, and temporal isolation.

The Process of Speciation

Key Questions

What types of isolation lead to the formation of new species?

What is a current hypothesis about Galápagos finch speciation?

Vocabulary

species
speciation
reproductive isolation
behavioral isolation
geographic isolation
temporal isolation

Taking Notes

Compare/Contrast Table
In a compare/contrast table, describe the three mechanisms of reproductive isolation.

Isolating mechanisms are essential to the formation of new species. Reproductive isolation occurs when members of a species share a common gene pool. Over time, genes are shared by interbreeding. Over time, isolated gene pools diverge into separate species.

Members of a species share a common gene pool. Over time, genes are shared by interbreeding.

Over time, isolated gene pools diverge into separate species.

FIGURE 17–11 Diverging Gene Pools

If two populations of a species become reproductively isolated, their gene pools can diverge, producing new species.

Teach for Understanding

ENDURING UNDERSTANDING

The diversity of life is the result of ongoing evolutionary change. Species alive today have evolved from ancient common ancestors.

GUIDING QUESTION

How do new species form?

EVIDENCE OF UNDERSTANDING

After completing the lesson, give students the following assessment to evaluate whether they understand how new species form from an ancestor species. Have students write on separate note cards a brief summary of each step in the speciation of Darwin’s finches. Then have them shuffle the cards and try to put them back in the correct order.

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**Behavioral Isolation** Suppose two populations that are capable of interbreeding develop differences in courtship rituals or other behaviors. **Behavioral isolation** can then occur. For example, eastern and western meadowlarks are similar birds whose habitats overlap. But, members of the two species will not mate with each other, partly because they use different songs to attract mates. Eastern meadowlarks don’t respond to western meadowlark songs, and vice versa.

**Geographic Isolation** When two populations are separated by geographic barriers such as rivers, mountains, or bodies of water, **geographic isolation** occurs. The Abert’s squirrel in **Figure 17–12**, for example, lives in the Southwest. About 10,000 years ago, a small population became isolated on the north rim of the Grand Canyon. Separate gene pools formed. Genetic changes that appeared in one group were not passed to the other. Natural selection and genetic drift worked separately on each group and led to the formation of a distinct subspecies, the Kaibab squirrel. The Abert’s and Kaibab squirrels are very similar, indicating that they are closely related. However, the Kaibab squirrel differs from the Abert’s squirrel in significant ways, such as fur coloring.

Geographic barriers do not always guarantee isolation. Floods, for example, may link separate lakes, enabling their fish populations to mix. If those populations still interbreed, they remain a single species. Also, a geographic barrier may separate certain organisms but not others. A large river may keep squirrels and other small rodents apart but probably won’t isolate bird populations.

**Temporal Isolation** A third isolating mechanism, known as **temporal isolation**, happens when two or more species reproduce at different times. For example, suppose three similar species of orchids live in the same rain forest. Each species has flowers that last only one day and must be pollinated on that day to produce seeds. Because the species bloom on different days, they cannot pollinate one another.

**Biology In-Depth**

**POSTMATING ISOLATING MECHANISMS**

The three types of reproductive isolating mechanisms described on this page prevent mating between organisms of different species. They are referred to generally as premating mechanisms. Other isolating mechanisms, called postmating mechanisms, occur at some point after mating occurs. For example, male gametes may be unable to reach female gametes because of differences in the anatomy of the reproductive organs. If male gametes do reach female gametes, they may be unable to fertilize them due to genetic differences in the gametes. If fertilization takes place and offspring are produced, the offspring may not survive, may be unable to reproduce, or may produce offspring of their own that are nonviable or infertile.

**Teach**

**Lead a Discussion**

Challenge students to infer the reproductive characteristics of species that are isolated by different mechanisms.

**Ask** What can you infer about species that are isolated by behavioral isolation? (They are likely to have complex mating behaviors, such as courtship rituals.)

**Ask** What can you infer about species that are isolated by temporal isolation? (Their reproductive behavior is likely to be limited to certain times of day or days of the year.)

**DIFFERENTIATED INSTRUCTION**

**LPR** **Less Proficient Readers** Suggest students make a **Concept Map** to show the types of isolating mechanisms that lead to speciation.


**ELL** **Focus on ELL:** **Build Background**

**BEGINNING SPEAKERS** Help students understand that visuals often provide clues to the meaning of text. Call students’ attention to the photos in **Figure 17–12**. Have an English-proficient student who speaks the beginners’ native language ask the beginners what the photographs show. (two different kinds of squirrels separated by the Grand Canyon) Ask the English-proficient student to explain the concept of geographic isolation to the beginning students, and to relate the concept to the map and the photos.

