Chapter 12
Forces of Evolutionary Change
A Disclaimer

• I am not here to argue against anyone’s religious beliefs

• We will focus on the ideas of evolution and the evidence for evolution- it is up to you to decide your own beliefs

• Natural selection and evolution are a model for explaining observations that has yet to be disproven
The Importance of Evolution

- This is the most important concept we will cover
- Links all of biology
- Everything we have talked about is a product of evolution
- Can explain nearly everything but how life began
What Is Evolution?

Why does this giraffe have a long neck? Why do these bleeding heart flowers have such a strange shape?
What Is Evolution?

Evolution explains the features of all organisms, from microbes to humans.

Bleeding hearts: © C Squared Studios/Getty Images RF; Giraffe © Anup Shah/Photodisc/Getty Images
Evolution is descent with modification—changes in heritable traits from generation to generation.
Recall that a **population** is a group of interbreeding organisms of the same species.
What Is Evolution?

Evolution occurs in a population when allele frequencies change from one generation to the next.
An **allele frequency** is calculated by the following equation:

\[
\frac{\text{# of copies of an allele}}{\text{Total # of alleles for the same gene in the population}}
\]
What Is Evolution?

Evolution is detectable by examining the population’s **gene pool**—the entire collection of genes and alleles.
What Is Evolution?

Even for the same species, gene pools differ from population to population. The gene pool for a population of Swedes differs from that of a population of Asians.
What Is Evolution?

If Swedes migrate to Asia and interbreed with locals, then allele frequencies in the gene pool will change. Evolution has occurred!
Clicker Question #1

Which of the following can evolve (according to the biological definition of evolution)?

A. a group of fir trees in Oregon
B. Earth’s climate
C. a single fly as it develops from larva to adult
D. a fossilized turtle
Clicker Question #1

Which of the following can evolve (according to the biological definition of evolution)?

A. a group of fir trees in Oregon
B. Earth’s climate
C. a single fly as it develops from larva to adult
D. a fossilized turtle

The correct answer is A.
12.1 Mastering Concepts

Why can evolution act only on populations and not on individuals?
Evolutionary Thought Has Evolved for Centuries

**Section 12.2**

Aristotle: © Science Source; Buffon, Hutton: © Getty Images; Cuvier: © George Bernard Shaw/Science Source; Lamarck: © Bettmann/Corbis; Lyell: © Corbis; Darwin: © Richard Milner; Wallace: © Hulton Archive/Getty Images
Evolutionary Thought Has Evolved for Centuries

**Uniformitarianism:** changes in nature are gradual

- **Aristotle:** Individuals in a species are basically identical and species are unchanging.
- **Hutton:** Changes in nature are gradual; uniformitarianism.
- **Lamarck:** New species come from existing species through environmental forces.
- **Lyell:** All changes in nature are gradual; renewed uniformitarianism.
- **Buffon:** Species change as they spread from their original location.
- **Cuvier:** Species reappear after catastrophes; fossils represent extinctions.
- **Darwin & Wallace:** Individuals in a population are different; species arise through the process of natural selection.

*Figure 12.2*
Fossils Provide Evidence for Slow Change Over Time

Helton’s principle of Uniformitarianism

Fossils of extinct species suggest that living organisms are descended from common ancestors.
Evolutionary Thought Has Evolved for Centuries

Uniformitarianism: changes in nature are gradual

Aristotle: Individuals in a species are basically identical and species are unchanging.

Hutton: Changes in nature are gradual; uniformitarianism.

Lamarck: New species come from existing species through environmental forces.

Darwin & Wallace: Individuals in a population are different; species arise through the process of natural selection.

Buffon: Species change as they spread from their original location.

Cuvier: Species reappear after catastrophes; fossils represent extinctions.

Lyell: All changes in nature are gradual; renewed uniformitarianism.

Catastrophism: brief, violent events produce changes in nature

Section 12.2

Aristotle: © Science Source; Buffon, Hutton: © Getty Images; Cuvier: © George Bernard Shaw/Science Source; Lamarck: © Bettmann/Corbis; Lyell: © Corbis; Darwin: © Richard Milner; Wallace: © Hulton Archive/Getty Images
Cuvier and Catastrophism

• Georges Cuvier (1769-1832) father of paleontology
• Studied living and fossil skeletons, but was fixed on special creation and fixity of species
• Explained fossil succession by his hypothesis of catastrophism
Evolutionary Thought Has Evolved for Centuries

Lamarck: proposed testable ideas about how species change

Aristotle: Individuals in a species are basically identical and species are unchanging.

