Biology

for Utah SEEd Standards
2020-2021

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Utah State Board of Education OER
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AUTHOR

USBE OER

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We especially wish to thank the amazing Utah science teachers whose collaborative efforts made the book possible. Thank you for your commitment to science education and Utah students!

Students as Scientists

What does science look and feel like?

If you're reading this book, either as a student or a teacher, you're going to be digging into the "practice" of science. Probably, someone, somewhere, has made you think about this before, and so you've probably already had a chance to imagine the possibilities. Who do you picture doing science? What do they look like? What are they doing?

Often when we ask people to imagine this, they draw or describe people with lab coats, people with crazy hair, beakers and flasks of weird looking liquids that are bubbling and frothing. Maybe there's even an explosion. Let's be honest: Some scientists do look like this, or they look like other stereotypes: people readied with their pocket protectors and calculators, figuring out how to launch a rocket into orbit. Or maybe what comes to mind is a list of steps that you might have to check off for your science fair project to be judged; or, maybe a graph or data table with lots of numbers comes to mind.

So let's start over. When you imagine graphs and tables, lab coats and calculators, is that what you love? If this describes you, that's great. But if it doesn't, and that's probably true for many of us, then go ahead and dump that image of science. It's useless because it isn't you. Instead, picture yourself as a maker and doer of science. The fact is, we need scientists and citizens like you, whoever you are, because we need all of the ideas, perspectives, and creative thinkers. This includes you.

Scientists wander in the woods. They dig in the dirt and chip at rocks. They peer through microscopes. They read. They play with tubes and pipes in the aisles of a hardware store to see what kinds of sounds they can make with them. They daydream and imagine. They count and measure and predict. They stare at the rock faces in the mountains and imagine how those came to be. They dance. They draw and write and write and write some more.

Scientists — and this includes all of us who do, use, apply, or think about science — don't fit a certain stereotype. What really sets us apart as humans is not just that we know and do things, but that we wonder and make sense of our world. We do this in many ways, through painting, religion, music, culture, poetry, and, most especially, science. Science isn't just a method or a collection of things we know. It's a uniquely human practice of wondering about and creating explanations for the natural world around us. This ranges from the most fundamental building blocks of all matter to the widest expanse of space that contains it all. If you've ever wondered "When did time start?", or "What is the smallest thing?", or even just "What is color?", or so many other endless questions then you're already thinking with a scientific mind. Of course you are; you're human, after all.

But here is where we really have to be clear. Science isn't just questions and explanations. Science is about a sense of wondering and the sense-making itself. We have to wonder and then really dig into the details of our surroundings. We have to get our hands dirty. Here's a good example: two young scientists under the presence of the Courthouse Towers in Arches National Park. We can be sure that they spent some amount of time in awe of the giant sandstone walls, but here in this photo they're enthralled with the sand that's just been re-washed by recent rain. There's this giant formation of sandstone looming above these kids in the desert, and they're happily playing in the sand. This is ridiculous. Or is it?

How did that sand get there? Where did it come from? Did the sand come from the rock or does the rock come from sand? And how would you know? How do you tell this story?

Look. There's a puddle. How often is there a puddle in the desert? The sand is wet and fine; and it makes swirling, layered patterns on the solid stone. There are pits and pockets in the rock, like the one that these two scientists are sitting in, and the gritty sand and the cold water accumulate there. And then you might start to wonder: Does the sand fill in the hole to form more rock, or is the hole worn away because it became sand? And then you might wonder more about the giant formation in the background: It has the same colors as the sand, so has this been built up or is it being worn down? And if it's being built up by sand, how does it all get put together; and if it's being worn away then why does it make the patterns that we see in the rock? Why? How long? What next?

Just as there is science to be found in a puddle or a pit or a simple rock formation, there's science in a soap bubble, in a worm, in the spin of a dancer and in the structure of a bridge. But this thing we call "science" is only there if you're paying attention, asking questions, and imagining possibilities. You have to make the science by being the person who gathers information and evidence, who organizes and reasons with this, and who communicates it to others. Most of all, you get to wonder. Throughout all of the rest of this book and all of the rest of the science that you will ever do, wonder should be at the heart of it all. Whether you're a student or a teacher, this wonder is what will bring the sense-making of science to life and make it your own.

Adam Johnston
Weber State University

Science and Engineering Practices

Science and Engineering Practices are what scientists do to investigate and explore natural phenomena

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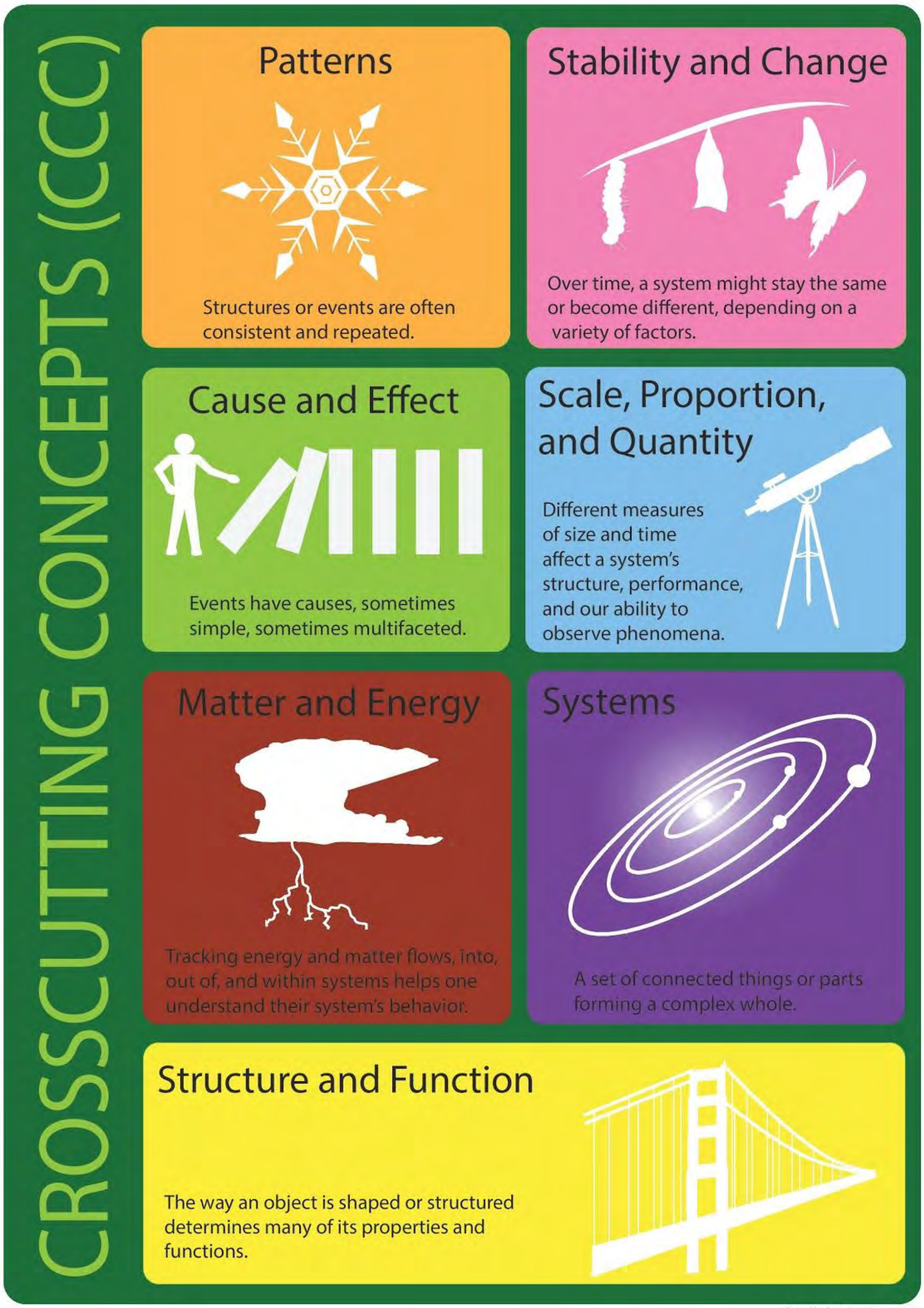
Cross Cutting Concepts

Crosscutting Concepts are the tools that scientists use to make sense of natural phenomena.



A Note to Teachers

This Open Educational Resource (OER) textbook has been written specifically for students as a reputable source for them to obtain information aligned to the Biology Science Standards. The hope is that as teachers use this resource with their students, they keep a record of their suggestions on how to improve the book. Every year, the book will be revised using teacher feedback and with new objectives to improve the book.

If there is feedback you would like to provide to support future writing teams please use the following online survey: http://go.uen.org/bFi

Table of Contents

CHAPTER 1

Strand 1: Interactions with Organisms and Their Environments

Chapter Outline

Image by Skeeze, pixabay.com, CC0

The cycling of matter and flow of energy are part of a complex system of interactions within an ecosystem. Through these interactions, an ecosystem can sustain relatively stable numbers and types of organisms. A stable ecosystem is capable of recovering from moderate biological and physical changes. Extreme changes may have a significant impact on an ecosystem's carrying capacity and biodiversity, altering the ecosystem. Human activities can lead to significant impacts on an ecosystem.

1.1 Abiotic Factors, Biotic Factors and Populations (Bio.1.1)

Explore this Phenomenon

Tide Pools by Penny Nickels, https://flic.kr/p/6hcHHT, CC-BY-NC

Organisms that live in tide pools have to be able to live in changing conditions. Sometimes they are submerged in ocean water, but other times their environment is dry.

1. Besides changes to the amount of water, what environmental changes would these organisms experience?
2. How might the changing conditions in the tidepool affect the individuals and populations that live there?
3. How could you investigate and collect data that you could use to better understand how the changing conditions in a tide pool affect the populations of organisms living there.

Bio.1.1 Abiotic Factors, Biotic Factors and Populations

Plan and carry out an investigation to **analyze and interpret data** to determine how biotic and abiotic factors can affect the stability and change of a population. Emphasize stability and change in populations' carrying capacities and an ecosystem's biodiversity. (LS2.A, LS2.C)

It is important to understand how different factors affect the stability or change of populations. As you read this chapter, look for different factors that cause populations to remain stable, and for factors that cause populations to change.

Ecosystem Structure

Image by sspeihs3, pixabay.com, CC0

Where can you find an ecosystem?

Just about everywhere you could go in nature, you would be taking a field trip to an ecosystem. There are underwater ecosystems and terrestrial ecosystems. There are small scale ecosystems and large ones. There are even ecosystems inside your body!

What is an ecosystem?

An ecosystem is a group of living things and their environment. The word ecosystem is short for “ecological system.” Like any system, an ecosystem is a group of parts that work together. Ecosystems exist on different scales. The forest pictured below is a big ecosystem. Besides trees, what living things do you think are part of the forest ecosystem? Smaller scale ecosystems exist within the larger forest ecosystem. The dead tree stump in the same forest is a small ecosystem. It includes plants, mosses, and fungi. It also includes insects and worms.

Dandeli by Alosh Bennett, https://flic.kr/p/7688fq, CC-BY

This forest is a big ecosystem. Besides trees, what living things do you think are part of the forest ecosystem?

Adapted from *DSC_0115* by erysimum9, https://flic.kr/p/bE8yKrm, CC-BY

A dead stump in the same forest is a small ecosystem. It includes plants, mosses, and fungi. It also includes insects and worms.

An ecosystem can be big or small. A small ecosystem can be part of a larger ecosystem.

Abiotic Factors

Image by U.S. Fish and Wildlife Service, https://www.fws.gov/invasives/volunteersTrainingModule/invasives/plants.html, public domain; CC-BY

Abiotic factors are the nonliving parts of ecosystems. They include air, sunlight, soil, water, and minerals. These are all things that are needed for life. They determine which living things—and how many of them—an ecosystem can support. Pictured below is an ecosystem and its abiotic factors.

Which abiotic factors do you see here?

Biotic Factors
Biotic factors are the living parts of ecosystems. They are the species of living things that reside together.

A species is a unique type of organism. Members of a species can interbreed and produce offspring that can breed (they are fertile). Organisms that are not in the same species cannot do this. Examples of species include humans, lions, and redwood trees. Can you name other examples?

All the members of a species that live in the same area form a population. Many different species live together in an ecosystem. All their populations make up a community. What populations live together in the grassland pictured below?

Hunting Lion, Tarangire National Park, Tanzania by Christoph Strässler, https://flic.kr/p/SFhnFo, CC-BY-SA

Biodiversity
Some ecosystems can support a greater variety of species than other ecosystems. Biodiversity is a measurement of the amount of variation of life that exists in a given area. More specifically, biodiversity can be defined as the variety of life and its processes, including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur. How might the abiotic factors in an ecosystem affect the amount of biodiversity in the system?

The rainforest shown below is an ecosystem with a high level of biodiversity. If abiotic factors in the rainforest changed, how would its biodiversity be affected? For example, if the temperature, amount of sunlight or water, or minerals in the system changed, how would the variation of life change?

Hiking trail in the Hoh Rain Forest, Olympic National Park, Washington by Diana Robinson, https://flic.kr/p/XCeEBT, CC-BY-NC-ND

Learn more about biodiversity and the role of keystone species in ecosystems in this Bozeman Science video from Paul Anderson: https://www.youtube.com/watch?time_continue=370&v=0-PE3ve3w2w

Population Growth Limits

How many geese are the right number for this area?

Snow Geese Flock at Water, public domain

As many as can survive and have healthy offspring! The figure above shows a flock of snow geese at the Kenai National Wildlife Refuge. Their population will tend to grow as big as it can for the resources it needs. Once it is too large, some of its members will die off. This keeps the population size at the right number.

Carrying Capacity

A population usually grows when it has what it needs. If there's plenty of food and other resources, the population will get bigger. For example, a single bacteria cell in a container of nutrients will be able to get all of the nutrients it needs. If the bacteria divides every 30 minutes, there were more than a million bacterial cells after just ten hours! If the bacterial population keeps growing at this rate, will there be enough nutrients for all of the bacteria?

A population can't keep growing bigger and bigger forever. Sooner or later, it will run out of things it needs. For a given species, there is a maximum population that can be supported by the environment. This maximum is called the carrying capacity. When a population gets close to the carrying capacity, it usually grows more slowly. When the population reaches the carrying capacity, it stops growing.

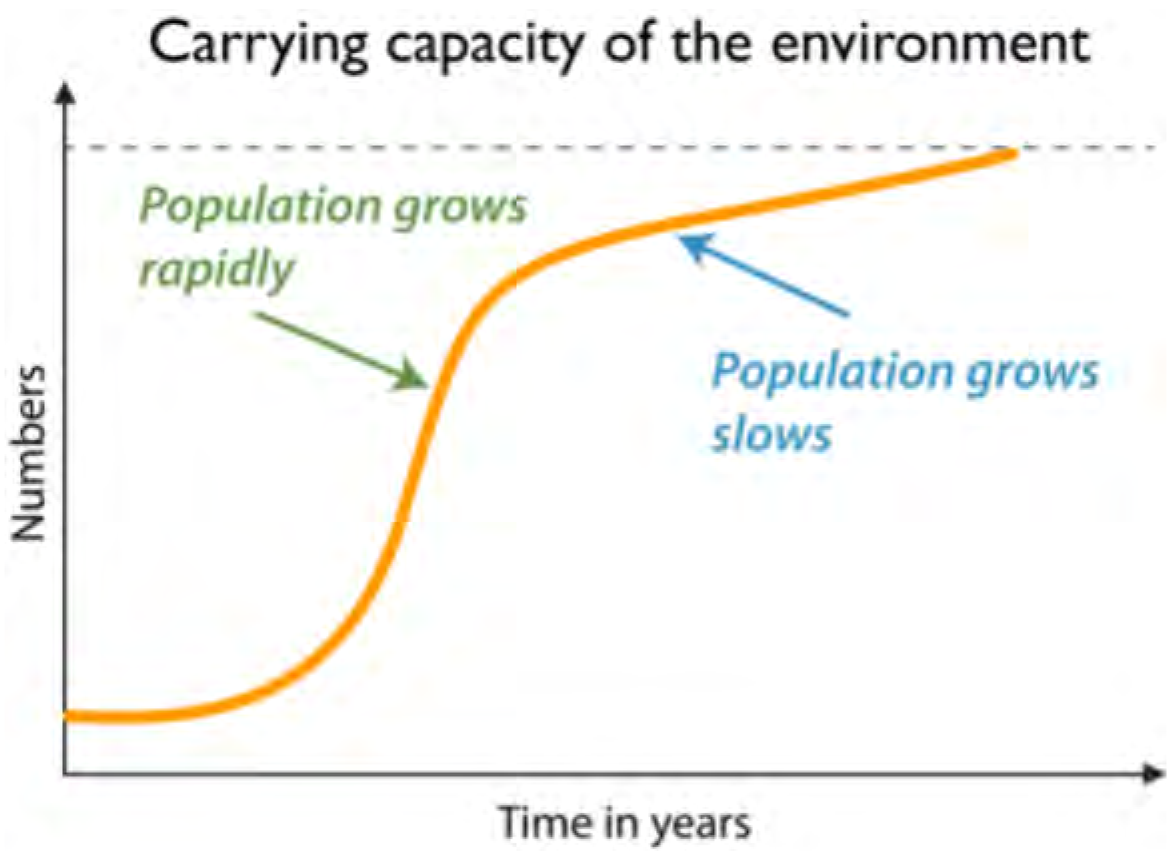


Image by Hana Zavadska; Laura Guerin, CK-12 Foundation, CC-BY-NC 3.0

A population can't get much larger than the carrying capacity. What might happen if it did?