Then point with your finger to the title of the figure, **Geographic Isolation**. With gestures, help students see that the title of the figure is the same as the blue heading and also the same as a yellow-highlighted vocabulary term. Help students understand that **Figure 17–12** is a visual representation of the text explanation of geographic isolation. Later in the lesson, when you discuss the process of speciation, reinforce the idea that visuals usually help clarify concepts explained in the written text.

**Answers**

**FIGURE 17–12** the Grand Canyon

**IN YOUR NOTEBOOK** When organisms reproduce at different times, they cannot interbreed. For example, when flowers bloom at different times, they cannot pollinate one another.
Lead a Discussion

Discuss the role of the founder effect and natural selection in the speciation of Darwin’s finches.

**Ask** How might the founder effect have contributed to genetic variation in finch populations on different islands? (Only a few finches are likely to have crossed to other islands from the first island the finches inhabited. Their allele frequencies could have differed, by chance, from those of finches on the first island.)

**Ask** Why did selection increase genetic variation among finches on the different islands? (Different traits were selected for, because the islands had different environments.)

**Ask** How did selection lead to speciation? (Selection led to different beak sizes, and differences in beak size prevented finches from mating. Therefore, the populations were reproductively isolated. Once populations have become reproductively isolated, they are separate species.)

**DIFFERENTIATED INSTRUCTION**

**LPR** Less Proficient Readers Have students make a Flowchart showing how the process of speciation occurred in Darwin’s finches.

**Study Wkbks A/B, Appendix S25, Flowchart. Transparencies, GO8.**

**LS** Advanced Students The Chapter 16 Mystery described a similar process of speciation that occurred on the Hawaiian Islands several million years ago in birds called honeycreepers. Ask interested students to learn about speciation in Hawaiian honeycreepers and then use maps of the islands to explain to the class what happened. Have them point out similarities and differences between speciation in the honeycreepers and Darwin’s finches.

**BIOLOGY.com** Have students use Data Analysis: Galápagos Finches: Evolution in Action to explore the data from the Grants’ study of Darwin’s finches. Then, have students use Tutor Tube: Organizing the Vocabulary of Speciation to help them organize what they have learned about the mechanisms of speciation.

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**Speciation in Darwin’s Finches**

What is a current hypothesis about Galápagos finch speciation?

Recall that Peter and Rosemary Grant spent years on the Galápagos islands studying changes in finch populations. The Grants measured and recorded anatomical characteristics such as beak length of individual medium ground finches. Many of the characteristics appeared in bell-shaped distributions typical of polygenic traits. As environmental conditions changed, the Grants documented directional selection among the traits. When drought struck the island of Daphne Major, finches with larger beaks capable of cracking the thickest seeds survived and reproduced more often than others. Over many generations, the proportion of large-beaked finches increased.

We can now combine these studies by the Grants with evolutionary concepts to form a hypothesis that answers a question: How might the founder effect and natural selection have produced reproductive isolation that could have led to speciation among Galápagos finches?

According to this hypothesis, speciation in Galápagos finches occurred by founding of a new population, geographic isolation, changes in the new population’s gene pool, behavioral isolation, and ecological competition.

**Founders Arrive** Many years ago, a few finches from South America—species M—arrived on one of the Galápagos islands, as shown in Figure 17–13. These birds may have gotten lost or been blown off course by a storm. Once on the island, they survived and reproduced. Because of the founder effect, allele frequencies of this founding finch population could have differed from allele frequencies in the original South American population.

**Geographic Isolation** The island’s environment was different from the South American environment. Some combination of the founder effect, geographic isolation, and natural selection enabled the island finch population to evolve into a new species—species A. Later, a few birds from species A crossed to another island. Because these birds do not usually fly over open water, they move from island to island very rarely. Thus, finch populations on the two islands were genetically isolated from each other and no longer shared a common gene pool.

**Changes in Gene Pools** Over time, populations on each island adapted to local environments. Plants on the first island may have produced small, thin-shelled seeds, whereas plants on the second island may have produced larger, thick-shelled seeds. On the second island, directional selection would have favored individuals with larger, heavier beaks. These birds could crack open and eat the large seeds more easily. Thus, birds with large beaks would be better able to survive on the second island. Over time, natural selection would have caused that population to evolve larger beaks, forming a distinct population, B, characterized by a new phenotype.