Hutton: Changes in nature are gradual; uniformitarianism.

Lamarck: New species come from existing species through environmental forces.

Darwin & Wallace: Individuals in a population are different; species arise through the process of natural selection.

Buffon: Species change as they spread from their original location.

Cuvier: Species reappear after catastrophes; fossils represent extinctions.

Lyell: All changes in nature are gradual; renewed uniformitarianism.

Section 12.2

Figure 12.2
Evolutionary Thought Has Evolved for Centuries

350 BCE
Aristotle
Individuals in a species are basically identical and species are unchanging.

AD 1749
Buffon
Species change as they spread from their original location.

1785
Hutton
Changes in nature are gradual; uniformitarianism.

1798
Lamarck
New species come from existing species through environmental forces.

1809
Lyell
Earth must be very old, since natural processes occur slowly

1830
Cuvier
Species reappear after catastrophes; fossils represent extinctions.

1859
Darwin & Wallace
Individuals in a population are different; species arise through the process of natural selection.
Evolutionary Thought Has Evolved for Centuries

The stage was set for great thinkers like Darwin and Wallace

Aristotle
Individuals in a species are basically identical and species are unchanging.

Hutton
Changes in nature are gradual; uniformitarianism.

Lamarck
New species come from existing species through environmental forces.

Darwin & Wallace
Individuals in a population are different; species arise through the process of natural selection.

Buffon
Species change as they spread from their original location.

Cuvier
Species reappear after catastrophes; fossils represent extinctions.

Lyell
All changes in nature are gradual; renewed uniformitarianism.

Section 12.2
Aristotle: © Science Source; Buffon, Hutton: © Getty Images; Cuvier: © George Bernard Shaw/Science Source; Lamarck: © Bettmann/Corbis; Lyell: © Corbis; Darwin: © Richard Milner; Wallace: © Hulton Archive/Getty Images
Lamarck's Theory

- Evolution was a natural progression towards perfection
- Organisms proceeded up a ladder from simple bacteria to complex organisms
- The parts of an organism that are used grow bigger and bigger, those that are not used disappear or diminish
- These inherited acquired characteristics are passed on to offspring
Example using Lamarck's Giraffe

- Each giraffe stretched, making his or her neck longer
- Passed that on to their offspring
- All necks became long
LAMARCK'S GIRAFFE

Original short-necked ancestor

Keeps stretching neck to reach leaves higher up on tree

and stretching

and stretching until neck becomes progressively longer

Driven by inner "need"
It Was a Very Good First Guess

- Not really how it works, but important none the less

- He developed the ideas of adaptation and heritability
Darwin’s Voyage Provided Evidence for Evolution

Charles Darwin was the naturalist on the HMS *Beagle*, a ship that sailed around the world in the 1830s.
Darwin’s time on the Galápagos Islands was especially influential to the development of evolutionary thought.
Darwin’s Voyage Provided Evidence for Evolution

He described 14 distinct types of finch, each different from the birds on the mainland yet sharing some features.
Darwin’s Voyage Provided Evidence for Evolution

In particular, the beak shape of the finches varied depending on the food supply on each island.
Darwin thought that these 14 finch species had probably descended from a single ancestral type of finch.
Darwin’s Voyage Provided Evidence for Evolution

Pondering the great variety of organisms in South America and their relationships to fossils and geology, he began to think that these were clues to how new species originate.
Darwin’s Reasoning

- Darwin speculations:
- Could finches have descend from mainland?
- Island speciation?

Birds of Paradise
Darwin’s Reasoning

Gradual accumulation of adaptations to an environment could lead to new species OVER LONG TIME PERIODS.
Two views of Evolution

(a) **Gradualism model.** Species descended from a common ancestor gradually diverge more and more in their morphology as they acquire unique adaptations.

(b) **Punctuated equilibrium model.** A new species changes most as it buds from a parent species and then changes little for the rest of its existence.

Darwin & Myself

Fossil Record flawed?
The First Published Work on Natural Selection

- Was not by Darwin!

- Alfred Wallace published first

- This led to Darwin's writing of *The Origin of Species*
The Importance of Strong Research!

- Evolution caught on very quickly among biologists
- Darwin had incredible amounts of evidence and a very logical and coherent theory
- He also was a well respected naturalist
- Darwin was much luckier than Copernicus or Galileo
  - The importance of strong, well documented research and showing your work!
A Note On Theory

• “A scientific theory is an explanation or model used to explain observations or experimental results about an observed phenomenon.”