Limiting Factors to Population Growth

For a population to be healthy, factors such as food, nutrients, water, and space must be available. What happens when there are not enough resources to support the population?

Limiting factors are resources or other factors in the environment that can lower the population growth rate. Limiting factors include a low food supply and lack of space. Limiting factors can lower birth rates, increase death rates, or lead to emigration.
If there were no limiting factors, a population would grow exponentially.

Curve A on the graph below represents the exponential growth of a population. As a population grows, it approaches the carrying capacity of the ecosystem. The carrying capacity is the maximum population size that a particular area can support without destroying the habitat. As a population approaches the carrying capacity, individuals must compete for food, water, space, and other resources. This competition causes a decline in the population growth.

Curve B on the graph below shows how the growth rate changes as the population size approaches the carrying capacity. How would the carrying capacity change if the amount of resources increased or decreased?

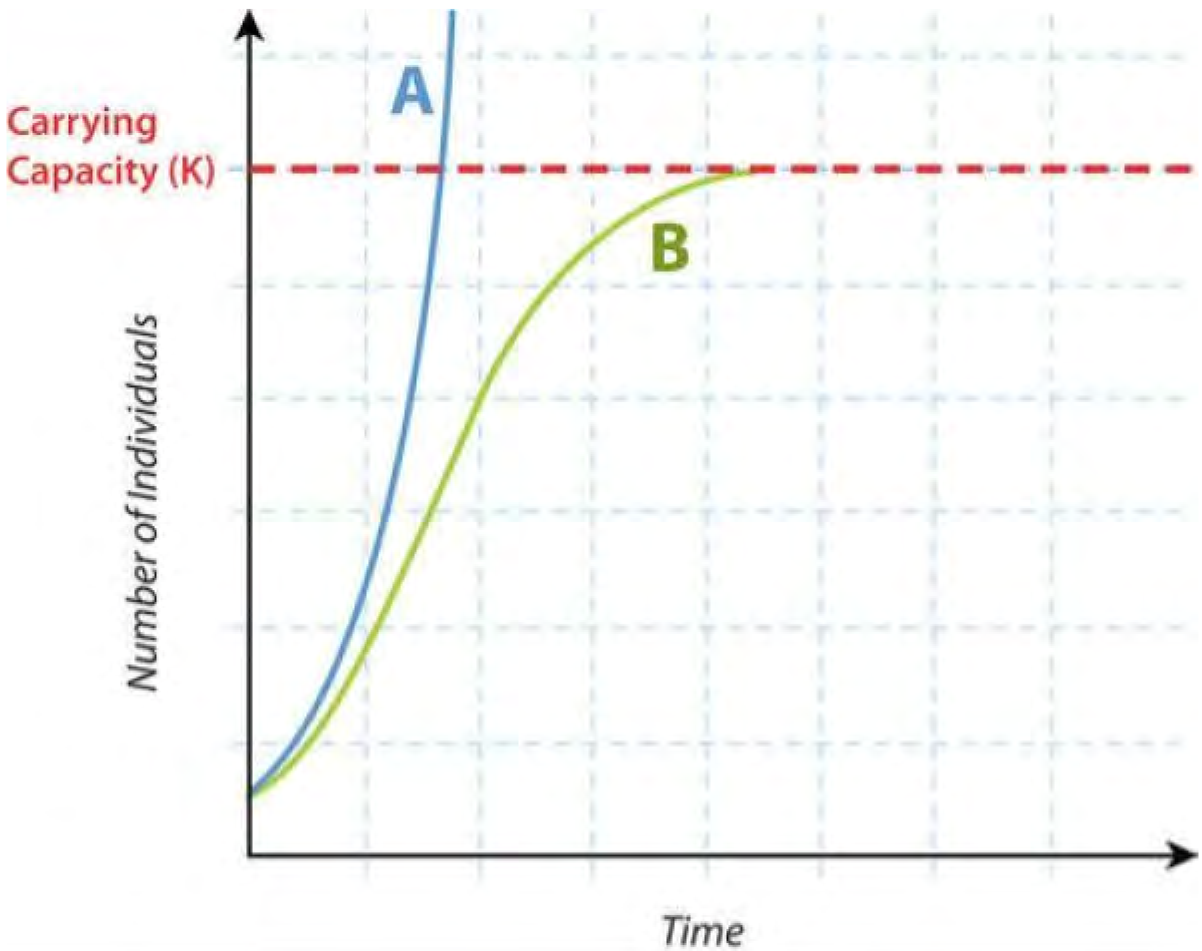


Image by Hana Zavadska; Laura Guerin, CK-12 Foundation, CC-BY-NC 3.0

Curve A shows the growth of the population with no limiting factors. Curve B shows how population growth changes as the population approaches the carrying capacity.

Examples of Limiting Factors

If there are 12 hamburgers at a lunch table and 24 people sit down at a lunch table, will everyone be able to eat? At first, maybe you will split hamburgers in half, but if more and more people keep coming to sit at the lunch table, you will not be able to feed everyone. This is what happens in nature. But in nature, organisms that cannot get food will die or find a new place to live. It is possible for any resource to be a limiting factor; however, a resource such as food can have dramatic consequences on a population.

Other limiting factors include light, water, nutrients or minerals, oxygen, the ability of an ecosystem to recycle nutrients and/or waste, disease and/or parasites, temperature, space, and predation.

Weather can also be a limiting factor. Whereas most plants like rain, an individual cactus-like Agave americana plant actually likes to grow when it is dry. Rainfall limits reproduction of this plant which, in turn, limits growth rate. Can you think of some other factors like this?

Human activities can also limit the growth of populations. Such activities include the use of pesticides, such as DDT, use of herbicides, and habitat destruction. These activities can result in the death of individuals or affect the resources available to other species.

What other factors could limit population growth?

In nature, when the population size is small, there is usually plenty of food and other resources for each individual. When there is plenty of food and other resources, organisms can easily reproduce, so the birth rate is high. As the population increases, the food supply, or the supply of another necessary resource, may decrease. When necessary resources decrease, some individuals will die. Overall, the population cannot reproduce at the same rate, so the birth rates drop. This will cause the population growth rate to decrease.

When the population decreases to a certain level that allows every individual to get enough food and other resources, and the birth and death rates become stable, the population has leveled off at its carrying capacity.

Putting It Together

Tide Pools by Penny Nickels, https://flic.kr/p/6hcHHT, CC-BY-NC

Organisms that live in tide pools have to be able to live in changing conditions. Sometimes they are submerged in ocean water, but other times their environment is dry.

1. After learning about how abiotic factors and biotic factors affect populations, how have your ideas about the effects of changing conditions in the tidepool on the populations living there changed?
2. Review your investigation design. How could you revise your investigation to collect data on factors that affect the population growth or carrying capacity in this ecosystem?

1.2 Energy and Matter Cycles (Bio.1.2)

Explore this Phenomenon

Each of the ecosystems pictured looks quite different, but they all have some things in common.

1. Use the pictures to identify patterns in ecosystems. What are some things that all of the ecosystems have in common?
2. What questions could you investigate to understand what causes the patterns we see across ecosystems?
3. Explain some of the patterns you identified. For example, why do ecosystems tend to have more plants than animals?

Bio.1.2 Energy and Matter Cycles

Develop and use a model to explain cycling of matter and flow of energy among organisms in an ecosystem. Emphasize the movement of matter and energy through the different living organisms in an ecosystem. Examples of models could include food chains, food webs, energy pyramids or pyramids of biomass. (LS2.B)

As you read this chapter, pay attention to the way that matter and energy move through the ecosystem. Look for similarities and differences in the way that matter and energy move through the biotic factors in the ecosystem.

Energy Flows Through Ecosystems

Public Domain

Where do these flowers get the energy they need to grow and reproduce?

The Sun supports most of Earth's ecosystems. Plants create chemical energy from abiotic factors that include solar energy. The food energy created by producers is passed through the food chain.

How Energy Flows Through Ecosystems

All living things need energy. They need it to power the processes of life. For example, it takes energy to grow. It also takes energy to produce offspring. In fact, it takes energy just to stay alive. Remember that energy can't be created or destroyed. It can only change form. Energy changes form as it moves through ecosystems.

Most ecosystems get their energy from the Sun. Only producers can use sunlight to make usable energy. Producers are organisms like plants and algae that can convert the sunlight into chemical energy or food. Producers form the base of all food chains. Consumers get some of that energy when they eat producers. They also pass some of the energy on to other consumers when they are eaten. In this way, energy flows from one living thing to another.

Food Chains

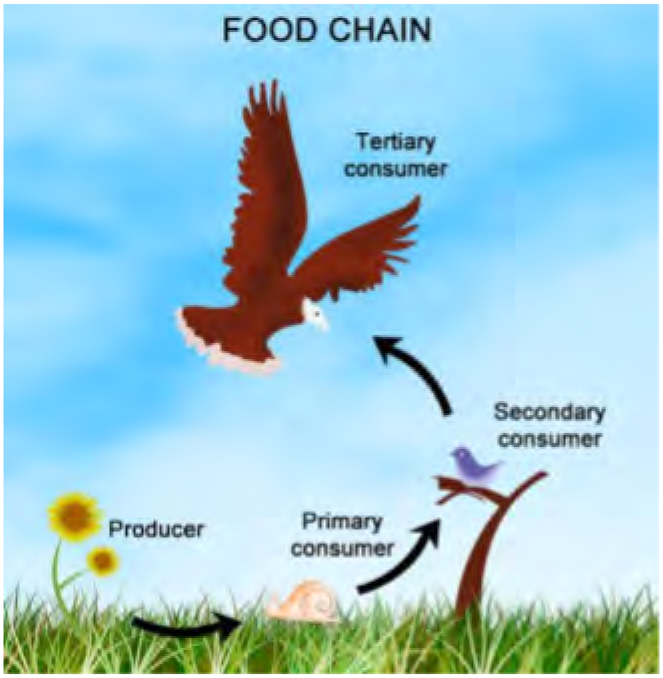


Image by Zappy's, CK-12 Foundation, CC-BY-NC 3.0

A food chain is a simple diagram that shows the path energy takes as it flows from one part of an ecosystem to the next. Pictured below is an example of a food chain. In this example, the grass and flower are the producers that convert light energy from the sun into chemical energy. The snail gets energy from the plants. The small bird gets energy from eating the snail, and the large bird gets energy when it eats the small bird.

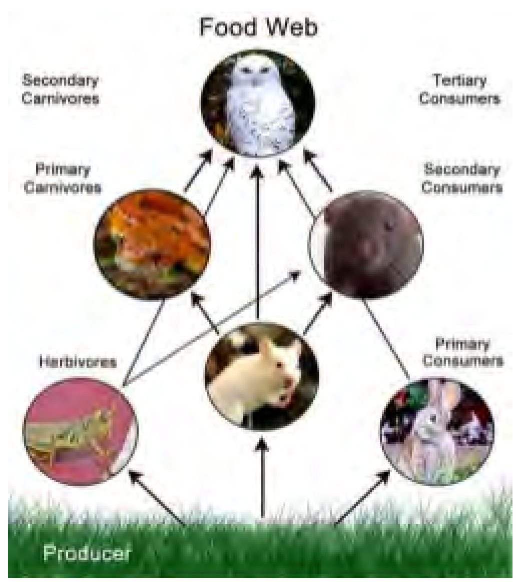
At each level of a food chain, a lot of energy is lost. Only about ten percent of the energy passes to the next level. Where does that energy go? Some energy is given off as heat. Some energy goes into animal wastes. Energy also goes into growing things that another consumer can't eat, like fur. It's because so much energy is lost that most food chains have just a few levels. There’s not enough energy left for higher levels.

Food Webs

Food chains are too simple to represent the real world. They don’t show all the ways that energy flows through an ecosystem. A more complex diagram is called a food web. Food webs more accurately represent the flow of energy through the ecosystem.

A food web consists of many overlapping food chains. Can you identify the food chains in the figure? How many food chains include the mouse?

Food webs also overlap. For example, an eagle is part of a land food web, but it might go to the sea to catch and eat a fish. That fish is part of a marine food web.



Credit: Owl: Marie Hale; Snake: Lauren Mitchell (Flickr:LOLren); Rat: Charles Jeffrey Danoff; Mouse: Giang Hồ Thị Hoàng; Rabbit: Don Debold; Grasshopper: Flickr:jster91
Source:
Owl: http://www.flickr.com/photos/15016964@N02/5909827861/
Snake: http://www.flickr.com/photos/laurenprofeta/4320516966/
Rat: http://www.flickr.com/photos/danoff/3323774401/
Mouse: http://www.flickr.com/photos/hthg1983/2237614948/
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Matter Cycles Through Ecosystems

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What happens when you don't get enough of a nutrient?

Millions of sailors in the 15th through 18th centuries died mysteriously. They developed a disease called scurvy. The scurvy, it turns out, was due to the lack of vitamin C in their diets. It wasn't until 1932 that the link between scurvy and vitamin C was made. Without the right types and amounts of matter, or nutrients, you can get sick or even die. Other animals and plants also need the right nutrients to live. Where does the matter organisms need to survive come from?

How Matter Moves Through Ecosystems

Living things need matter as well as energy. What do you think matter is used for? It's used to build bodies. It's also needed to carry out the processes of life. Matter that living things need are called nutrients. Carbon and nitrogen are examples of nutrients. Unlike energy, matter is recycled in ecosystems. For example, decomposers break down dead organisms, and release the matter in the organisms. The matter is then taken up by plants through their roots. When an animal eats the plant, the matter passes to the animal. When living things die, the matter that makes up their bodies is released by decomposers, and they cycling of matter starts over.

Can you explain how the movement of matter and energy through ecosystems is the same? How is the movement of matter and energy different? Use the model below to compare and contrast the movement of energy and matter in ecosystems.

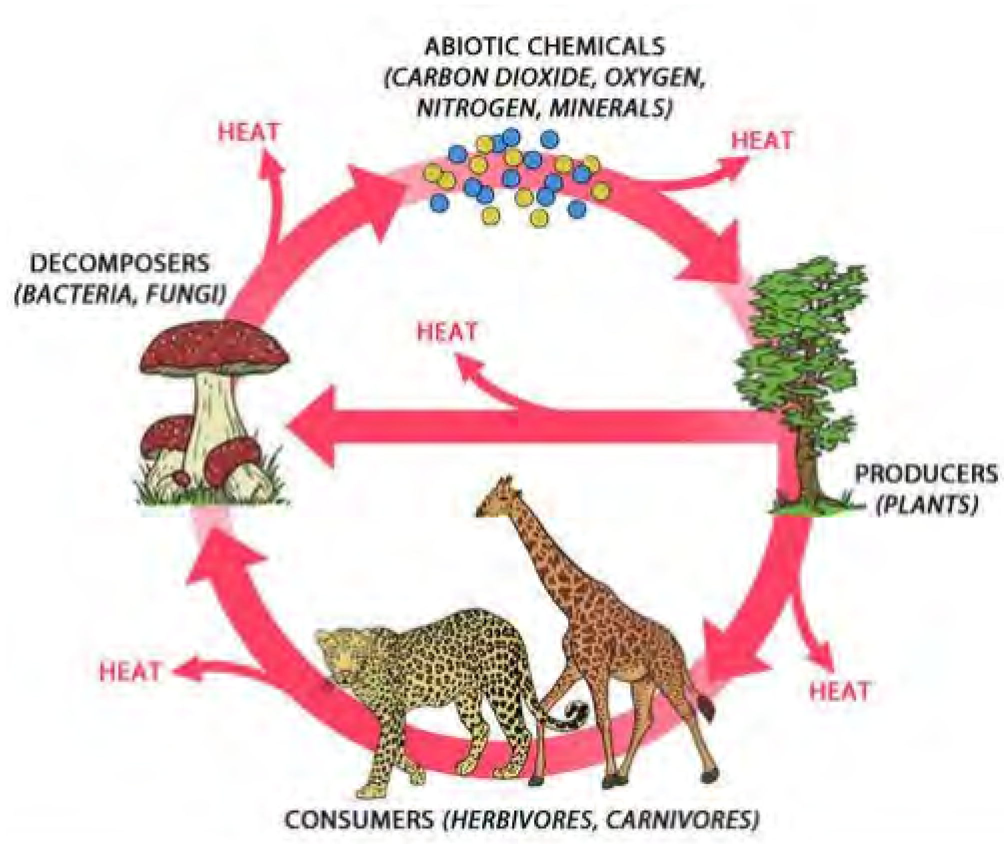
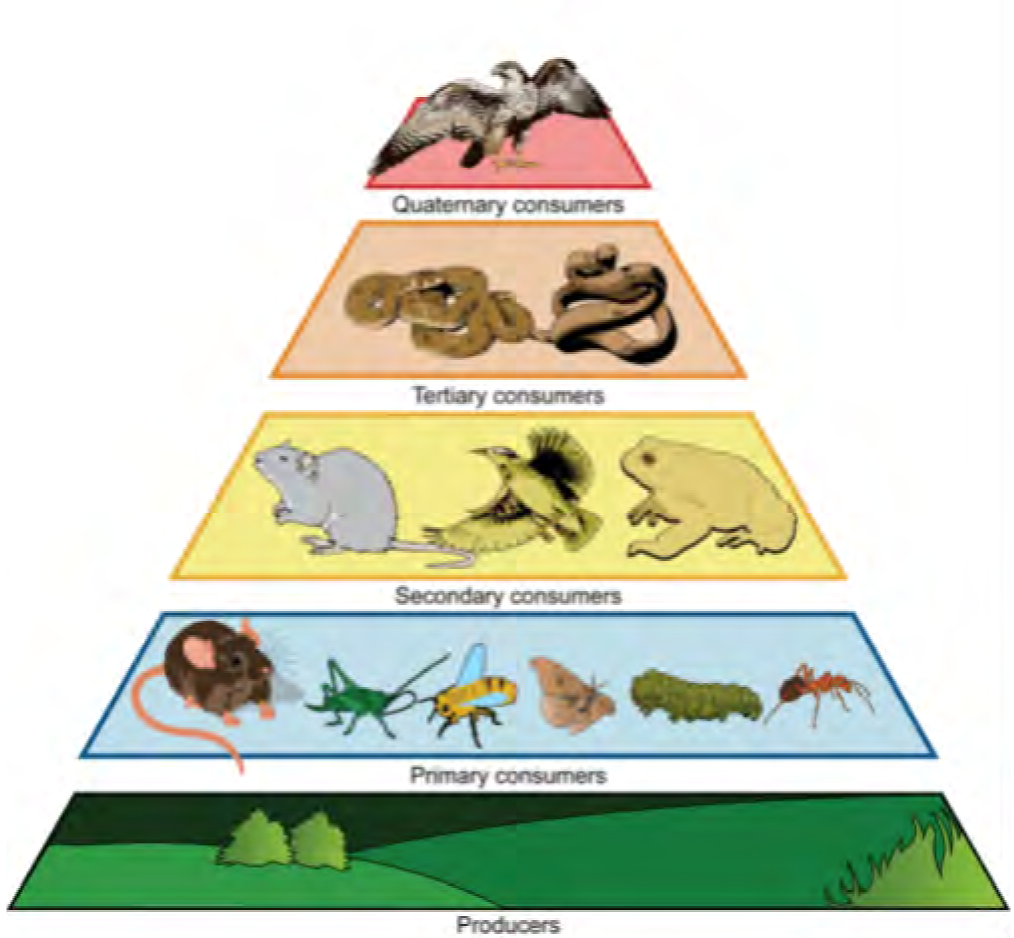