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**Check for Understanding**

**ORAL QUESTIONING**

Ask students to respond to the following question on a piece of paper: In the speciation in Darwin’s finches, why did geographic isolation have to occur before changes happened in the two gene pools? (If geographic isolation hadn’t happened first, there would not have been two distinct populations with separated gene pools.)

**ADJUST INSTRUCTION**

If students do not understand the sequence, refer them to Figure 17–11. Use this diagram to show how two distinct gene pools develop after populations become isolated from one another.
Behavioral Isolation Now, imagine that a few birds from the second island cross back to the first island. Will population-A birds breed with population-B birds? Probably not. These finches choose mates carefully. During courtship, they closely inspect a potential partner’s beak. Finches prefer to mate with birds that have the same-size beak as they do. Big-beaked birds prefer to mate with other big-beaked birds, and smaller-beaked birds prefer to mate with other smaller-beaked birds. Because the populations on the two islands have evolved differently sized beaks, they would probably not mate with each other.

Thus, differences in beak size, combined with mating behavior, could lead to reproductive isolation. The gene pools of the two bird populations remain isolated—even when individuals live in the same place. The populations have now become two distinct species.

Competition and Continued Evolution As these two new species live together on the first island, they compete for seeds. During the dry season, birds that are most different from each other have the highest fitness. That is because the more specialized birds have less competition for certain kinds of seeds and other foods. Over time, species evolve in a way that increases the differences between them. The species-B birds on the first island may evolve into a new species, C.

The combined processes of geographic isolation on different islands, genetic change, and behavioral isolation could have repeated itself again and again across the Galápagos chain. Over many generations, the process could have produced the 13 different finch species found there today.

In Your Notebook Explain how natural selection and behavioral isolation may have lead to reproductive isolation in Darwin’s finches.

17.3 Assessment

Review Key Concepts

1. a. Review What is geographic isolation?
   b. Predict A newly formed lake divides a population of a beetle species into two groups. What other factors besides isolation might lead to the two groups becoming separate species?

2. a. Review What types of reproductive isolation may have been important in Galápagos finch speciation? Explain.
   b. Apply Concepts Explain how the vegetarian tree finch, which feeds on fruit, might have evolved.

Assessment Answers

1a. Geographic isolation is the situation in which two populations cannot interbreed because they are separated by geographic barriers, such as rivers.

1b. Sample answer: the founder effect and varied selection pressures in different environments

2a. Geographic isolation may have been important initially as populations of finches became separated on different islands, because they would no longer share a common gene pool. Later, if different species lived in the same place, behavioral isolation may have been important. The birds now had different-sized beaks and would not mate with each other, so their gene pools remained isolated.

2b. Finches that ate seeds or insects may have arrived on an island where fruit was available. Birds with beak variations that made them better-suited for eating fruit would have been favored by selection. Eventually, selection might have led to the evolution of a new species of fruit-eating finches.

3. Temporal isolation occurs when two or more species reproduce at different times, such as different times of day or days of the year.

4. Yes, because organisms on an island are geographically isolated from organisms that do not live on the same island.
Getting Started

Objectives
17.4.1 Explain how molecular clocks are used.
17.4.2 Explain how new genes evolve.
17.4.3 Describe how Hox genes may be involved in evolutionary change.

Student Resources
Study Workbooks A and B, 17.4 Worksheets
Spanish Study Workbook, 17.4 Worksheets

Build Background
On the board, draw a short section of DNA. Call on a student to sketch the same section of DNA on the board with a single point mutation. Call on another student to sketch the section of DNA with an additional point mutation. Tell students they will learn how DNA mutations like these reveal how species are related.

Answers
IN YOUR NOTEBOOK A neutral mutation is more likely to persist in a population than a negative one, because a negative mutation is likely to be eliminated by natural selection.

Build Background

Timing Lineage Splits: Molecular Clocks

What are molecular clocks?
When researchers use a molecular clock, they compare stretches of DNA to mark the passage of evolutionary time. A molecular clock uses mutation rates in DNA to estimate the time that two species have been evolving independently.

Neutral Mutations as “Ticks” To understand molecular clocks, think about old-fashioned pendulum clocks. They mark time with a swinging pendulum. A molecular clock also relies on a repeating process to mark time—mutation. As you’ve learned, simple mutations occur all the time, causing slight changes in the sequence of DNA. Some mutations have a major positive or negative effect on an organism’s phenotype. These types of mutations are under powerful pressure from natural selection.