• Not a haphazard guess. A theory must survive scientific scrutiny, experimentation and review. I.e. the Theory of Gravity

• Very different from a hypothesis
The Two Major Features of *The Origin of Species*

- Descent with Modification
- Natural Selection as the main mechanism
Descent with Modification

- All species originated from a single species
- Over time slight modifications in offspring lead to all of the diversity found on Earth
- The Tree of Life
Nature Selects for Reproductive Success

In natural selection, environmental factors cause the differential reproductive success of individuals with particular genotypes.
Natural Selection

- Darwin's main focus – the mechanism
- In my humble opinion, the most important theory in all of science
Table 12.1: The Logic of Natural Selection: A Summary

<table>
<thead>
<tr>
<th>Observations of nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Genetic variation: Within a species, no two individuals (except identical siblings) are exactly alike. Some of this variation is heritable.</td>
</tr>
<tr>
<td>2. Limited resources: Every habitat contains limited supplies of the resources required for survival.</td>
</tr>
<tr>
<td>3. Overproduction of offspring: More individuals are born than survive to reproduce.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inferences from observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Struggle for existence: Individuals compete for the limited resources that enable them to survive.</td>
</tr>
<tr>
<td>2. Unequal reproductive success (natural selection): The inherited characteristics of some individuals make them more likely to obtain resources, survive, and reproduce.</td>
</tr>
<tr>
<td>3. Descent with modification: Over many generations, natural selection can change the characteristics of populations, even giving rise to new species.</td>
</tr>
</tbody>
</table>
My Quick Version

• Everyone Wants to Reproduce (fitness)
• They Don’t
• They Can’t
• There is *competition*
• Everyone is different
• The differences are genetic
• Survival (and reproduction) *depends on genes*
• *Adaptive genes survive* and become common
Natural Selection Summarized

- Traits that help organisms survive and reproduce become more common
- Thus the population changes over time
NOTE

- ONLY traits that help survival or reproduction
- NOT helpful traits or convenient traits
- ONLY acts on traits that are already present
Evidence: Humans Artificially Alter Allele Frequencies

Artificial selection, or selective breeding, also helped Darwin form the theory of evolution by natural selection.
In artificial selection, a human chooses desired features, then allows only the individuals that best express those qualities to reproduce.
Evolutionary Theory Continues to Expand

Much subsequent research has corroborated and expanded on Darwin’s findings.
Clicker Question #2

Which of the following statements supports the concept of natural selection?

A. Individuals with the traits best suited to the prevailing conditions tend to leave more surviving, fertile offspring.
B. Traits that increase survival and reproduction in the current generation will be more common in the next generation.
C. Both A and B are correct.
D. None of the choices is correct.
Clicker Question #2

Which of the following statements supports the concept of natural selection?

A. Individuals with the traits best suited to the prevailing conditions tend to leave more surviving, fertile offspring.
B. Traits that increase survival and reproduction in the current generation will be more common in the next generation.
C. Both A and B are correct.
D. None of the choices is correct.

The correct answer is C.
12.2 Mastering Concepts

How is artificial selection different from natural selection?
This seahorse blends almost perfectly into its habitat. How could an organism like this arise?
Natural Selection Molds Evolution

Each generation, the best camouflaged individuals survive to reproduce. The alleles conferring camouflage become more common in each generation.

Figure 1.7
Pygmy seahorse © Mark Webster www.photocouk/Getty Images
But natural selection does not create camouflage alleles. Instead, it strongly selects for camouflage alleles that arise by chance.
Natural selection operates on the variation present in a population. Since more individuals are born than resources can support, the struggle to survive is inevitable.
Natural Selection Molds Evolution

Some individuals in a population are better than others at surviving and reproducing.
The heritable traits conferring these advantages are adaptations—features that provide a selective advantage because they improve an organism’s ability to survive and reproduce.
Bacteria that are resistant to antibiotics have an adaptive trait that non-resistant bacteria lack. When antibiotics are administered, resistant bacteria are strongly selected for.
Natural Selection Molds Evolution

Antibiotics can not *create* a resistance allele. The variation in resistance was already present in the population; the presence of antibiotics caused the resistance allele frequency to shift.
As environmental conditions change, the phenotypes that natural selection favors will also change. Adaptations that seem “perfect” in one environment would be completely wrong in another.
Evolution Never Stops

This orchid and its wasp pollinator have evolved alongside one another for long enough that no other animal can pollinate the flower.
Evolution Does Not Have a Goal

But the orchid does not evolve *in order to* be better-pollinated by the wasp. Neither the orchid nor natural selection has foresight.
Instead, orchids that are best-suited to wasp pollination are the most likely to reproduce, so their alleles get passed to the next generation most often.
Survival of the “Fittest”

**Fitness** describes an organism’s genetic contribution to the next generation. To have high fitness, an individual must reproduce.
Clicker Question #3

Ferns require moisture to reproduce. What will happen to a fern population during a prolonged drought?