Image by Laura Guerin, CK-12 Foundation, CC-BY-NC

Energy and Biomass Pyramids

The way that matter and energy move through ecosystems affects the structure of the system. Each step of the food chain is called a trophic level. Most of the energy at one trophic level is lost and not available to the organisms in the next trophic level. How will the decreasing amount of available energy affect the amount of matter at each level of the food chain?

Because there is less energy at higher trophic levels, there are usually fewer organisms as well. Organisms tend to be larger in size at higher trophic levels, but their smaller numbers still result in less biomass. Biomass is the total mass of organisms in a trophic level (or other grouping of organisms). The ecological pyramid shows how the available energy and amount of biomass changes from first to higher trophic levels in a food chain.



Ecological Pyramid. This pyramid shows how energy and biomass decrease from lower to higher trophic levels. Assume that producers in this pyramid have 1,000,000 kilocalories of energy. How much energy is available to primary consumers?

Only about 10% of the energy available at one trophic level will be passed up to the next trophic level. If the producers in the ecological pyramid have 1,000,000 kilocalories of energy, how much energy will be available to the primary consumers?

The materials in dead organisms and wastes at all trophic levels are broken down by decomposers. Organisms such as detritivores and saprotrophs return needed elements to the ecosystem and use up most remaining energy. Because of the reduction in energy at each trophic level, virtually no energy remains. Therefore, energy must be continuously added to ecosystems by producers.

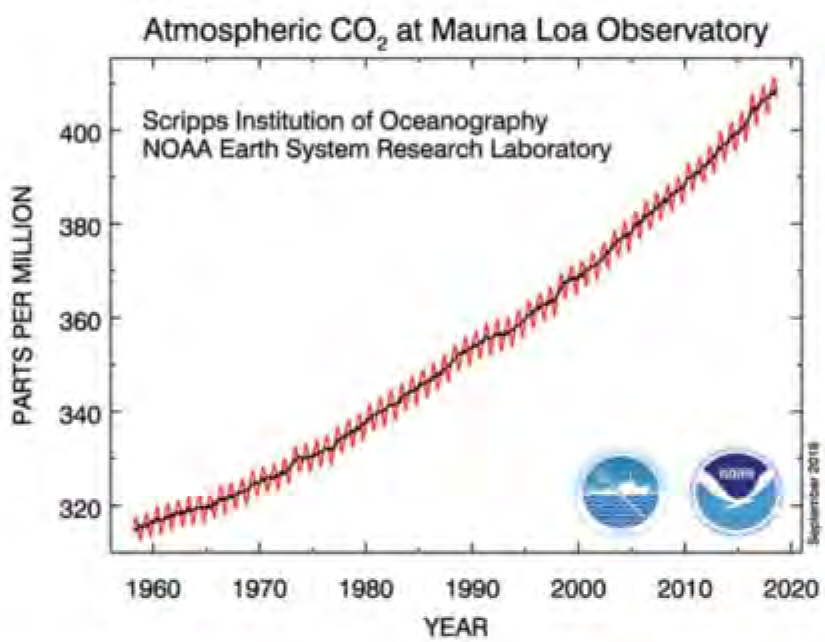
Putting It Together

Each of the ecosystems pictured looks quite different, but they all have some things in common.

1. Use the pictures to identify patterns in ecosystems. What new patterns can you identify now that you know about the way energy and matter move through ecosystems?
2. Use what you learned about the movement of matter and energy to explain the patterns you identified. Try creating a model that can explain the patterns.

1.3 Carbon Cycle (Bio.1.3)

Explore this Phenomenon



Public Domain

The amount of CO_2 in the atmosphere has been measured at Mauna Loa Observatory since 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2. [Figure4]

1. What do you notice about the amount of atmospheric Carbon Dioxide Concentration over the past six decades?
2. What do you think is causing the trend that is being observed with Carbon Dioxide Concentration?

Bio.1.3 Carbon Cycle

Analyze and interpret data to determine the effects of photosynthesis and cellular respiration on the scale and proportion of carbon reservoirs in the carbon cycle. Emphasize the cycling of carbon through the biosphere, atmosphere, hydrosphere, and geosphere and how changes to various reservoirs impact ecosystems. Examples of changes to the scale and proportion of reservoirs could include deforestation, fossil fuel combustion, or ocean uptake of carbon dioxide. (PS3.D, LS1.C, LS2.B)

It is important to understand how photosynthesis and cellular respiration affect the scale and proportion of carbon in different reservoirs. As you read this chapter, look for ways that photosynthesis and cellular respiration move carbon from one reservoir to another, and how this affects the proportion of carbon in each reservoir.

Matter Cycles During Photosynthesis and Respiration

The Carbon Cycle

How does carbon move through different ecosystems and what are some of those effects?

Flowing water can slowly dissolve carbon in sedimentary rock. Most of this carbon ends up in the ocean. The deep ocean can store carbon for thousands of years or more. Sedimentary rock and the ocean are major reservoirs of stored carbon. Carbon is also stored for varying lengths of time in the atmosphere, in living organisms, and as fossil fuel deposits. These are all parts of the carbon cycle, which is shown in the next figure.

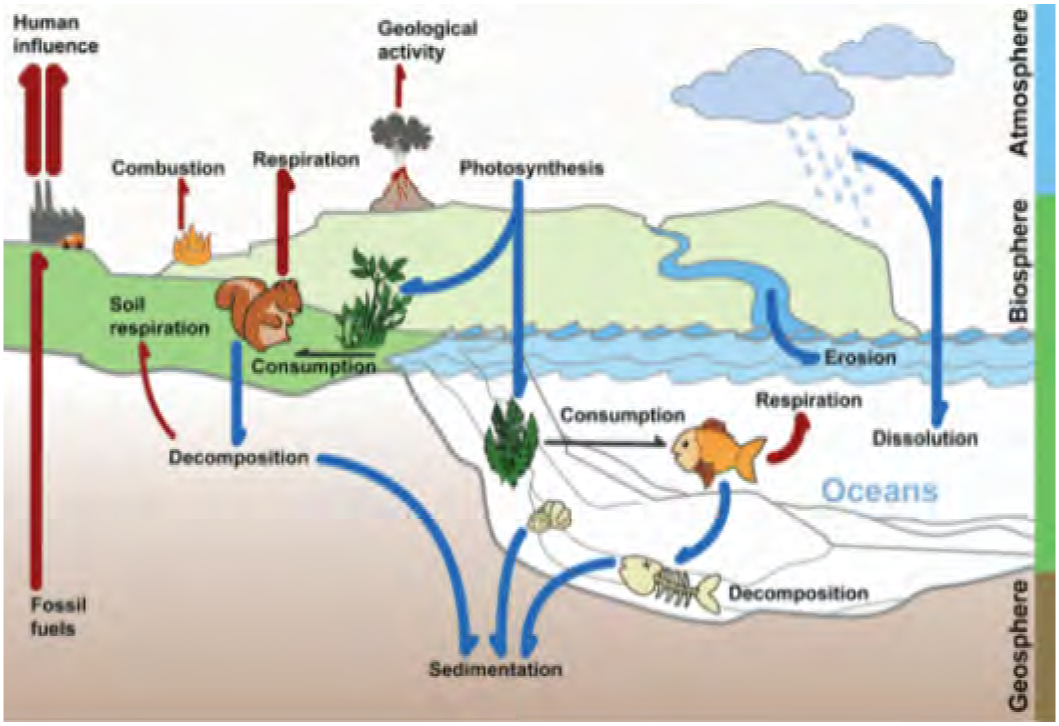


Image by Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation, CC-BY-NC 3.0

The Carbon Cycle. Carbon moves from one reservoir to another in the carbon cycle. What role do organisms play in this cycle?

Why is recycling carbon important? Carbon is the cornerstone of organic compounds, the compounds necessary for life. But do organisms make their own carbon? Do they have the genes that encode proteins necessary to make carbon? No. In fact, there are no such genes. Carbon must be recycled from other living organisms, from carbon in the atmosphere, and from carbon in other parts of the biosphere.

Photosynthesis and cellular respiration recycle carbon. Autotrophs take carbon from the atmosphere and convert it to organic molecules. Protein, carbohydrates, and fats are all parts of heterotrophs and all contain carbon. When organisms break down food to produce energy, they break down protein, carbohydrates, and fat, and release carbon dioxide.

Carbon in the Atmosphere

Though carbon can be found in ocean water, rocks and sediment and other parts of the biosphere, the atmosphere may be the most recognizable reservoir of carbon. Carbon occurs in various forms in different parts of the carbon cycle. Some of the different forms in which carbon appears are described in the Table below.

KEY: C = Carbon, O = Oxygen, H = Hydrogen

Form of Carbon	Chemical Formula	State	Main Reservoir
Carbon Dioxide	CO_2	Gas	Atmosphere
Carbonic Acid	H_2CO_3	Liquid	Ocean
Bicarbonate Ion	HCO_3^-	Liquid (dissolved ion)	Ocean
Organic Compounds	Examples: $C_6H_{12}O_6$ (Glucose), CH_4 (Methane)	Solid Gas	Biosphere Organic Sediments (Fossil Fuels)
Other Carbon Compounds	Examples: $CaCO_3$ (Calcium Carbonate), $CaMg(CO_3)_2$ (Calcium Magnesium Carbonate)	Solid Solid	Sedimentary Rock, Shells

Carbon in Carbon Dioxide

Carbon cycles quickly between organisms and the atmosphere via photosynthesis and respiration. In the atmosphere, carbon exists primarily as carbon dioxide (CO2). Carbon dioxide cycles through the atmosphere by several different processes, including those listed below.

- Living organisms release carbon dioxide as a byproduct of cellular respiration.
- Photosynthesis removes carbon dioxide from the atmosphere and uses it to make organic compounds.
- Carbon dioxide is given off when dead organisms and other organic materials decompose.
- Burning organic material, such as fossil fuels, releases carbon dioxide.
- Carbon cycles far more slowly through geological processes such as sedimentation. Carbon may be stored in sedimentary rock for millions of years.
- When volcanoes erupt, they give off carbon dioxide that is stored in the mantle.
- Carbon dioxide is released when limestone is heated during the production of cement.
- Ocean water releases dissolved carbon dioxide into the atmosphere when water temperature rises.
- Carbon dioxide is also removed when ocean water cools and dissolves more carbon dioxide from the air.

Because of human activities, there is more carbon dioxide in the atmosphere today than in the past hundreds of thousands of years. Burning fossil fuels and has released great quantities of carbon dioxide into the atmosphere. Cutting forests and clearing land has also increased carbon dioxide into the atmosphere because these activities reduce the number of autotrophic organisms that use up carbon dioxide in photosynthesis. In addition, clearing often involves burning, which releases carbon dioxide that was previously stored in autotrophs. Carbon cycles through the atmosphere relatively quickly.

Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO2 when they form, but they are a source for CO2 when they are burned.

The equation for combustion of propane, which is a simple hydrocarbon looks like this:

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\,O_2} \rightarrow \underset{\text{carbon dioxide}}{3\,CO_2} + \underset{\text{water}}{4\,H_2O}$$

The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO2, the result is the increase in atmospheric CO2 seen in the Figure above.

The second largest source of atmospheric CO2 is deforestation (Figure below). Trees naturally absorb CO2 while they are alive. Trees that are cut down lose their ability to absorb CO2. If the tree is burned or decomposes, it becomes a source of CO2. A forest can go from being a carbon sink to being a carbon source.

Lacanja burn by Jami Dwyer, https://commons.wikimedia.org/wiki/File:Lacanja_burn.JPG, public domain

This forest in Mexico has been cut down and burned to clear forested land for agriculture.

Effects of Carbon in the Oceans on Ecosystems

As the oceans absorb CO_2, the minerals in the seawater change. Normally, the ocean has a lot of calcium carbonate available. Shellfish and coral use this mineral to build and repair their shells. When an area of the ocean experiences an increase in carbon dioxide, a chemical reaction makes the calcium carbonate unavailable. Shells thin. Coral stops growing. Animals die. Many sea animals spend at least part of their life cycles on the reefs. As these ecosystems disappear, species will die out, the food web will experience disruptions, and our oceans will become less diverse.

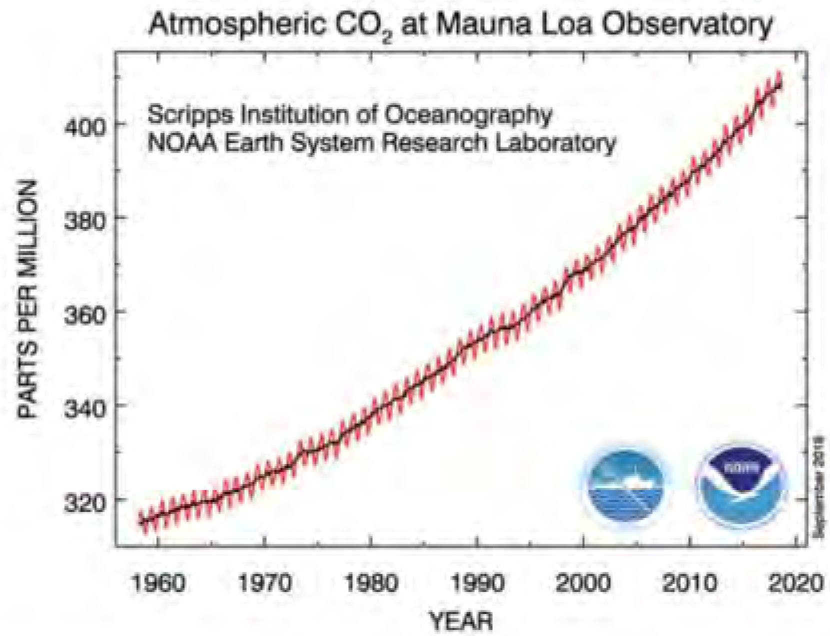
Image by USFWS, https://flic.kr/p/jzU8F1, CC-BY-NC

Many oceanographers say that this threat to the ecosystem is actually more urgent than the threat posed by global warming. Coral reefs take thousands of years to grow, but can deteriorate in only a few decades. Without some sort of a change, we may be looking at a future where the seas are a little more acidic, and a lot less lively.