Many mutations, however, have no effect on phenotype. These neutral mutations tend to accumulate in the DNA of different species at about the same rate. Researchers can compare such DNA sequences in two species. The comparison can reveal how many mutations have occurred independently in each group, as shown in Figure 17–18. The more differences there are between the DNA sequences of the two species, the more time has elapsed since the two species shared a common ancestor.

THINK ABOUT IT Recall that an organism’s genome is its complete set of genetic information. Thousands of ongoing projects are analyzing the genomes of organisms ranging from viruses to humans. The analysis of genomes enables us to study evolution at the molecular level. By comparing DNA sequences from all of these organisms, we can often solve important evolutionary puzzles. For example, DNA evidence may indicate how two species are related to one another, even if their body structures don’t offer enough clues.

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The use of molecular clocks is not simple, because there is not just one molecular clock in a genome. There are many different clocks, each of which “ticks” at a different rate. This is because some genes accumulate mutations faster than others. These different clocks allow researchers to time different evolutionary events. Think of a conventional clock. If you want to time a brief event, you use the second hand. To time an event that lasts longer, you use the minute hand or the hour hand. In the same way, researchers choose a different molecular clock to compare great apes than to estimate when mammals and fishes shared a common ancestor.

Researchers check the accuracy of molecular clocks by trying to estimate how often mutations occur. In other words, they estimate how often the clock they have chosen “ticks.” To do this, they compare the number of mutations in a particular gene in species whose age has been determined by other methods.

**Gene Duplication**

Where did new genes come from? Modern genes probably descended from a much smaller number of genes in the earliest life forms. But how could that have happened? One way in which new genes evolve is through the duplication, and then modification, of existing genes.

Most organisms carry several copies of various genes. Sometimes organisms carry two copies of the same gene. Other times there may be thousands of copies. Where do those extra copies come from, and what happens to them?

Remember that homologous chromosomes exchange DNA during meiosis in a process called crossing-over. Sometimes crossing-over involves an unequal swapping of DNA. In other words, one chromosome in the pair gets extra DNA. That extra DNA can carry part of a gene, a full gene, or a longer length of chromosome. Sometimes, in different ways, an entire genome can be duplicated.

**Calibrating the Clock**

Think of a conventional clock. If you want to time a brief event, you use the second hand. To time an event that lasts longer, you use the minute hand or the hour hand. In the same way, researchers choose a different molecular clock to compare great apes than to estimate when mammals and fishes shared a common ancestor.

Researchers check the accuracy of molecular clocks by trying to estimate how often mutations occur. In other words, they estimate how often the clock they have chosen “ticks.” To do this, they compare the number of mutations in a particular gene in species whose age has been determined by other methods.

**Teach**

**Lead a Discussion**

Use Figure 17-8 to discuss molecular clocks.

**Ask** Why are neutral mutations, and not negative or positive mutations, used in molecular clocks? (Neutral mutations, unlike positive and negative mutations, are not under pressure from natural selection. Therefore, changes among the genes in which these mutations are found will accumulate at a fairly steady rate.)

**DIFFERENTIATED INSTRUCTION**

**ELL Struggling Students** Pair struggling students to carry out a Think-Pair-Share activity. Ask students to think about why negative and positive mutations do not tend to accumulate at a constant rate in organisms. Have them confer with their partner and present their ideas to the class.

**Study Wkbks A/B, Appendix S14, Think-Pair-Share.**

**Focus on ELL: Extend Language**

**INTERMEDIATE SPEAKERS** Explain that some words have different meanings depending on context. Point out that in everyday usage, a clock is a device for keeping track of time in hours, minutes, and seconds. However, a molecular clock keeps track of the time in which two species have been evolving independently, and the time is measured in millions of years. Point out that the word **molecular** indicates that this type of clock depends on differences between molecules of DNA.

Use this example as a springboard for discussing multiple-meaning words in general. In the first paragraph on this page, for example, tick indicates the sound that a clock makes. Tick can also indicate a tiny animal with eight legs that is related to a spider. Encourage students to share words in their native languages that have more than one meaning.

**Answers**

**FIGURE 17-18** Species B and C differ from one another by just two mutations, and they both differ from species A by four mutations.