A. To save the species, some of the ferns will acquire the ability to reproduce without water.
B. If none of the ferns already have the ability to reproduce without water, the ferns might go extinct.
Clicker Question #3

Ferns require moisture to reproduce. What will happen to a fern population during a prolonged drought?

A. To save the species, some of the ferns will acquire the ability to reproduce without water.

B. If none of the ferns already have the ability to reproduce without water, the ferns might go extinct.
12.3 Mastering Concepts

How can natural selection favor different phenotypes at different times?
Allele Frequencies Always Change

Scientists test evolution against a null hypothesis, which states that allele frequencies do not change from one generation to the next.
Allele Frequencies Always Change

**Hardy-Weinberg equilibrium** is the unlikely situation in which allele frequencies do not change between generations.

Section 12.4  
Figure 12.12
Allele Frequencies Always Change

Hardy-Weinberg equilibrium occurs if a population meets all of the following assumptions:

1. natural selection does not occur
2. no mutations
3. the population is large enough to eliminate random changes in allele frequencies
4. individuals mate at random
5. no migration

Figure 12.12

Section 12.4
Allele Frequencies Always Change

Assuming the assumptions of Hardy-Weinberg equilibrium are met, two equations represent the relationship between allele frequencies and genotype frequencies.

\[ p + q = 1 \]

\[ p^2 + 2pq + q^2 = 1 \]

\( p \) is the frequency of the dominant allele and \( q \) is the frequency of the recessive allele.
Allele Frequencies Always Change

Since the $D$ gene has two alleles, the frequency of the dominant allele plus the frequency of the recessive allele must equal 1.

\[ p + q = 1 \]

\[ p^2 + 2pq + q^2 = 1 \]

$p$ is the frequency of the dominant allele and $q$ is the frequency of the recessive allele.
Allele Frequencies Always Change

Multiplying the frequency of the dominant allele by itself gives the frequency of homozygous dominant individuals in the next generation.

\[ p + q = 1 \]

\[ p^2 + 2pq + q^2 = 1 \]

\( p \) is the frequency of the dominant allele and \( q \) is the frequency of the recessive allele.

\[ p^2 + 2pq + q^2 = 1 \]
Allele Frequencies Always Change

Multiplying the frequency of the recessive allele by itself gives the frequency of homozygous recessive individuals in the next generation.

\[ p + q = 1 \]

\[ p^2 + 2pq + q^2 = 1 \]

\( p \) is the frequency of the dominant allele and \( q \) is the frequency of the recessive allele.

\[ p^2 = (0.6)^2 = 0.36 \]

\[ pq = (0.6)(0.4) = 0.24 \]

\[ q^2 = (0.4)^2 = 0.16 \]
Allele Frequencies Always Change

The frequency of the dominant allele times the frequency of the recessive allele times 2 gives the frequency of heterozygous individuals in the next generation.

\[ p + q = 1 \]

\[ p^2 + 2pq + q^2 = 1 \]

\( p \) is the frequency of the dominant allele and \( q \) is the frequency of the recessive allele.
Allele Frequencies Always Change

Hardy-Weinberg equilibrium is a useful model for converting known allele frequencies to genotype frequencies (or vice versa), but in real populations, the assumptions of Hardy-Weinberg are always violated.
Clicker Question #4

A population of 100 starfish is in Hardy-Weinberg equilibrium. The trait for long arms is completely dominant to the trait for short arms. In this population, 40% of all alleles for this trait are recessive, and 60% of all alleles for this trait are dominant. How many individuals would you expect to be homozygous dominant?

A. 80  B. 60  C. 36  D. 16
Clicker Question #4

A population of 100 starfish is in Hardy-Weinberg equilibrium. The trait for long arms is completely dominant to the trait for short arms. In this population, 40% of all alleles for this trait are recessive, and 60% of all alleles for this trait are dominant. How many individuals would you expect to be homozygous dominant?

A. 80  B. 60  C. 36  D. 16
12.4 Mastering Concepts

What five conditions are required for Hardy–Weinberg equilibrium?
Natural Selection Can Shape Populations in Many Ways

Three modes of natural selection—directional, disruptive, and stabilizing—are distinguished by their effects on the phenotypes in a population.