See for Yourself

- https://www.youtube.com/watch?v=t1AyIs1xNCk

Putting It Together



Public Domain

The amount of CO_2 in the atmosphere has been measured at Mauna Loa Observatory since 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2. [Figure4]

1. What do you notice about the amount of atmospheric Carbon Dioxide Concentration over the past six decades?
2. What do you think is causing the trend that is being observed with Carbon Dioxide Concentration?
3. How is this increase in Carbon affecting different ecosystems on the Earth?

1.4 Stability and Change in Ecosystems (Bio.1.4)

Explore this Phenomenon

Dandelion rising by Jelle, https://flic.kr/p/7VU7E5, CC-BY

These flowers are growing out of hardened lava! The lava flow destroyed all the plants it came in contact with, but after the lava hardened into a rock, these plants began growing out of it.

1. How do drastic changes, such as volcanoes, affect ecosystems?
2. What questions could you investigate to learn more about how the lava rock and plants affect the stability of the ecosystem?
3. What other factors could affect the number and types of organisms in an ecosystem?

Bio.1.4 Stable Ecosystems

Develop an argument from evidence for how ecosystems maintain relatively consistent numbers and types of organisms in stable conditions. Emphasize how changing conditions may result in changes to an ecosystem. Examples of changes in ecosystem conditions could include moderate biological or physical changes such as moderate hunting or a seasonal flood; and extreme changes, such as climate change, volcanic eruption, or sea level rise. (LS2.C)

The stability of factors in ecosystems affects the number and types of organisms in the ecosystem. As you read this chapter, look for evidence that you can use to show how the stability of ecosystems correlates with the number and types of organisms in the system.

Organisms Depend on the Environment and Each Other

What other species do you need to survive?

Giant moray eel being cleaned by a bluestreak cleaner wrasse
by Silke Baron, https://en.wikipedia.org/wiki/Cleaning_symbiosis#/media/File:Giant_Moray_Eel_getting_cleaned.jpg, CC BY 2.0

Species cannot live alone. All life needs other life to survive. The image shows a bluestreak cleaner wrasse eating algae and other small organisms off a giant moray eel. This is an example of a symbiotic relationship.

Interdependence of Living Things

All living things depend on their environment to supply them with what they need, including food, water, and shelter. Their environment consists of physical factors—such as soil, air, and temperature—and also of other organisms. An organism is an individual living thing. Many living things interact with other organisms in their environment. In fact, they may need other organisms in order to survive. This is known as interdependence. For example, living things that cannot make their own food must eat other organisms for food. Other interactions between living things include symbiotic relationships and competition for resources.

Since living things depend on their environment and other organisms, changes to the environment or one population can affect other populations. The numbers and types of organisms in an ecosystem are not usually static because ecosystems adjust to gradual changes. As conditions change, the numbers and types of species in the ecosystem gradually change over time. If conditions remain stable, what will happen to the number and types of organisms in the ecosystem?

Moderate Changes

Minor to moderate changes happen from season to season. Seasonal floods, hunting, climate change, and other factors can create changes to an ecosystem in a short period of time. The changes are typically not big enough to completely disrupt the ecosystem, but do affect the populations that inhabit the ecosystem. Ecosystems typically recover from this type of disturbance quickly.

Extreme Changes

A catastrophic event, such as a volcano, can destroy an existing ecosystem and also set the stage for a new ecosystem to be created. Primary succession occurs when an area has never been colonized; in other words, there are no living organisms or even soil in the area. Bacteria and lichens that can live on bare rock, along with wind and water, help weather the rock and form soil. Once soil begins to form, plants can move in. At first, the plants include grasses and other species that can grow in thin, poor soil. As more plants grow and die, organic matter is added to the soil. This improves the soil and helps it hold water. The improved soil allows shrubs and trees to move into the area.

Primary Succession. New land from a volcanic eruption is slowly being colonized by a pioneer species.

Rhyolite (Palisade Rhyolite, North Shore Volcanic Group, Mesoproterozoic, 1096-1097 Ma; Rt. 1 roadcut just north of Ilgen City, Minnesota, USA) 2 by James St. John, https://flic.kr/p/ACAUrG, CC-BY

Secondary Succession occurs in a formerly inhabited area that was disturbed. The disturbance could be a fire, flood, or human action such as farming. This type of succession is faster because the soil is already in place. In this case, plants such as grasses, birch trees, and fireweed are the first plants to grow. Organic matter from the first plants improves the soil. This lets other plants move into the area.

Secondary Succession. Two months after a forest fire, new plants are already sprouting among the charred logs.

Putting It Together

Dandelion rising by Jelle, https://flic.kr/p/7VU7E5, CC-BY

These flowers are growing out of hardened lava! The lava flow destroyed all the plants it came in contact with, but after the lava hardened into a rock, these plants began growing out of it.

1. Explain this phenomenon. How are plants able to grow out of rock?
2. Predict if conditions in this ecosystem will remain stable or change, and use evidence about how organisms interact with each other and their environment to support your prediction.

1.5 Human Impact (Bio.1.5)

Explore this Phenomenon

Image by Andrea Bohl (Wildfaces), pixabay.com, CC0

Wolverines are one species that is affected by human activities. Female wolverines need to make a den in snow to give birth. Human activities are causing the climate to change, which results in less territory for wolverines to live and give birth.

1. What are some possible solutions to this problem?
2. What other human activities affect ecosystems and biodiversity?
3. What solutions could be applied to help reduce the impacts of human activities on ecosystems?

Bio.1.5 Human Impact

Design a solution that reduces the impact caused by human activities on the environment and biodiversity. *Define the problem, identify criteria and constraints, develop possible solutions using models, analyze data to make improvements from iteratively testing solutions, and optimize a solution.* Examples of human activities could include building dams, pollution, deforestation, or introduction of invasive species. (LS2.C, LS4.D, ETS1.A, ETS1.B, ETS1.C)

Humans can cause changes to the environment and biodiversity. As you read this chapter, think about ways that we could reduce the impacts on ecosystems that are caused by our activities.

Human Activities Affect the Environment

What is involved in Engineering Design?

Engineering is a creative process where each new version of a design is tested and then modified, based on what has been learned up to that point. This process includes a number of stems:

1. Identifying the problem and defining criteria and constraints.
2. Generating ideas for how to solve the problem. Engineers can use research, brainstorming and collaboration with others to come up with ideas for solutions and designs.
3. Build and then test the prototypes. Using data collected, the engineer can analyze how well the various prototypes meet the given criteria and constraints.
4. Evaluate what is needed to improve the leading design or devise a better one.

Recall from the beginning of this section that female wolverines need to make a den in snow to give birth. As human activities cause the climate to change, wolverines have less territory to build dens. Your task is to design a solution to this problem.

To design a solution to the problem, you will need to start by identifying the criteria and constraints. Then develop several possible solutions. Once you have several possible solutions, use the criteria and constraints to evaluate each. You should test the solution that will best meet the criteria and constraints, and then determine how to improve the solution, based on test results. Testing the solution may include modeling, working with materials, using mathematical relationships, etc.

In this section, you will be learning about how human activities affect ecosystems and biodiversity. You will also be learning about some possible solutions. Think about how human activities are affecting ecosystems, and how realistic and effective different solutions for mitigating the effects are. When you finish this section, apply your experience evaluating possible solutions to designing and evaluating a solution to the problem of wolverines losing territory for their dens.

Water Pollution

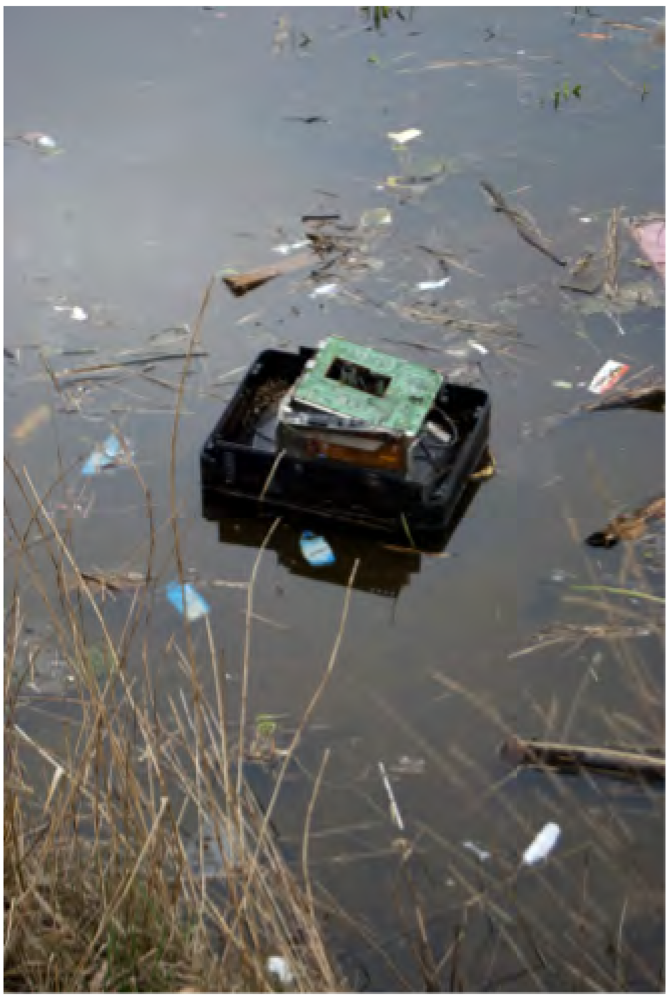


Image by CK-12 Foundation, CC-BY-NC

Do you live near water? Do you see pollution?

Water pollution is a worldwide problem. Almost anything released into the air or onto the land can end up in Earth's water.

Water pollution may come from one source. For example, chemicals from a factory may empty into a stream. Water pollution may come from more than one source, too. For example, chemicals may rain from the air into that same stream. It is much more difficult to control pollution from more than one source.

In the developed nations there are three main sources of water pollution:

1. Agriculture
2. Industry
3. Municipal, or community

Agriculture

Chemicals that are applied to farm fields include fertilizers and pesticides. Excess chemicals can be picked up by rainwater. The chemicals can end up in streams, ponds, lakes, or the ocean. Dissolved fertilizer causes tremendous numbers of water plants and algae to grow. This can lead to dead zones where nothing can live in lakes or the coastal oceans.

Waste from livestock can also pollute water. The waste contains pathogens that can cause diseases. Many farms in the U.S. have thousands of animals. These farms produce millions of gallons of waste. The waste is stored in huge lagoons, like the one pictured below. Many leaks from these lagoons have occurred.

Image by USDA Agricultural Research Services, http://www.ars.usda.gov/is/graphics/photos/mar05/d033-1.htm, public domain

This is a pond of hog manure. Check out the vehicles at the bottom of the picture for scale.

Industry

Factories and power plants may pollute water with harmful substances.

- Many industries produce toxic chemicals.
- Nuclear power plants produce radioactive wastes.
- Oil tanks and pipelines can leak.

Oil spills are hard to clean up and kill a lot of wildlife.

Image by Marine Photobank, https://commons.wikimedia.org/wiki/File:Oiled_Bird_-_Black_Sea_Oil_Spill_111207.jpg, CC-BY 2.0

Municipal

“Municipal” refers to the community. Households and businesses in a community can pollute the water supply. Municipal pollution comes from sewage, storm drains, septic tanks, boats, and runoff from yards. For example:

- People apply chemicals to their lawns. The excess can run off into surface waters.
- People may dispose of harmful substances incorrectly. For example, motor oil must not be drained into a storm sewer.
- Municipal sewage treatment plants dump treated wastewater into rivers or lakes. But the wastewater may not be treated for everything, or it may not be treated well enough.

What are some solutions to water pollution? Inventor Adam Katzman is using natural processes to treat sewage.

Go to https://www.youtube.com/watch?time_continue=234&v=sjvN2vt3kbg to see his eco-friendly floating toilet, and evaluate his design solution.

Habitat Destruction

Lacanja burn crop by Jami Dwyer, https://en.wikipedia.org/wiki/Wildlife_conservation#/media/File:Lacanja_burn_crop.JPG, public domain

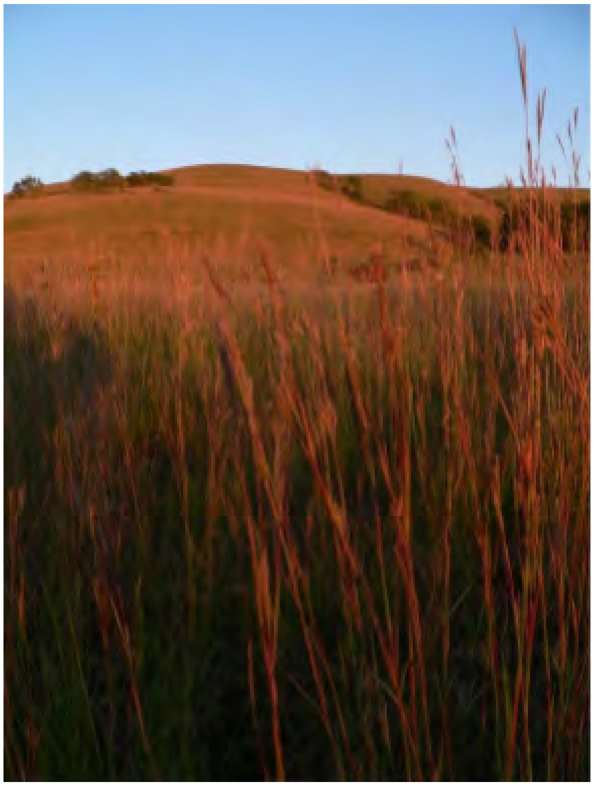
What's happening to this land?

This picture, taken in southern Mexico, shows land being cleared for agriculture. The forest has been cut down and burned to make room for a farm. In the process, homes to many plants and animals were destroyed. This is an example of habitat destruction.

From a human point of view, a habitat is where you live, go to school, and go to have fun. Your habitat can be altered, and you can easily adapt. Most people live in a few different places and go to a number of different schools throughout their life. But a plant or animal may not be able to adapt to a changed habitat. A habitat is the natural home or environment of an organism. Humans often destroy the habitats of other organisms. Habitat destruction can cause the extinction of species. Extinction is the complete disappearance of a species. Once a species is extinct, it can never recover. Some ways humans cause habitat destruction are by clearing land and by introducing non-native species of plants and animals.

Land Loss

Clearing land for agriculture and development is a major cause of habitat destruction. Within the past 100 years, the amount of total land used for agriculture has almost doubled. Land used for grazing cattle has more than doubled. Agriculture alone has cost the United States half of its wetlands and almost all of its tallgrass prairies. Native prairie ecosystems, with their thick fertile soils, deep-rooted grasses, diversity of colorful flowers, burrowing prairie dogs, and herds of bison and other animals, have virtually disappeared.



The Flint Hills contain some of the largest remnants of tallgrass prairie habitat remaining in North America.

Prairie Grass by USFWS Mountain-Prairie, https://flic.kr/p/aryfN3, CC-BY

Herds of bison also made up part of the tallgrass prairie community.

Image from https://commons.wikimedia.org/wiki/File:Tallgrass_Prairie_Nature_Preserve_in_Osage_County.jpg, public domain

Slash-and-Burn Agriculture

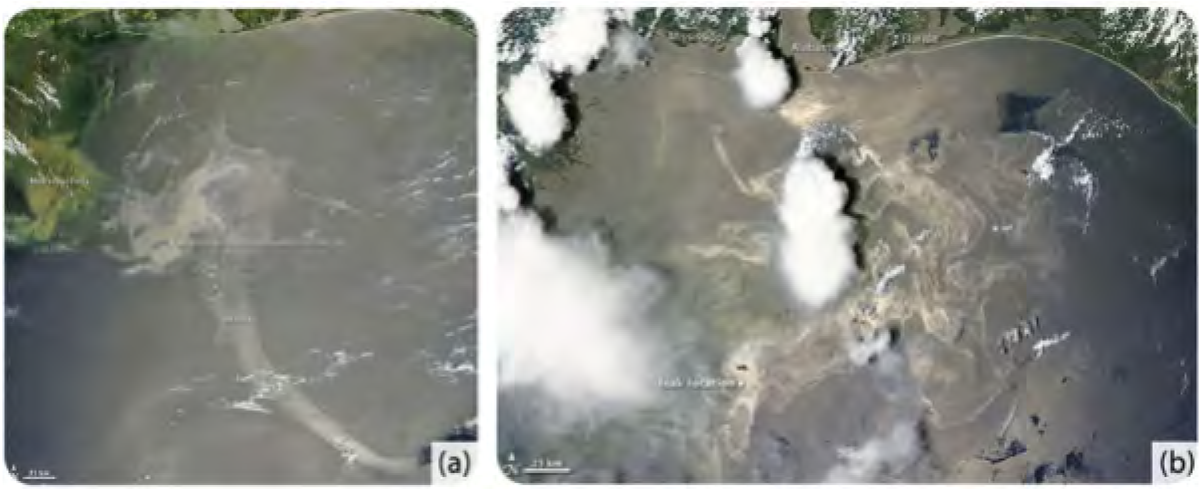
Other habitats that are being rapidly destroyed are forests, especially tropical rainforests. The largest cause of deforestation today is slash-and-burn agriculture . This means that when people want to turn a forest into a farm, they cut down all of the trees and then burn the remainder of the forest. This technique is used by over 200 million people in tropical forests throughout the world.