**MOLECULAR CLOCKS AND VIRAL EVOLUTION**

Molecular clocks are particularly useful for studying viruses. After all, viruses do not leave fossils, so there is no tangible record of their appearance. Discovering when particular strains of viruses evolved may help explain the origins of important human diseases. Until recently, for example, some researchers speculated that human immunodeficiency virus (HIV) evolved from simian deficiency virus (SIV), when primate tissues contaminated with SIV were used in the manufacture of the oral polio vaccine. If this were true, HIV in humans would have originated in the 1950s, when the vaccine was administered. However, molecular clock data suggest that HIV probably diverged from SIV around 1800 and emerged in humans around 1930. Although the molecular data do not show how HIV evolved, they indicate that the production of the polio vaccine was not the origin.
LESSON 17.4

Build Study Skills

Tell students that, if they can’t explain a topic and make it understandable to another person, they probably do not understand it themselves. Therefore, a useful study skill is to try to explain to someone else what they have read. Give students a chance to practice this skill. Divide the class into pairs, and have partners take turns explaining to one another how duplicate genes evolve. Any students who are unable to provide clear explanations should reread the passage for greater understanding.

DIFFERENTIATED INSTRUCTION

**Advanced Students** Pair advanced students with struggling students. Have the advanced students work with the struggling students to help the latter understand how genes become duplicated and then evolve into genes with new functions. Advanced students should use Figure 17–19 as well as the text explanation. Also encourage them to use the analogy (an essay that is reconfigured for a different purpose) to clarify the process of gene evolution.

**Answers**

1. Hypothesis A indicates that fishes B and G evolved twice from the same ancestor, once in Lake 1 and once in Lake 2. Hypothesis B indicates that fish B evolved from a brown ancestor in Lake 1 and fish G from a gold ancestor in Lake 2.

2. In hypothesis A, brown (B) and gold (G) fish populations each evolved independently.

3. This evidence supports hypothesis A in which the brown and gold fish share a recent common ancestor.

**Purpose** Students will draw conclusions from DNA about evolutionary relationships among fish species.

**Planning** Tell students to study the diagrams of hypotheses A and B carefully, paying close attention to the arrows and the colors of the fishes. Also have them look at the key below the diagram.

**Duplicate Genes Evolve** What’s so important about gene duplication? Think about using a computer to write an essay for English class. You then want to submit a new version of the essay to your school newspaper. So, you make an extra copy of the original file and edit it for the newspaper.

Duplicate genes can work in similar ways. Sometimes, extra copies of a gene undergo mutations that change their function. The original gene is still around, just like the original copy of your English essay. So, the new genes can evolve without affecting the original gene function or product. Figure 17–19 shows how this happens.

**Gene Families** Multiple copies of a duplicated gene can turn into a group of related genes called a gene family. Members of a gene family typically produce similar, yet slightly different, proteins. Your body, for example, produces a number of molecules that carry oxygen. Several of these compounds—called globins—are hemoglobins. The globin gene family that produces these molecules evolved after gene duplication, from a single ancestral globin gene. Some of the most important evolution research focuses on another gene family—Hox genes.

**Developmental Genes and Body Plans** How may Hox genes be involved in evolutionary change?

One exciting new research area is nicknamed “evo-devo” because it studies the relationship between evolution and embryological development. Darwin himself had a hunch that changes in the growth of embryos could transform adult body shape and size. Researchers now study how small changes in Hox gene activity could produce the kinds of evolutionary changes we see in the fossil record.

**Figure 17–19 Gene Duplication** In this diagram, a gene is first duplicated, and then one of the two resulting genes undergoes mutation.

In hypothesis B, the brown (B) fish populations in both lakes evolved from fish type A in Lake 1, and the gold (G) fish populations in both lakes evolved from Fish type A in Lake 2.
**Hox Genes and Evolution**  As you read in Chapter 13, Hox genes determine which parts of an embryo develop arms, legs, or wings. Groups of Hox genes also control the size and shape of those structures. In fact, homologous Hox genes shape the bodies of animals as different as insects and humans—even though those animals last shared a common ancestor no fewer than 500 million years ago!

Small changes in Hox gene activity during embryological development can produce large changes in adult animals. For example, insects and crustaceans are related to ancient common ancestors that possessed dozens of legs. Today’s crustaceans, including shrimp and lobsters, still have large numbers of paired legs, but insects have just 3 pairs of legs. What happened to those extra legs? Recent studies have shown that mutations in a single Hox gene, known as Ubx, turns off the growth of legs in the abdominal regions of insects. Thus, a change in one Hox gene accounts for a major evolutionary difference between two important animal groups.