Section 12.5
In **directional selection**, one phenotype is favored over another.
Natural Selection Can Shape Populations in Many Ways

In **disruptive selection**, extreme phenotypes are favored over an intermediate phenotype.

Section 12.5
In **stabilizing selection**, an intermediate phenotype is favored over the extreme phenotypes.
However, these three models do not explain why natural selection maintains some harmful alleles in the population.
Natural Selection Can Shape Populations in Many Ways

One explanation for why some harmful alleles persist in the population is **heterozygote advantage**, in which a heterozygote is favored over homozygotes.
For example, heterozygotes for the sickle cell allele do not have sickle cell disease and are protected against malaria. But if two heterozygotes mate, their child might have sickle cell disease.
Clicker Question #5

As humans migrated out of Africa and towards northern Europe, reduced exposure to ultraviolet radiation selected for lighter skin color. What type of natural selection does this example illustrate?

A. stabilizing selection  
B. disruptive selection  
C. directional selection
Clicker Question #5

As humans migrated out of Africa and towards northern Europe, reduced exposure to ultraviolet radiation selected for lighter skin color. What type of natural selection does this example illustrate?

A. stabilizing selection
B. disruptive selection
C. directional selection
12.5 Mastering Concepts

Distinguish among directional, disruptive, and stabilizing selection.
Sexual Selection Directly Influences Reproductive Success

At face value, building complex nests, flashing showy plumage, and butting heads with rival males all appear to waste energy. How can natural selection allow for traits that apparently reduce survival?
Sexual selection is a type of natural selection resulting from variation in the ability to obtain mates.
Sexual Selection Directly Influences Reproductive Success

Sexual selection results either from competition for access to the other sex (e.g., these rams) or from one sex choosing attractive mates of the other sex.

Weaver bird: © James Warwick/Stone/Getty Images; Bird of paradise: © Michael S. Yamashita/Corbis; Bighorn sheep: © Sumio Harada/Minden Pictures
Generations of choosy females have selected for males with nest-building traits or elaborate ornamentation.
Sexual Selection Directly Influences Reproductive Success

Although the yellow weaver bird uses time and energy making nests for females, this behavior might secure a mating opportunity.

Section 12.6

Weaver bird: © James Warwick/Stone/Getty Images; Bird of paradise: © Michael S. Yamashita/Corbis; Bighorn sheep: © Sumio Harada/Minden Pictures

Figures 12.15, 12.16
Sexual Selection Directly Influences Reproductive Success

Sexual selection violates the “individuals mate at random” criterion of Hardy-Weinberg.
Sexual Selection Directly Influences Reproductive Success

Since Hardy-Weinberg does not apply, evolution occurs.
12.6 Mastering Concepts

Describe two ways that competition for access to mates can lead to sexual selection.
Evolution Occurs in Several Other Ways

Other factors change allele frequencies over time:

Mutation

Section 12.7

Figure 12.23
Evolution Occurs in Several Other Ways

Other factors change allele frequencies over time:

Genetic drift
Evolution Occurs in Several Other Ways

Genetic drift occurs purely by chance. It is most common in small populations.
Evolution Occurs in Several Other Ways

When only a few individuals establish a new population, the allele frequency might change. This process illustrates the **founder effect**.

Figure 12.18
Ellis-van Creveld syndrome: Courtesy of Dr. Victor A. McKusick/Johns Hopkins Hospital
Evolution Occurs in Several Other Ways

A population **bottleneck** occurs if a disaster drastically reduces the size of a population.

Original cheetah population contains 25 different alleles of a particular gene.  
Cheetah population is drastically reduced.  
Repopulation occurs. Only three different alleles remain.
Evolution Occurs in Several Other Ways

Other factors change allele frequencies over time:

Gene flow

Section 12.7
Evolution Occurs in Several Other Ways

Gene flow moves alleles between populations. This might affect the allele frequencies in both populations.
12.7 Mastering Concepts

How does sampling error cause genetic drift?
Evolution by means of natural selection has practical applications, such as establishing fishing regulations.
If the largest fish were always removed from a lake, what might you predict about the size of fish in future generations? What if the smallest fish were always removed?
Researchers conducted studies of fish size over several generations to find out how fish harvesting affects average fish size.
They established three populations and applied the following treatments:

- Removing large fish
- Removing random fish
- Removing small fish
Predictably, the average weight of harvested fish was highest for the large harvested population at the start of the study.
However, after just four generations, the small harvested population had a much higher average size than the large harvested population.
Also, fish in the small harvested population developed more quickly than those in the large harvested population.
These results are not surprising, which is a testament to the predictive power of natural selection.