As a consequence of slash-and-burn agriculture, nutrients are quickly lost from the soil. This often results in people abandoning the land within a few years. Then the top soil erodes and desertification can follow. Desertification turns forest into a desert, where it is difficult for plants to grow. Half of the Earth's mature tropical forests are gone. At current rates of deforestation, all tropical forests will be gone by the year 2090.

What are some ways that we could either reduce the amount of habitat that is destroyed, or mitigate the effects of habitat destruction on other species? Scientists and engineers are developing ways to use resources more sustainably.

Watch https://www.youtube.com/watch?time_continue=10&v=eEFwaQej_0E to learn about and evaluate some sustainable development solutions.

Oil Spills



Images adapted from NASA Earth Observatory, public domain

Can you see the oil in a big oil spill?

Of course. The photo on the left shows the Gulf of Mexico oil spill after oil has leaked for nearly one month. About a month later, about twice as much oil was spilled into the Gulf, as seen on the right. The water moves and so the oil moves with it.

Oil rigs are built in the oceans to get at oil buried beneath the seafloor. These rigs pump oil from beneath the ocean floor. Huge ocean tankers carry oil around the world. If something goes wrong with a rig or a tanker, millions of barrels of oil may end up in the water. The oil may coat and kill ocean animals. Some of the oil will wash ashore. This oil may destroy coastal wetlands and ruin beaches.

New drilling techniques allow oil companies to drill in deeper waters than ever before. In April 2010 a rig in the Gulf of Mexico exploded. Eleven workers were killed and 17 injured. When the drill rig sank, a pipe was disconnected and oil gushed into the Gulf. Three months later the well was capped. But 4.9 million barrels had entered the Gulf, about 16 times more oil than the largest oil spill to date.

Cleanup

Once the oil is in the water, there are three ways to try to clean it:

1. Removal: Corral and then burn the oil.
2. Containment: Use containment booms to trap the oil.
3. Dispersal: Use chemicals to get the oil to disperse, called chemical dispersants. Some scientists think that the harm to the environment from the dispersants is as great as the harm from the oil.

The total effect of the oil spill on the environment of the Gulf is not yet known. Oil is found in the sediments on the seafloor. Many people who fish or are involved in Gulf tourism were also impacted. Studies of the effects of the oil spill on people and animals will continue for many years.

Mining

Image from NPS.gov, public domain

Can you tell that this was mine?

Mining can do a lot of damage to a region. Mining companies are now supposed to return the land to its natural state when they are done. Sometimes this works really well. It's hard to tell there was a mine here!

Mining provides people with many resources they need. But mining can be hazardous to the environment. For surface mines, miners clear the land of soil and plants. Nearby lakes and streams may be inundated with sediment. The mined rock may include heavy metals. These also enter the sediment and water. Removing metals from rock may involve toxic chemicals. Acid flow from a mine site will change the chemistry of a nearby stream or lake.

Mine Pollution

Mining can cause pollution. Chemicals released from mining can contaminate nearby water sources. Pictured below is water that is contaminated from a nearby mine. The United States government has mining standards to protect water quality.

This water has been polluted by a mountaintop removal mine.

Why East Kentucky Kids Use Orange Crayons to Draw Streams by iLoveMountains.org, https://flic.kr/p/7UHJEF, CC-BY

Land Reclamation

One way that scientists and engineers have tried to mitigate the effects of mining is to reclaim the land. U.S. law states that once mining is complete, the land must be restored to its natural state. This process is called reclamation. A pit may be refilled with dirt. It may be filled with water to create a lake. The pits may be turned into landfills. Underground mines may be sealed off or left open as homes for bats. The land is reshaped. Native plants are planted.

Putting It Together

Image by Andrea Bohl (Wildfaces), pixabay.com, CC0

Wolverines are one species that is affected by human activities. Female wolverines need to make a den in snow to give birth. Human activities are causing the climate to change, which results in less territory for wolverines to live and give birth.

1. As we develop solutions to mitigate the effects of human impacts, we will also have to develop criteria. What criteria should our solutions meet?
2. One solution that has been proposed is to create a corridor to increase habitat for wolverines. Evaluate the solutions proposed in this video: (https://www.ck12.org/biology/habitat-destruction/rwa/Wheres-My-Snow-Den/?referrer=concept_details).
3. What are some other solutions that could be used to mitigate the effects of human impacts on wolverines?
4. Evaluate each of the solutions you created for question two using the criteria you developed for question one. Which solutions meet the criteria?

CHAPTER 2

Strand 2: Structure and Function of Life

Chapter Outline

Image by Limassol/Cyprus (www_slon_pics), pixabay.com, CC0

Living cells are composed of chemical elements and molecules that form macromolecules. The macromolecules in a cell function to carry out important reactions that allow cycling of matter and flow of energy within and between organisms. All organisms are made of one or more cells. The structure and function of a cell determines the cell's role in an organism. Multicellular organisms have systems of tissues and organs that work together to meet the needs of the whole organism. Cells grow, divide, and function in order to accomplish essential life processes. Feedback systems help organisms maintain homeostasis.

2.1 Macromolecules (Bio.2.1)

Explore this Phenomenon

Image by RitaE, pixabay.com, CC0

image by www.medicalgraphics.de, http://www.medicalgraphics.de/en/free-pictures/organs/torso-organs.html, CC-BY-ND

The food you eat becomes part of your body and helps your cells function.

1. How does the matter you eat change to become part of your body and help your cells function? Create a diagram to show how the matter in your food becomes part of your cells.
2. How does the matter you eat affect the way your cells function? If you eat different foods, do your cells function differently?

Bio.2.1 Macromolecules

Construct an explanation based on evidence that all organisms are primarily composed of carbon, hydrogen, oxygen, and nitrogen, and that the matter taken into an organism is broken down and recombined to make macromolecules necessary for life functions. Emphasize that molecules are often transformed through enzymatic processes and the atoms involved are used to make carbohydrates, proteins, fats/lipids, and nucleic acids. (LS1.C)

Organisms take in matter, which ends up being incorporated into their cells. As you read this chapter, look for evidence that shows how the matter that an organism takes in is recombined into the macromolecules needed by cells. Also pay attention to the mechanisms that an organism uses to make macromolecules.

Molecules from Food

Turkey Taco Salad by Maggie Hoffman, https://flic.kr/p/7ySjhg, CC-BY

What makes up a healthy diet?

A healthy diet includes protein, fats, and carbohydrates. Why? Because these compounds are three of the main building blocks that make up your body. You obtain these building blocks from the food that you eat, and you use these building blocks to make the organic compounds necessary for life.

The main chemical components of living organisms are known as organic compounds. Organic compounds are molecules built around the element carbon (C). Living things are made up of very large molecules. These large molecules are called macromolecules because “macro” means large; they are made by smaller molecules bonding together. Our body gets these smaller molecules, the "building blocks” of organic molecules from the food we eat.

The four main types of macromolecules found in living organisms, shown in the table below, are:

1. Proteins.
2. Carbohydrates.
3. Lipids.
4. Nucleic Acids.

	Proteins	Carbohydrates	Lipids	Nucleic Acids
Elements	C, H, O, N, S	C, H, O	C, H, O, P	C, H, O, P, N
Examples	Enzymes, muscle fibers, antibodies	Sugar, glucose, starch, glycogen, cellulose	Fats, oils, waxes, steroids, phospholipids in membranes	DNA, RNA, ATP
Monomer (small building block molecule)	Amino acids	Monosaccharides (simple sugars)	Often include fatty acids	Nucleotides

Review the elements found in each type of macromolecule. What pattern do you see?

Carbon, hydrogen, oxygen, and nitrogen are the building blocks for the macromolecules our cells need to function. Each macromolecule has a different function.

Carbohydrates

Carbohydrates are sugars. Cells use carbohydrates for energy. Some carbohydrate molecules, such as glucose, are relatively small, and are called simple sugars. Glucose has the chemical formula $C_6H_{12}O_6$. Other carbohydrates are made of many simple sugars connected together into a long chain. These long chains often consist of hundreds or thousands of simple sugars. Plants store sugar in large molecules called starch. Animals store sugar in large molecules called glycogen. You get the carbohydrates you need for energy from eating carbohydrate-rich foods, including fruits and vegetables, as well as grains, such as bread, rice, or corn.

Image by PublicDomainImages, pixabay.com, CC0

Lipids

Have you ever tried to put oil in water? They don't mix. Oil is a type of lipid. Lipids are molecules such as fats, oils, and waxes. The most common lipids in your diet are probably fats and oils. Animals use fats for long-term energy storage and to keep warm. Plants use oils for long-term energy storage. When preparing food, we often use animal fats, such as butter, or plant oils, such as olive oil or canola oil. There are many more types of lipids that are important to life. One of the most important are the phospholipids that make up the protective outer membrane of all cells.These lipid membranes are impermeable to most water soluble compounds.

Phospholipids in a membrane, shown as two layers (a bilayer) of phospholipids facing each other.

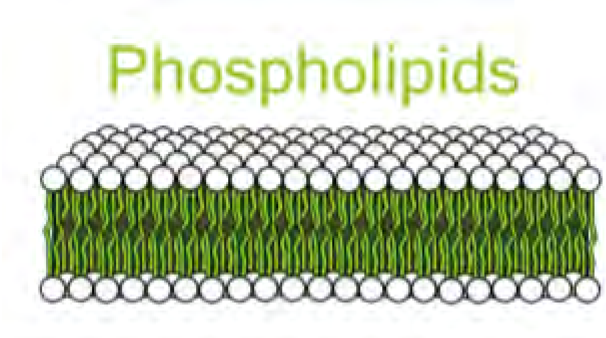


Image adapted from https://commons.wikimedia.org/wiki/File:Phospholipids_aqueous_solution_structures.svg, CC0

Nucleic acids

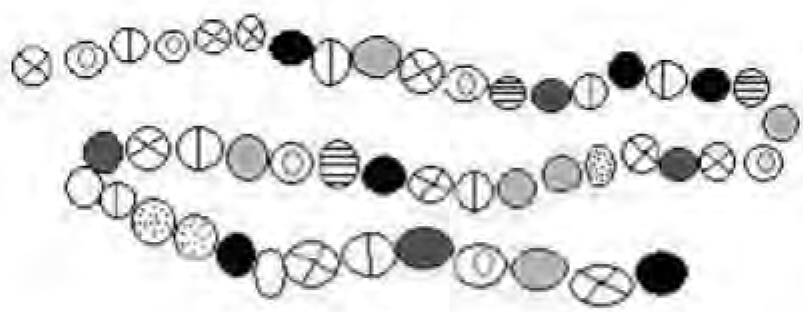
Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are the two main nucleic acids. DNA is a double-stranded nucleic acid. DNA is the molecule that stores our genetic information. DNA contains the instructions to build proteins, and is the molecule that stores genetic information and is passed from parent to offspring. The single-stranded RNA is involved in making proteins.

Image by PublicDomainImages, pixabay.com, CC0

Proteins

Proteins are molecules that have many different functions in living things. It's important for you and other animals to eat food with protein, because we cannot make certain amino acids on our own. You can get protein from plant sources, such as beans, and from animal sources, like milk or meat. When you eat food with protein, your body breaks the proteins down into individual amino acids and uses them to build new proteins. You really are what you eat!

All proteins are made of smaller molecules called amino acids that connect together like beads on a necklace.



A chain of amino acids

Chain of Amino Acids by Sunshineconnelly at English Wikibooks, https://commons.wikimedia.org/wiki/File:Chain_of_amino_acids.jpg, CC-BY

Proteins do all of the work in cells. Some proteins help move molecules into and out of the cell. Other proteins break down molecules or build molecules. Every protein has a unique function. The order of the amino acids determines the function of the protein.

Enzymes are special proteins

Enzymes are a special type of protein that speed up chemical reactions. For example, your stomach would not be able to break down food if it did not have special enzymes to speed up the rate of digestion. Enzymes also recombine the elements you eat into carbohydrates, lipids, and nucleic acids that your cells need.

Putting It Together

Image by RitaE, pixabay.com, CC0

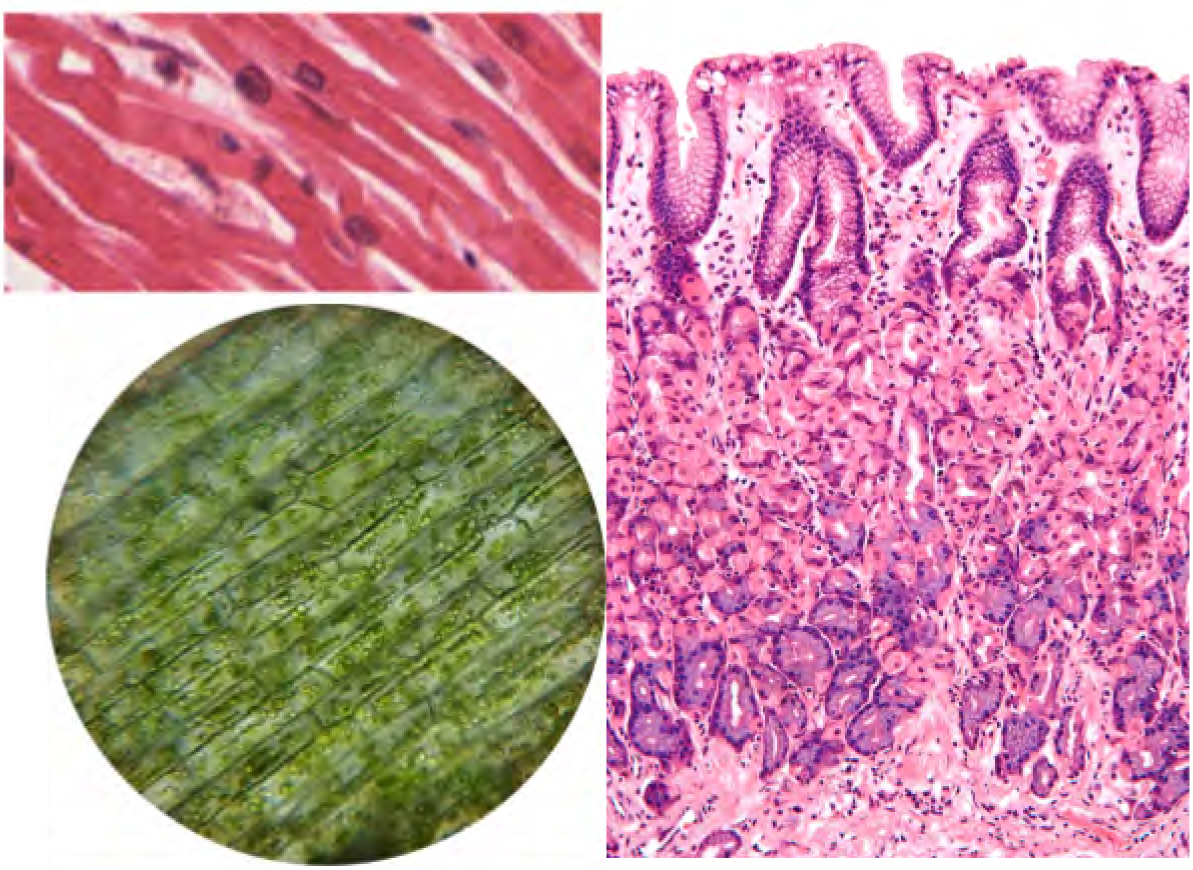
image by www.medicalgraphics.de, http://www.medicalgraphics.de/en/free-pictures/organs/torso-organs.html, CC-BY-ND

The food you eat becomes part of your body and helps your cells function.

1. Review the diagram you made before reading this chapter. Revise your diagram to show how the matter you eat is changed into molecules in your body that help your cells function.

2.2 Cell Structure and Function (Bio.2.2)

Explore this Phenomenon



(Top) Image by OpenStax, https://commons.wikimedia.org/wiki/File:414_Skeletal_Smooth_Cardiac.jpg, *CC-BY*
(Bottom) Image by Andrea Vierschilling, pixabay.com, CC0
(Right) Image by Nephron,
https://en.wikipedia.org/wiki/Stomach#/media/File:Normal_gastric_mucosa_intermed_mag.jpg, CC-BY-SA 3.0

The pictures above show different types of cells. The cell types look different, even though they all have to perform the same functions to stay alive.

1. What do you think causes the cells to look different?
2. What are three questions you could investigate to figure out why cells look different

Bio.2.2 Cell Structure and Function

Ask questions to plan and carry out an investigation to determine how (a) the structure and function of cells, (b) the proportion and quantity of organelles, and (c) the shape of cells result in cells with specialized functions. Examples could include mitochondria in muscle and nerve cells, chloroplasts in leaf cells, ribosomes in pancreatic cells, or the shape of nerve cells and muscle cells. (LS1.A)

The structures in a cell affect how it functions. As you read this chapter, pay attention to the different structures in cells, and how these structures affect the cell's function.

Cell Structure: What are cells made of?