**Timing Is Everything**  Each part of an embryo begins to grow at a certain time, grows for a specific time, and stops growing at a specific time. Small changes in starting and stopping times can make a big difference in organisms. For example, small timing changes can make the difference between long, slender fingers and short, stubby toes. No wonder “evo-devo” is one of the hottest areas in evolutionary biology!

**Assess and Remediate**

**EVALUATE UNDERSTANDING**

Ask students to use the text and Figure 17–20 to explain why fruit flies and brine shrimp have different numbers of legs. Then, have students complete the 17.4 Assessment.

**REMEDIATION SUGGESTION**

- **Struggling Students**  If students have difficulty answering Question 4, suggest they reread the information about molecular clocks and then carefully compare the order of the bases for Species A, B, and C.

**Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.**
Pre-Lab
Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab
Tell students they will perform the chapter lab Competing For Resources described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY
Students should be careful when using sharp objects and handling seeds. Be aware of any allergies students may have to nuts or seeds.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 420.

Pre-Lab Answers

BACKGROUND QUESTIONS
a. Speciation is the formation of a new species.
b. Sample answer: Over time, populations of finches on different islands no longer shared the same gene pool.
c. An adaptation is a trait that increases an organism’s ability to survive and reproduce in its environment.

PRE-LAB QUESTIONS
1. The tools represent different types of beaks.
2. Answers will vary with the types of tools. Tweezers or small spoons might work well with small seeds. Pliers or ice tongs might work well with large seeds.
3. Sample answer: Limiting the time gives an advantage to those with tools that are better adapted to pick up a certain type of seed.

Problem How can competition lead to speciation?
Materials assorted tools, large and small seeds, large and small paper plates, timer or clock with second hand

Lab Manual Chapter 17 Lab
Skills Focus Use Models, Predict, Apply Concepts

Connect to the Big idea Speciation is not easy to see in nature. Usually, new phenotypes take years to emerge or become common enough to be noticed. Also, new phenotypes can be difficult to track in a complex environment. For scientists who want to study speciation, islands can provide an ideal environment.

Peter and Rosemary Grant spent years studying finches on the Galápagos Islands. They measured and recorded the traits and diets of hundreds of birds. During a year with a severe drought, the Grants were able to observe natural selection in action as food became scarce. In this lab you will model variation in bird beaks and diet to demonstrate the impact of competition on survival and speciation.

Background Questions
a. Review What is speciation?
b. Relate Cause and Effect How did geographic isolation lead to speciation among the Galápagos finches?
c. Compare and Contrast How does an adaptation differ from other inherited traits?
Study Online

**Performance Tasks**

**SUMMATIVE TASK** Have students work in small groups to create a poster illustrating how a hypothetical species splits to form two new species. Groups should use graphs, matrices, or other visuals to represent genes, genotypes, or phenotypes of the original species and its descendant species. They should also identify factors—for example, mutations, founder effect, geographic isolation, and selection—that are responsible for speciation occurring.

**TRANSFER TASK** Ask each student to write a short science-fiction story about a population of imaginary organisms on a planet in space. In their story, students should describe how the organisms evolve and come to have different phenotypes after several generations. The story should include details about conditions such as genetic bottlenecks or severe environmental stresses that cause the population to undergo genetic change.

**Answers**

**THINK VISUALLY**

Students’ concept maps should show that there are three sources of genetic variation: mutation, genetic recombination in sexual reproduction, and lateral gene transfer.
Lesson 17.1

UNDERSTAND KEY CONCEPTS

1. a  2. c  3. b
4. Allele frequency is the number of times an allele occurs in a gene pool, compared with the total number of times all alleles for the same gene occur. For example, in a mouse population, the allele frequency of the allele for black fur might be 40 percent, compared with an allele frequency of 60 percent for the allele for brown fur color.
5. Each chromosome in a pair moves independently during meiosis, producing millions of possible gene combinations in gametes. Crossing-over creates an even greater number of possible gene combinations.
6. The number of phenotypes depends on how many genes control the trait. A single-gene trait with two alleles has at most three phenotypes. A polygenic trait can have many phenotypes.
7. the passing of genes from one organism to another organism that is not its offspring
8. any change in the relative frequency of alleles in the gene pool of a population over time

THINK CRITICALLY

9. a mutation in an egg cell, because it may be passed on to offspring and become part of the gene pool
10. Natural selection acts directly on phenotypes, not genotypes. However, phenotypes depend partly on genotypes, so natural selection may affect allele frequencies in gene pools.
11. Natural selection acts directly on individuals, but the resulting changes in allele frequencies show up at the population level. Populations, rather than individuals, evolve.
12. It increases genetic variation.