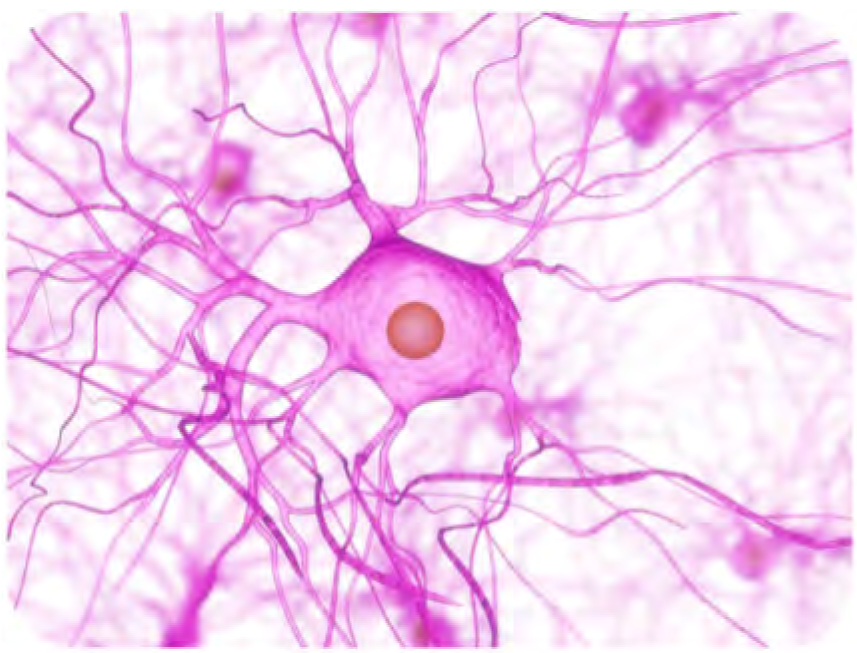


Image by Zachary Wilson, CK-12 Foundation, CC-BY-NC 3.0

A close-up view of a spider web? Some sort of exotic bacteria? What do you think this is?

This is actually a nerve cell, the cell of the nervous system. This cell carries signals from one part of your body to another. Why are nerve cells shaped like this? Why aren't all cells shaped like this?

Understanding the structure and function of cells is essential to understanding how living organisms work. To understand why cells have different structures, you need to first understand the basic components of the cell, which include the:

- Cell membrane
- Nucleus and chromosomes
- Other organelles

The Plasma Membrane and Cytosol

All cells have a cell membrane. The cell membrane is a double layer of specialized lipids, known as phospholipids, along with many special proteins. The function of the cell membrane is to control what moves in and out of the cell.

The cell membrane is semipermeable, which means that some molecules molecules can go through the cell membrane while others can't. Without a cell membrane, a cell would be unable to maintain a stable internal environment separate from the external environment.

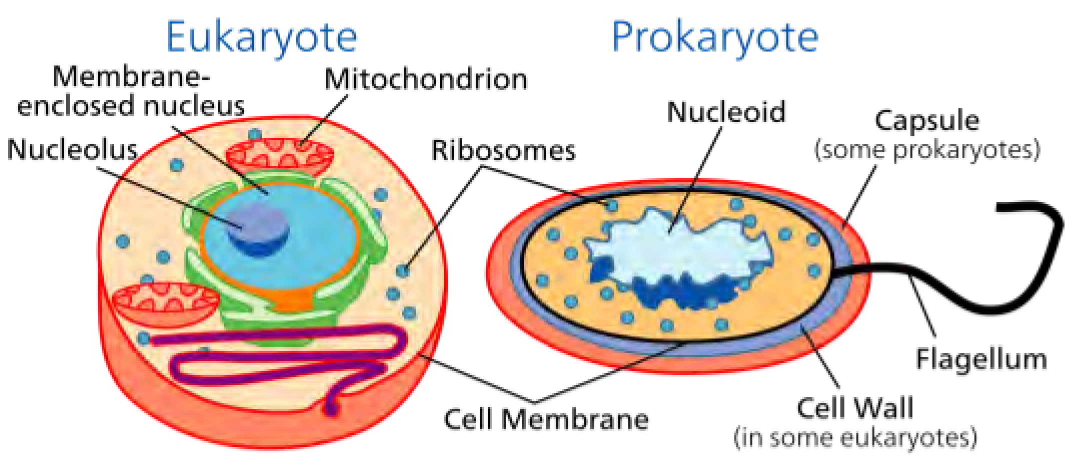
Cells also share an internal fluid-like substance called the cytoplasm. The cytoplasm is composed of water and other molecules, including enzymes that speed up the cell's chemical reactions

The Nucleus and Chromosomes

The nucleus is a membrane-enclosed structure that contains most of the genetic material, or DNA, of the cell. The nucleus is surrounded by a membrane, which controls which molecules go in and out of the nucleus.

Inside the nucleus are the chromosomes, which consist of DNA that is wrapped in special proteins. The genetic information on the chromosomes is stored, made it available to the cell when necessary, and also duplicated when it is time to pass the genetic information on when a cell divides. All the cells of a species carry the same number of chromosomes. For example, human cells each have 23 pairs of chromosomes. Each chromosome in turn carries hundreds or thousands of genes that encode proteins that help determine traits as varied as tooth shape, hair color, or kidney function.

Not all cells have a nucleus. The DNA in bacterial cells is not enclosed in a membrane.



The cells of eukaryotes (left) and prokaryotes (right) by Science Primer (National Center for Biotechnology Information), public domain

The Other Organelles

Cells contain organelles, which are specialized structures. Each organelle has a different function. See the table below for a list of organelles and their functions.

ORGANELLE	FUNCTION
Ribosomes	Involved in making proteins
Golgi apparatus	Packages proteins and some polysaccharides
Mitochondria	Makes ATP (energy)
Smooth Endoplasmic Reticulum	Makes lipids, transports
Rough Endoplasmic Reticulum	Makes proteins, transports
*Chloroplast	Makes sugar (photosynthesis)
Lysosomes	Digests macromolecules
*Cell Wall	Support, structure
Cell Membrane	Regulates input & output; semipermeable
Vacuole	Storage of water, nutrients and wastes
Cytoplasm	Fluid that contains organelles
Nucleus	Controls functions of the cell, contains DNA
Nucleolus	Where ribosomes are made
^Centriole	Aids in cell division

**indicates structures specific to plant cells.*
^indicates structures specific to animal cells.

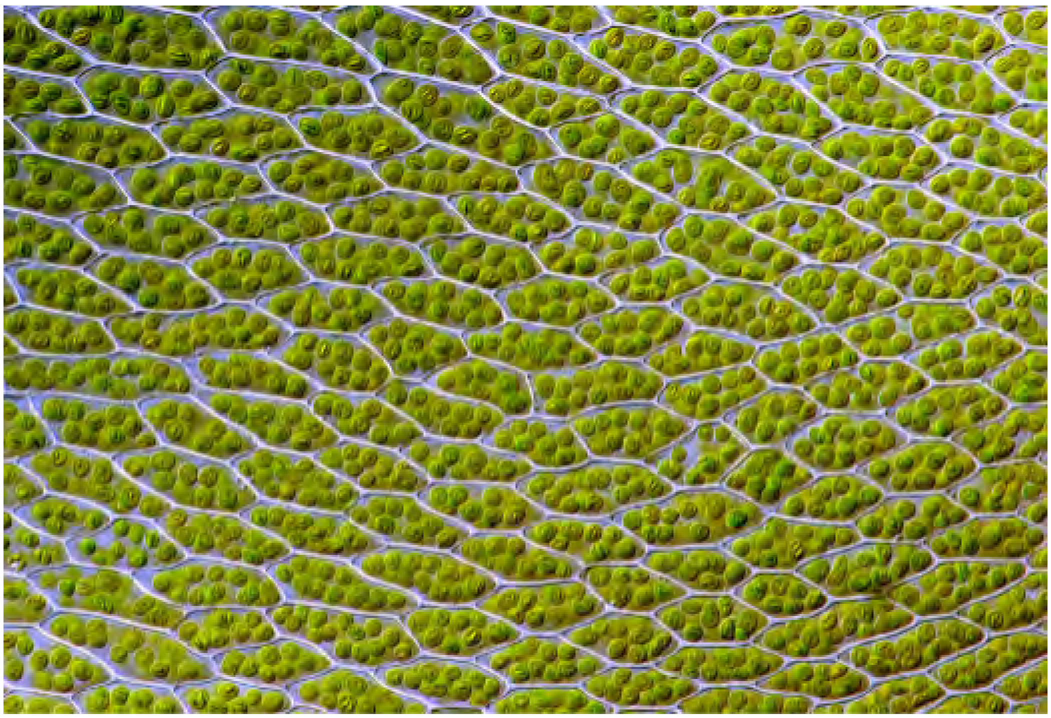
Plant Cells

Plant cells differ in some ways from animal cells. Use the table above to identify organelles that are found in plant cells but not in animal cells. Consider the functions of these organelles. How does having a different structure affect the function of plant cells?

First, plant cells are unique in having a large central vacuole that holds a mixture of water, nutrients, and wastes. A plant cell's vacuole can make up 90% of the cell's volume. In animal cells, vacuoles are much smaller.

Second, plant cells have a cell wall, animal cells do not. A cell wall gives the plant cell strength, rigidity, and protection. Although bacteria and fungi also have cell walls, a plant cell wall is made of a different material.

Third, plant cells have chloroplasts. These organelles convert light energy from the sun into chemical energy that can be stored and used by cells.



In this photo of plant cells, the cell walls appear purple, and the chloroplasts are green circles inside each cell.

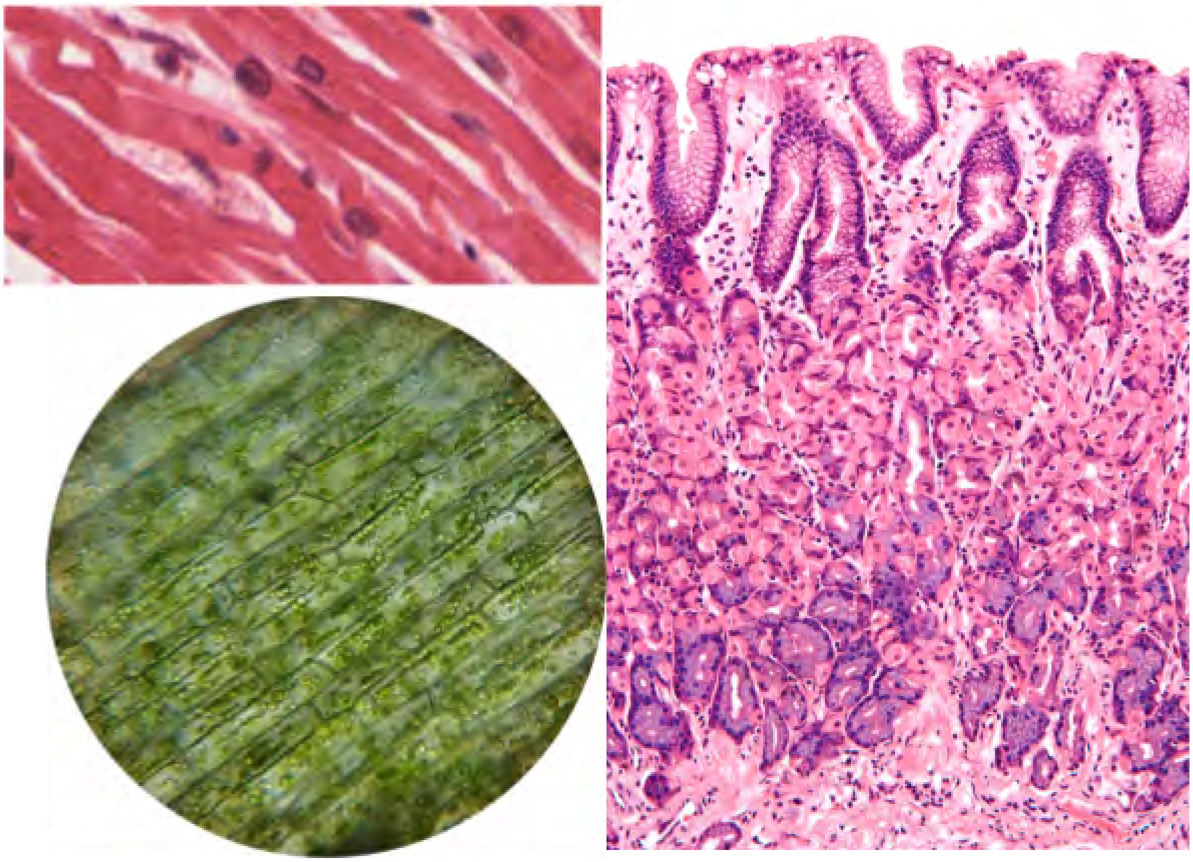
Image by Des_Callaghan
https://en.wikipedia.org/wiki/Chloroplast#/media/File:Bryum_capillare_leaf_cells.jpg

Examples of Various Structure and Function

All cells have to carry out some functions to stay alive. For example, cells must all be able to take in energy and reproduce. Cells may also have specialized functions. For example, nerve cells must be able to send signals, and muscle cells must be able to contract. Cells may have different structures to enable them to perform their function. How do the structures and function of the following types of cells compare?

- Plant cell vs. Animal cell
- Nerve cell vs. Muscle cell
- Normal blood cell vs. Sickle blood cell
- Prokaryote vs. Eukaryote

Putting It Together



(Top) Image by OpenStax, https://commons.wikimedia.org/wiki/File:414_Skeletal_Smooth_Cardiac.jpg, *CC-BY*
(Bottom) Image by Andrea Vierschilling, pixabay.com, CC0
(Right) Image by Nephron,
https://en.wikipedia.org/wiki/Stomach#/media/File:Normal_gastric_mucosa_intermed_mag.jpg, CC-BY-SA 3.0

The pictures above show different types of cells. The cell types look different, even though they all have to perform the same functions to stay alive.

1. How have your ideas about what causes the cells to look different changed?
2. Based on your understanding of cell structure and function, predict the function of cells with various structures. For example, what might be a function of a cell that contains high numbers of mitochondria?

2.3 Photosynthesis and Respiration (Bio.2.3)

Explore this Phenomenon

Moss Terrarium in a Jar by Gergely Hideg, https://flic.kr/p/m9RPYK, CC-BY

Terrariums, like the one shown above, are closed systems. This means that the container is sealed. Plants can survive for a long time in a terrarium, even though no water or air is added to the system. Plants have been growing in one terrarium since 1960, and water has only been added to the terrarium once (in 1972)!

1. Write an explanation or create a model to show how plants can survive in a closed system.
2. What are three questions we could investigate to figure out how the plants can live for so long without water or air being added to the system.

Bio.2.3 Photosynthesis and Respiration

Develop and use a model to illustrate the cycling of matter and flow of energy through living things by the processes of photosynthesis and cellular respiration. Emphasize how the products of one reaction are the reactants of the other and how the energy transfers in these reactions. (PS3.D, LS1.C, LS2.B)

Photosynthesis and cellular respiration move matter and energy through living things. As you read this chapter, gather information about how matter and energy move through organisms during photosynthesis and cellular respiration.

Matter Cycles and Energy Flows

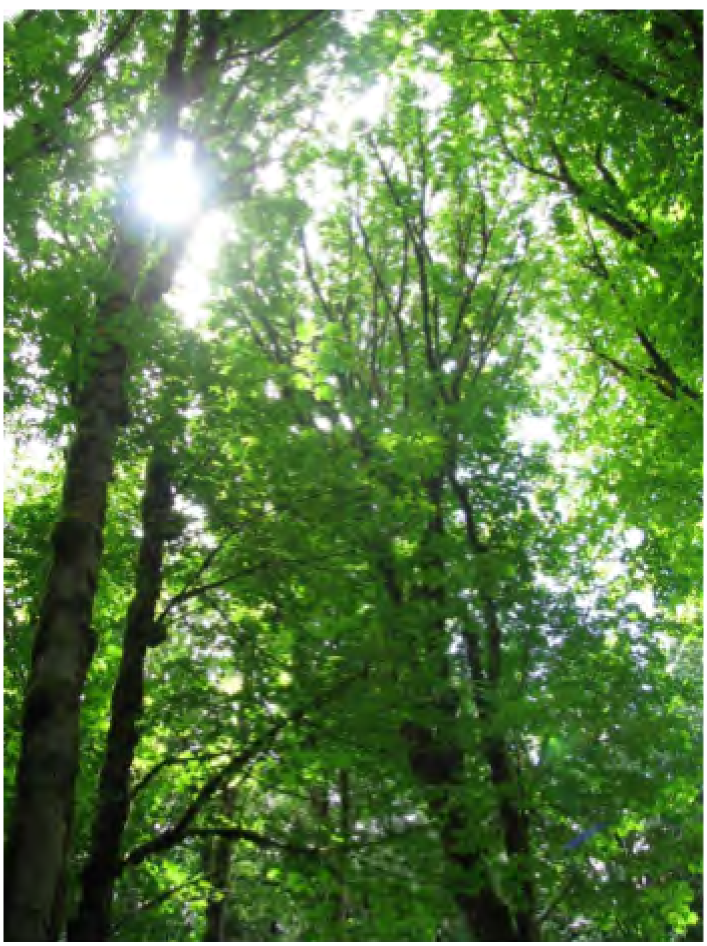


Image by LadyofHats, CK-12 Foundation, CC-BY-NC 3.0

Matter cycles, which means that it is used over and over again. Matter can move from one part of an ecosystem to another, and then return back to where it started. In section 1.3, you learned that carbon can move from the atmosphere to plants and then to animals in the biosphere, and back to the atmosphere. The carbon is reused as it cycles through the ecosystem.