Lesson 17.2

UNDERSTAND KEY CONCEPTS

13. b  14. a  15. b
16. success in passing genes to the next generation
17. Stabilizing selection occurs when individuals near the center of the distribution of phenotypes have higher fitness than individuals at either end. It keeps the center of the distribution in the same place but narrows the overall curve. Disruptive selection occurs when individuals at both ends of the distribution have higher fitness than those near the center. It causes the curve to have a peak at both ends and a low point in the center.
18. Genetic equilibrium is the situation in which allele frequencies in a population remain the same. It occurs when the population is very large, there are no mutations, there is random mating, there is no movement into or out of the population, and there is no natural selection.

THINK CRITICALLY

19. For single-gene traits, natural selection leads to a change in frequency of one or a few distinct phenotypes. For polygenic traits, natural selection leads to changes in the frequency distribution of many, slightly different phenotypes. Natural selection on polygenic traits can lead to directional selection, stabilizing selection, or disruptive selection.
20. directional selection
21. no, because there has not been a change in allele frequencies
22. Only insects that were resistant to DDT survived. The small population of survivors had a high frequency of the allele for resistance. With repeated exposure to DDT, natural selection led to the evolution of insect populations with greater DDT resistance.
17.1 High mutation rates in flu viruses and different strains can swap genes if they infect the same host at the same time. These characteristics produce genetic diversity that enables the virus to evolve.

17.2 Flu viruses also undergo natural selection. Think of our bodies as the environment for viruses. Our immune system attacks viruses by “recognizing” proteins on the surface of the viruses. Viruses whose proteins our bodies can recognize and destroy have low fitness. Viruses our bodies can’t recognize have higher fitness.

Viral evolution regularly produces slightly different surface proteins that our immune systems can’t recognize right away. These strains evade the immune system long enough to make people sick. That’s why you can catch the flu every winter, and why new flu vaccines must be made every year.

But now and then, influenza evolution produces radically new molecular “disguises” that our immune systems can’t recognize at all. These can be deadly, like the 1918 strain. If a strain like that were to appear today, it could kill many people. That’s why researchers are worried about “bird flu”—a strain of flu that can pass from birds, such as chickens, to humans.

1. **Connect to the Big idea** Explain why mutation and natural selection make developing new flu vaccines necessary every year.

2. **Infer** People do not need to receive a new measles vaccination every year. What does this suggest about a difference between flu viruses and the measles virus?

3. **Apply Concepts** Can you think of any other issues in public health that relate directly to evolutionary change?

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**Lesson 17.3**

**UNDERSTAND KEY CONCEPTS**

23. **c**

24. **b**

25. Some combination of the founder effect, geographic isolation, and natural selection enabled the finch populations on different Galápagos islands to evolve into new species.

**THINK CRITICALLY**

26. If populations are not reproductively isolated, genetic changes continue to spread among individuals through interbreeding. Only after reproductive isolation can genetic changes cause a divergence between gene pools and, therefore, speciation.

27. Sample answer: The new species originated from the two known species by becoming reproductively isolated, perhaps by flowering at different times, and then had different mutations and selective pressures.
Lesson 17.4

UNDERSTAND KEY CONCEPTS

28. d  29. c

30. During meiosis, crossing-over may involve an unequal swapping of DNA so that one chromosome in the pair gets an extra copy of a gene.

31. mutations that have no effect on phenotype

32. The study of “evo-devo” is the study of the relationship between evolution and embryological development. “Evo-devo” researchers study how small changes in Hox genes produce major evolutionary changes.

THINK CRITICALLY

33. Sample answer: Can we identify the specific changes in genes that determine precisely where an organism’s eyes, limbs, etc., are located?

34. The more recently two species shared a common ancestor, the more similar their genes are likely to be.

Connecting Concepts

USE SCIENCE GRAPHICS

35. The frequency of Allele B steadily decreased over time, while the frequency of Allele b steadily increased over time.

36. In their current environment, individuals with allele b were more likely to survive and reproduce than individuals with allele B.

WRITE ABOUT SCIENCE

37. A mutation may have occurred in one or more Hox genes controlling the development of legs. The mutated gene might “turn off” the growth of some pairs of legs.