Energy does not cycle. It can move from one part of an ecosystem to another, but unlike matter, it doesn't return to its starting place. Energy is converted from one form to another as it moves through the ecosystem, and at the end, it is not in a form that can be reused. Light energy from the sun is converted by plants into chemical energy, and the chemical energy can be passed to the animals that eat the plants. The chemical energy is converted to heat, sound, and other forms of energy.

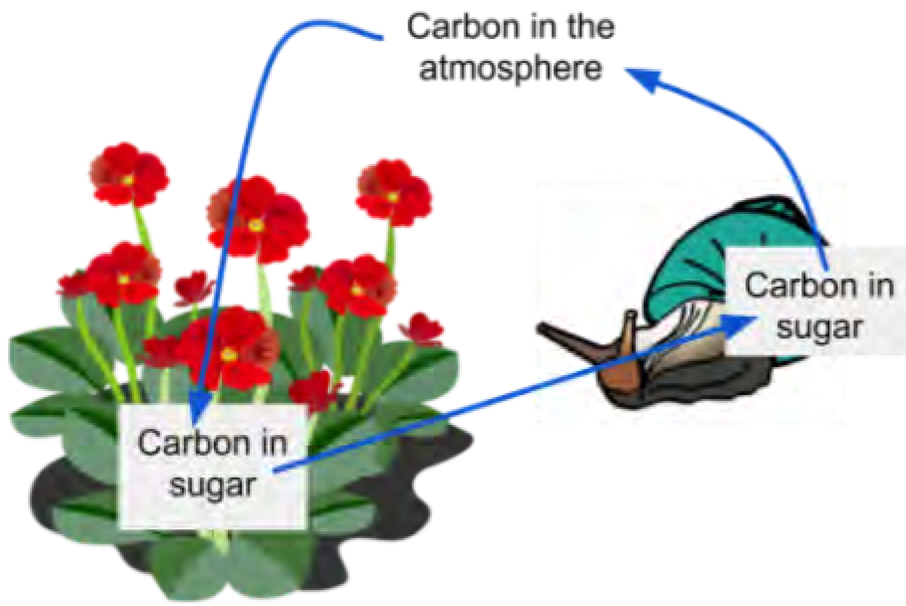


Image adapted from pixabay.com, CC0

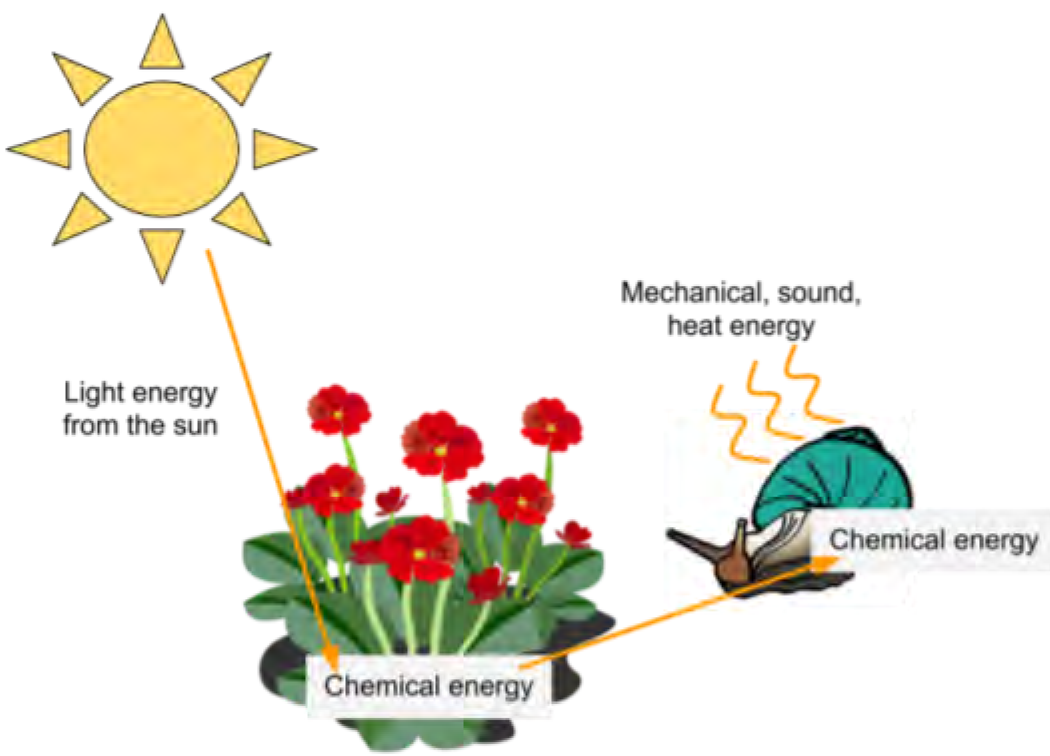


Image adapted from pixabay.com, CC0

Photosynthesis and Cellular Respiration are Opposite Reactions

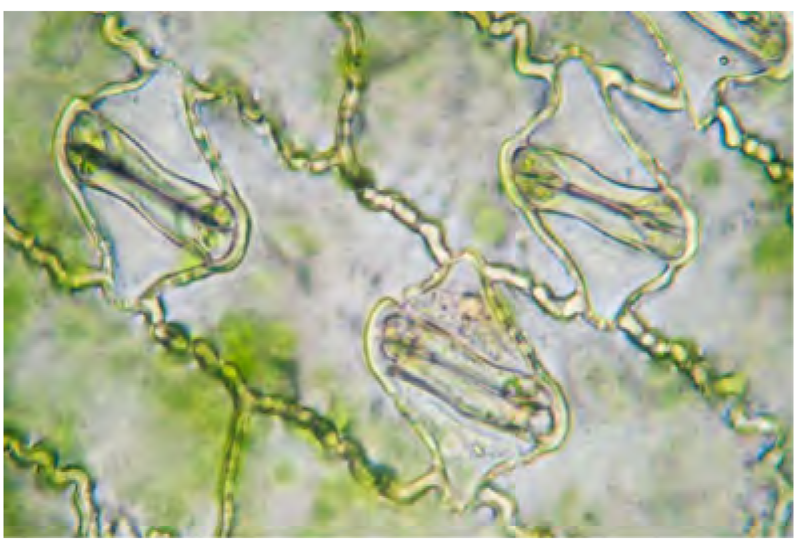
Photosynthesis and cellular respiration are connected through an important relationship. This relationship enables life to survive as we know it. The products of one process are the reactants of the other. Notice that the equation for cellular respiration is the direct opposite of photosynthesis:

	Photosynthesis	Respiration
Reactants	Carbon dioxide Water	Sugar (glucose) Oxygen
Products	Sugar (glucose) Oxygen	Carbon dioxide Water
Equation	$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$	$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6CO_2 + 6\ H_2O$

Photosynthesis

Photosynthesis is the process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy. During photosynthesis, carbon dioxide and water combine with solar energy, yielding glucose (the carbohydrate) and oxygen. The carbon dioxide and water molecules have less energy than the carbohydrate molecules that they are used to make. Where does the extra energy in the carbohydrates come from?

Plants convert light energy from the sun into the chemical energy in carbohydrates. The energy in the carbohydrates can be stored, or the plants can use the energy to perform necessary life functions.



Stomata are special pores that allow gases to enter and exit the leaf.

Photosynthesis mostly takes place in the leaves of a plant. The green pigment in leaves, chlorophyll, helps to capture solar energy. The veins within a leaf carry water which originates from the roots, and carbon dioxide enters the leaf from the air through special pores called stomata.

The overall chemical reaction for photosynthesis is six molecules of carbon dioxide (CO_2) and 6 molecules of water (H_2O), with the addition of solar energy, yields 1 molecule of glucose ($C_6H_{12}O_6$) and 6 molecules of oxygen (O_2). Using chemical symbols the equation is represented as follows:

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow{\text{Light}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Oxygen is a byproduct of the process of photosynthesis and is released to the atmosphere through the stomata. Therefore, plants and other photosynthetic organisms play an important ecological role in converting carbon dioxide into oxygen. Animals need oxygen to carry out the energy-producing reactions of their cells. Without photosynthetic organisms, many other organisms would not have enough oxygen in the atmosphere to survive. Oxygen is also used as a reactant in cellular respiration. Oxygen cycles through both processes of photosynthesis and cellular respiration.

Respiration

Image from Public Domain Pictures, pexels.com, CC0

How does the food you eat provide energy? When you need a quick boost of energy, you might reach for an apple or a candy bar. Although foods with sugars can give you a quick boost of energy, they cannot be used for energy directly by your cells. Energy is simply stored in these foods. Through the process of cellular respiration, the energy in food is changed into energy that can be used by the body's cells.

Glucose and oxygen are converted to ATP, which is a molecule that your cells can use for energy. During this process, carbon dioxide and water are formed. Cellular respiration is simply a process that changes one type of chemical energy, the energy stored in sugar, into another type, ATP.

Most often, cellular respiration proceeds by breaking down glucose into carbon dioxide and water. As this breakdown of glucose occurs, energy is released. Glucose has more energy than the carbon dioxide and water molecules that it is broken down to form. What happens to the extra energy?

Energy that is released from glucose is transferred to molecules of ATP. Your cells can use the energy in the ATP molecules to perform work, such as contracting your muscles as you walk down the street, performing active transport, or generating heat to keep you warm.

Notice that the equation for cellular respiration is the direct opposite of photosynthesis. While water was broken down to free hydrogen and oxygen during photosynthesis, in cellular respiration oxygen is combined with hydrogen to form water. While photosynthesis requires carbon dioxide and releases oxygen, cellular respiration requires oxygen and releases carbon dioxide. This cycle of carbon dioxide and oxygen in all the organisms that use photosynthesis and/or cellular respiration worldwide, helps to balance atmospheric oxygen and carbon dioxide.

Plants, animals, fungi, and bacteria all use respiration to get energy from carbohydrates. Plants are able to produce their own carbohydrates; however, animals, fungi, and bacteria all rely on plants to convert energy from the sun into a form of energy they can use. They also rely on plants to produce oxygen.

Putting It Together

Moss Terrarium in a Jar by Gergely Hideg, https://flic.kr/p/m9RPYK, CC-BY

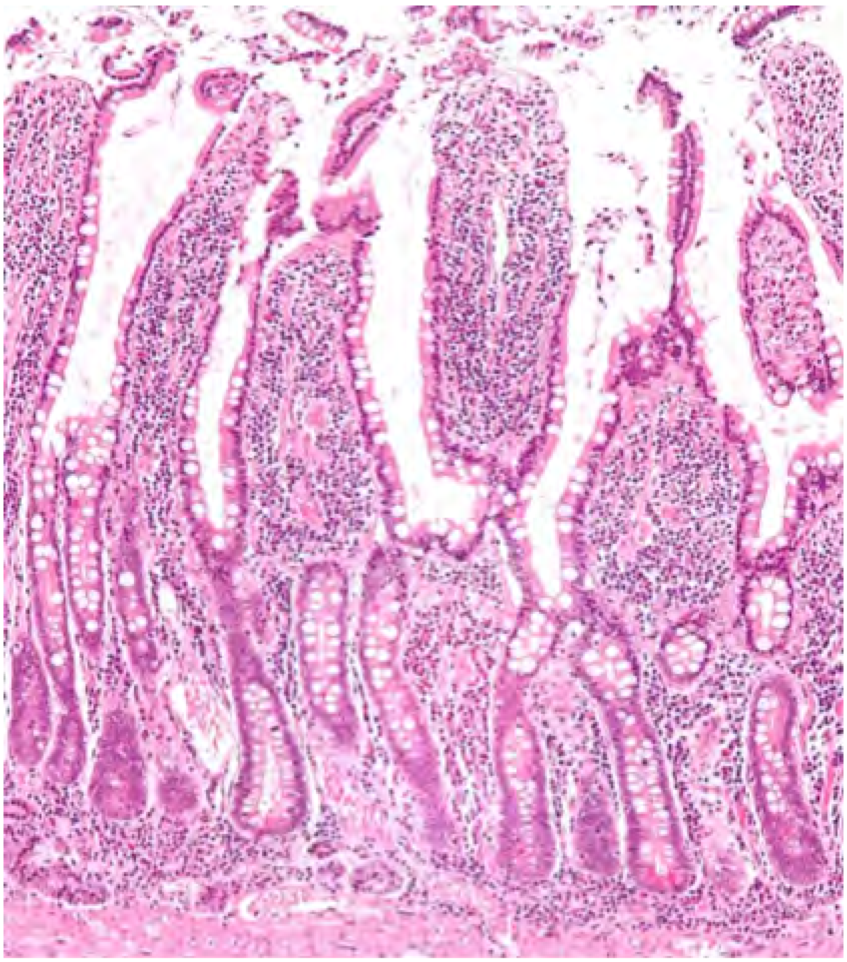
Terrariums, like the one shown above, are closed systems. This means that the container is sealed. Plants can survive for a long time in a terrarium, even though no water or air is added to the system. Plants have been growing in one terrarium since 1960, and water has only been added to the terrarium once (in 1972)!

1. Review your original explanation or model that shows how plants can survive in a closed system. After reading this chapter, what revisions should be made to make your explanation or model more complete?

2. What other phenomena could be explained using your understanding of photosynthesis and respiration?

2.4 Cell Transport and Homeostasis (Bio.2.4)

Explore this Phenomenon



Small intestine low mag by Nephron, https://commons.wikimedia.org/wiki/File:Small_intestine_low_mag.jpg,

Your intestinal cells must take in glucose and other nutrients from the food you eat, and then transport the glucose into blood cells.

1. How do you think the glucose molecules get from the food you eat into the cells? Create a model to communicate your idea.
2. How could we investigate the movement of matter, like glucose, in and out of plant or animal cells? Describe the steps we could take to investigate the movement of matter across cell membranes.

Bio.2.4 Transporting Materials

Plan and carry out an investigation to determine how cells maintain stability within a range of changing conditions by the transport of materials across the cell membrane. Emphasize that large and small particles can pass through the cell membrane to maintain homeostasis. (LS1.A)

Cells can maintain stability, even when conditions around the cell are changing, by transporting materials in or out of the cell. As you read this chapter, pay attention to how transport of materials across the membrane helps a cell maintain homeostasis.

Homeostasis

Rock balancing by Claudio, https://flic.kr/p/2hcqGaG, CC-BY-NC-ND

What happens if stability is disrupted?

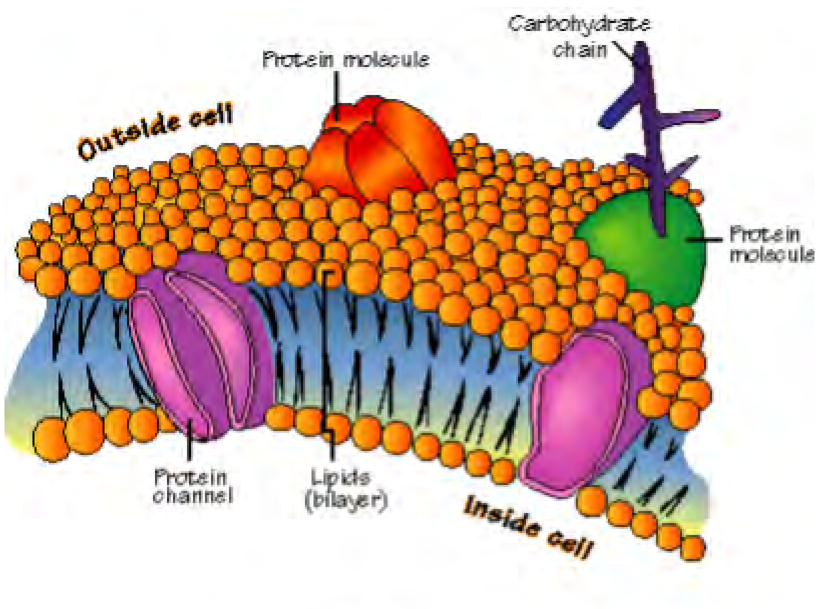
If any of the stones were removed, the whole arch would collapse. The same is true for the human body. All the systems work together to maintain stability or homeostasis. If one system is disrupted, the other systems can also be affected.

Homeostasis refers to the balance, or equilibrium, within the cell or a body. It is an organism's ability to keep a constant internal environment. Keeping a stable internal environment requires constant adjustments as conditions change inside and outside the cell. Abiotic factors like temperature and pH must be kept at just the right levels to support life processes. Homeostasis is a dynamic equilibrium rather than an unchanging state. For example, if your body temperature decreases, you start to shiver. This generates heat, causing your temperature to rise. If your body temperature increases too much, you begin to sweat. This lowers your body temperature. Even though your temperature is changing, it never gets too high or too low.

Individual cells must also maintain homeostasis. This includes keeping the right amount of salt, water, sugars, and other molecules inside the cell. As the surrounding conditions change, cells must not let the amount of these substances increase or decrease too much.