38. Ecology is the scientific study of interactions among organisms and between organisms and their environment. These same interactions also determine the nature of natural selection in populations. For example, predator-prey relationships or availability of food plants may favor certain phenotypes, which are more likely to pass copies of their genes to the next generation. Ecological conditions change through time, leading to changes in selective pressures and the evolution of populations.

Understand Key Concepts

28. A group of related genes that resulted from the duplication and modification of a single gene is called a
   a. gene pool.
   b. molecular clock.
   c. lateral gene transfer.
   d. family.

29. Each “tick” of a molecular clock is an occurrence of
   a. gene drift.
   b. crossover.
   c. DNA mutation.
   d. mitosis.

30. How do chromosomes gain an extra copy of a gene during meiosis?

31. What are neutral mutations?

32. What is the study of “evo-devo,” and how is it related to evolution?

Think Critically

33. Pose Questions What kinds of questions would scientists who are studying the evolution of Hox genes most likely be asking?

34. Apply Concepts Describe the relationship between evolutionary time and the similarity of genes in two species.

Use Science Graphics

Use the data table to answer questions 35 and 36.

<table>
<thead>
<tr>
<th>Year</th>
<th>Frequency of Allele B</th>
<th>Frequency of Allele b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1910</td>
<td>0.81</td>
<td>0.19</td>
</tr>
<tr>
<td>1930</td>
<td>0.49</td>
<td>0.51</td>
</tr>
<tr>
<td>1950</td>
<td>0.25</td>
<td>0.75</td>
</tr>
<tr>
<td>1970</td>
<td>0.10</td>
<td>0.90</td>
</tr>
</tbody>
</table>

35. Interpret Tables Describe the trend shown by the data in the table.

36. Form a Hypothesis What might account for the trend shown by the data?

Write About Science

37. Explanation Explain the process that may have caused fruit flies to have fewer legs than their ancestors had.

38. Assess the Big Idea Sometimes, biologists say, “Evolution is ecology over time.” Explain that statement.

39. Interpret Graphs What is the shortest beak length observed in species A?
   a. 3 mm
   b. 6 mm
   c. 9 mm
   d. 12 mm

40. Analyze Data Which of the following is a logical interpretation of the data?
   a. Species B eats the smallest seeds.
   b. About 30 percent of species C eats seeds that are 20 mm long.
   c. Species C eats the largest seeds.
   d. All three species eat seeds of the same size.

ANSWERS

39. b
40. c
Multiple Choice
1. Which of the following conditions is MOST likely to result in changes in allele frequencies in a population?
   A random mating  
   B small population size  
   C no migrations into or out of a population  
   D absence of natural selection
2. Mutations and the genetic recombination that occurs during sexual reproduction are both sources of
   A genetic variation.  
   B stabilizing selection.  
   C genetic equilibrium.  
   D genetic drift.
3. In a population of lizards, the smallest and largest lizards are more easily preyed upon than medium-size lizards. What kind of natural selection is MOST likely to occur in this situation?
   A genetic drift  
   C stabilizing selection  
   B sexual selection  
   D directional selection
4. Populations of antibiotic-resistant bacteria are the result of the process of
   A natural selection.  
   C genetic drift.  
   B temporal isolation.  
   D artificial selection.
5. If species A and B have very similar genes and proteins, what is probably true?
   A Species A and B share a relatively recent common ancestor.  
   B Species A evolved independently of species B for a long period.  
   C Species A is younger than species B.  
   D Species A is older than species B.
6. When two species reproduce at different times, the situation is called
   A genetic drift.  
   B temporal selection.  
   C temporal isolation.  
   D lateral gene transfer.
7. The length of time that two taxa have been evolving separately can be estimated using
   A genetic drift.  
   C a molecular clock.  
   B gene duplication.  
   D Hox genes.
Questions 8–9
The graphs below show the changes in crab color at one beach.

8. What process occurred over the 40-year period?
   A artificial selection  
   C stabilizing selection  
   B directional selection  
   D disruptive selection
9. Which of the following is MOST likely to have caused the change in the distribution?
   A a new predator arrived that preferred dark-tan crabs.  
   B a new predator arrived that preferred light-tan crabs.  
   C a change in beach color made medium-tan crabs the least visible to predators.  
   D a change in beach color made medium-tan crabs the most visible to predators.
Open-Ended Response
10. How does evolution change the relative frequency of alleles in a gene pool? Why does this happen?