Diffusion

The membrane surrounding the cell helps maintain the correct amount of substances inside the cell. The following figure shows the parts of a cell membrane.



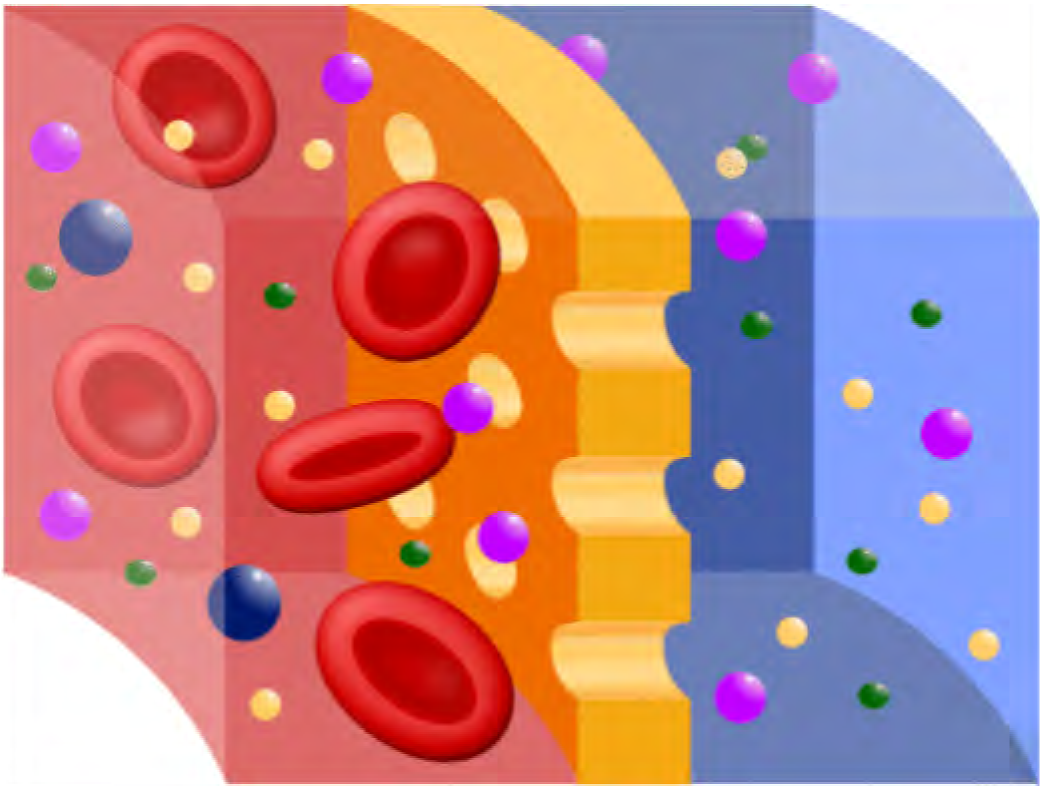
Sell membrane by 140264jd, https://flic.kr/p/azA4wq, CC-BY-SA

Cell transport is the movement of substances across the cell membrane either into or out of the cell. Small molecules like oxygen, carbon dioxide, and water can pass through the cell membrane freely.

If a molecule is big, it won't make it through the cell membrane on its own. Larger molecules need the assistance of a protein.

These proteins act like a doorway that larger molecules can go through. The protein channel in the diagram is one example of a protein that enables larger molecules to move into or out of the cell.

Because not all molecules can move through the cell membrane on their own, we say that the cell membrane is selectively permeable, or semipermeable. This gives the cell some control over which molecules move into or out of the cell. In this way, cell membranes help maintain a state of homeostasis within the cell (and tissues, organs, and organ systems) so that an organism can stay alive and healthy.



Semipermeable membrane, https://commons.wikimedia.org/wiki/File:Semipermeable_membrane.png, CC0

A selectively permeable, or semipermeable, membrane allows certain molecules through, but not others. Can you tell which molecules can move through the center membrane and which would need a protein doorway?

Which direction?

What determines if molecules will move from the outside of the cell to the inside, or from the inside of the cell to the outside?

Molecules tend to move from an area with a high concentration to an area with a low concentration. If there is a higher concentration of carbon dioxide molecules outside the cell than inside, more molecules of carbon dioxide will move from the outside of the cell to the inside of the cell.

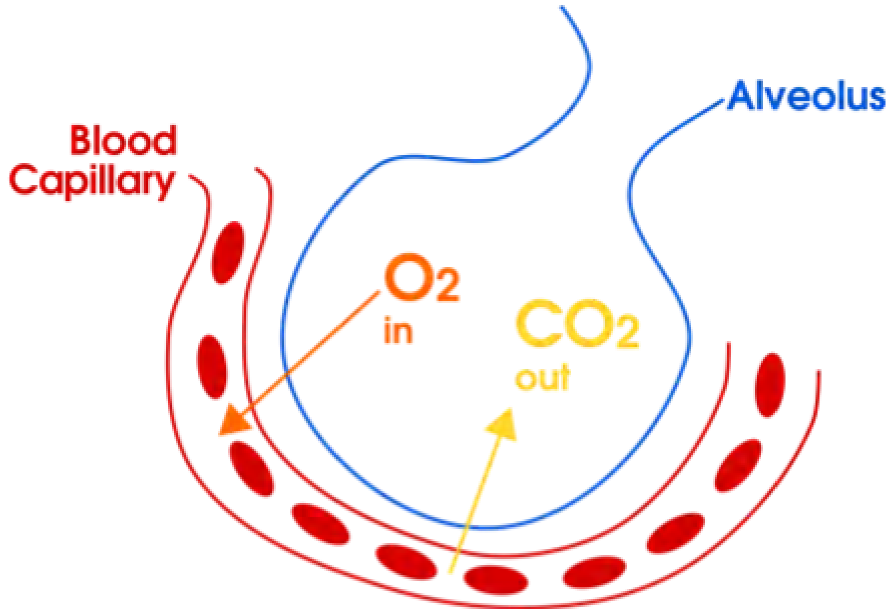


Image by domdomegg, CC-BY 4.0, https://simple.wikipedia.org/wiki/Exchange_of_gases#/media/File:Gas_exchange_in_the_alveolus_simple_(en).svg

Image caption: The alveolus of the lungs contain a lower concentration of CO_2 and a higher concentration of O_2 than the blood. The CO_2 and O_2 diffuse across cell membranes from a high concentration to a low concentration. What are the relative concentrations in the lungs and blood that cause the CO_2 to diffuse into the lung and the O_2 to diffuse out of the lung?

The movement of molecules from a high to a low concentration is called diffusion, and it requires no energy. If the molecules must use a protein doorway to diffuse through the cell membrane, it is called facilitated diffusion. Facilitated diffusion does not require energy.

Diffusion can help cells maintain homeostasis. For example, as a cell uses oxygen molecules, the concentration of oxygen inside the cells decreases. When the concentration of oxygen inside the cell becomes lower than the concentration of oxygen outside the cell, oxygen molecules will move into the cell through diffusion. This helps the cell maintain homeostasis, because as oxygen molecules inside the cell are used, they will be replaced by oxygen molecules diffusing into the cell.

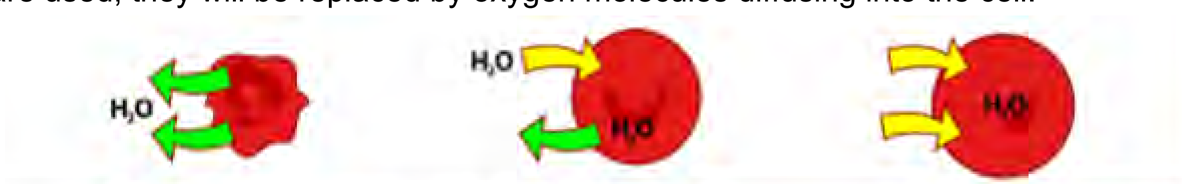


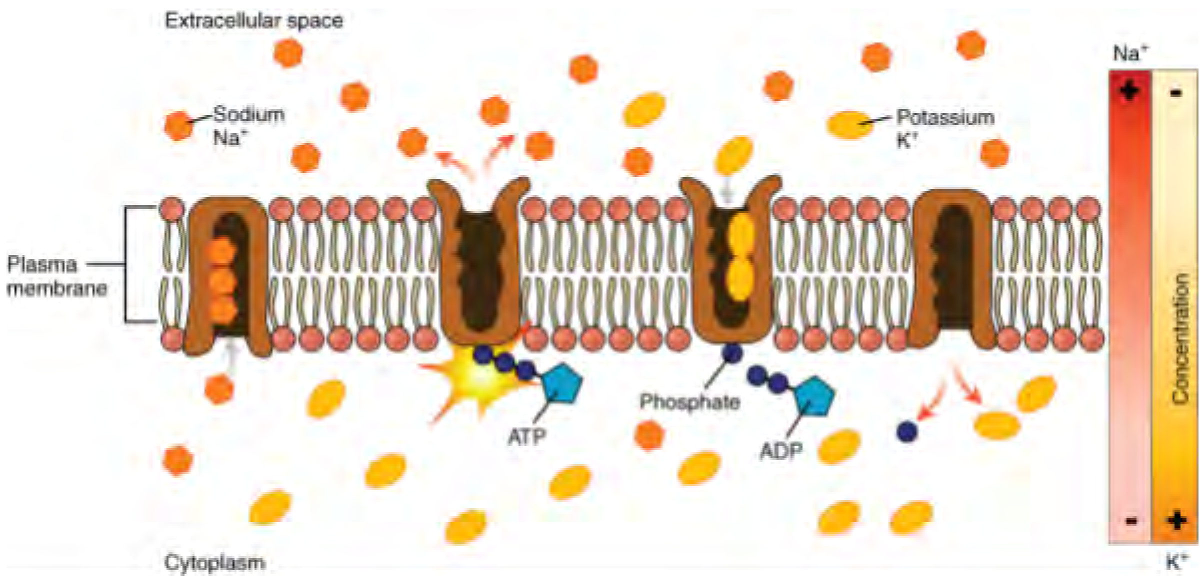
Image by Clker-Free-Vector-Images (pixabay.com), CC0

The picture above shows a red blood cell in three different environments. Describe the conditions in each environment that would cause water to move as shown in the picture.

Active Transport

There may be times when a cell needs to move molecules from a low concentration to a high concentration to maintain homeostasis. In this case, molecules will diffuse in the opposite direction that the cell needs them to. How does a cell maintain homeostasis in this situation?

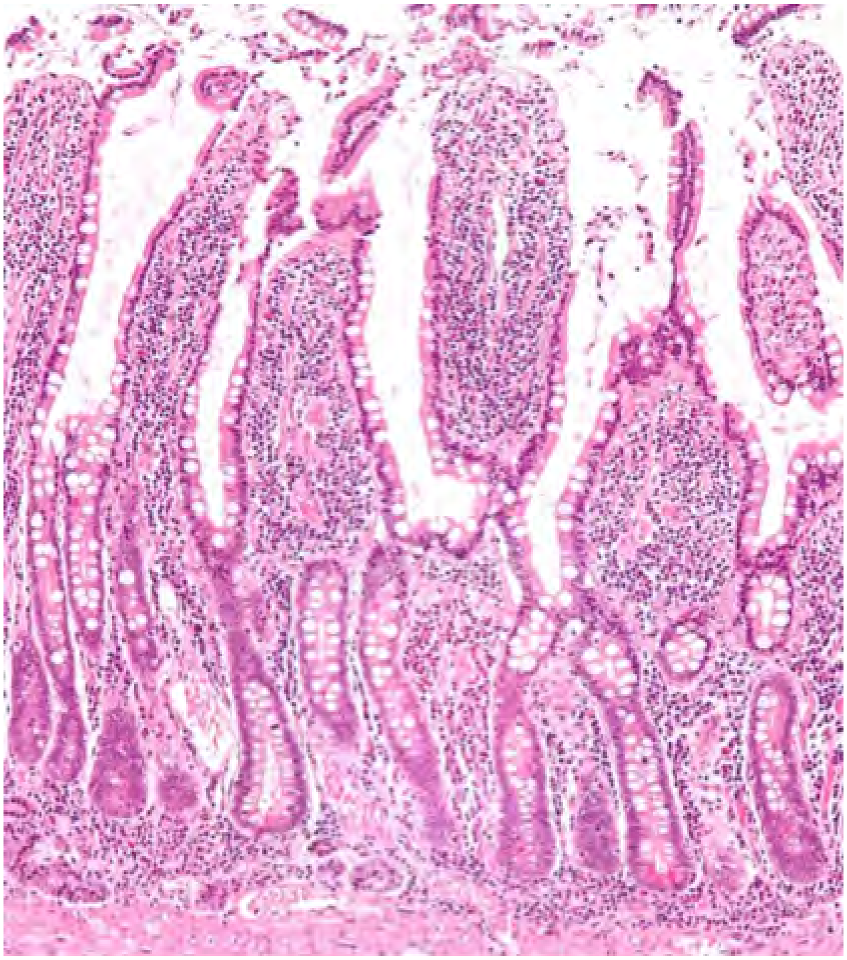
Active transport is a process that moves molecules from a low concentration to a high concentration. This process requires a protein to move the molecules, and it also requires energy. Active transport is important in helping cells maintain the right concentration of molecules, even when the concentration of molecules outside the cell is changing.



Na+/K+ - ATPase, by OpenStax,
https://en.wikipedia.org/wiki/Na%2B/K%2B-ATPase#/media/File:0308_Sodium_Potassium_Pump.jpg, *CC-BY 4.0*

Image caption: The proteins in the plasma membrane (cell membrane) are moving the potassium and sodium from one side to another. When ATP is broken into ADP + Phosphate, energy is made available for the proteins to transport particles across the membrane. Are the potassium and sodium moving from a high to a low concentration, or a low to a high concentration?

Putting It Together



Small intestine low mag by Nephron, https://commons.wikimedia.org/wiki/File:Small_intestine_low_mag.jpg,

Your intestinal cells must take in glucose and other nutrients from the food you eat, and then transport the glucose into blood cells.

1. Review and revise your model showing how glucose molecules get from the food you eat into your intestinal cells.
2. The conditions in your intestines are always changing. Develop a model or explanation to show how your intestinal cells are able to maintain homeostasis, even when the concentrations of molecules in the intestines are always changing.
3. What other phenomena can you use your understanding of homeostasis and cell transport to explain?

2.5 Mitosis and Differentiation (Bio.2.5)

Explore this Phenomenon

Axolotl by Mike Licht, https://flic.kr/p/jVDiJX, CC-BY

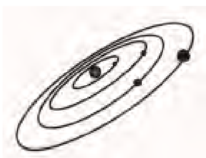
Axolotls are amphibians that can regenerate almost any body part. If they lose a limb, it will grow back. The new limb will have the same structure and function as the original.

1. If an axolotl's leg was lost, what would have to happen at the cellular level for the leg to grow back?
2. What other examples of regeneration can you think of? Are there other species that can regrow body parts?
3. What questions could we investigate to figure out how and why axolotls can regenerate their limbs?

For additional information about limb regeneration in axolotls, see this video: https://www.youtube.com/watch?time_continue=7&v=rFjxJELnN4k

Bio.2.5 Levels of Organization

Construct an explanation about the role of mitosis in the production, growth, and maintenance of systems within complex organisms. Emphasize the major events of the cell cycle including cell growth and DNA replication, separation of chromosomes, and separation of cell contents. (LS1.B)



Complex organisms are made of interacting systems, which are made up of cells. Use the information in this chapter to determine the role that cell division plays in the maintenance of systems in an organism.

Cell Division

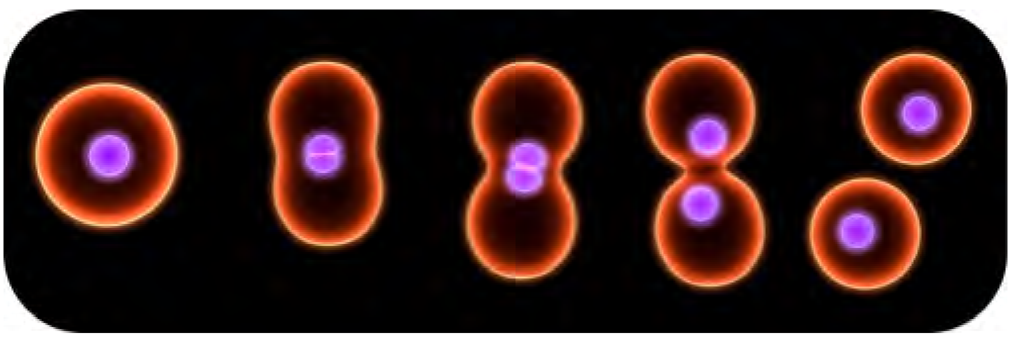


Image by Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation, CC-BY-NC 3.0

You consist of a great many cells, but like all other organisms, you started life as a single cell. How did you develop from a single cell into an organism with trillions of cells? The answer is cell division. All cells come from preexisting cells through the process of cell division. After cells grow to their maximum size, they divide into two new cells. These new cells are small at first, but they grow quickly and eventually divide and produce more new cells. This process keeps repeating in a continuous cycle.

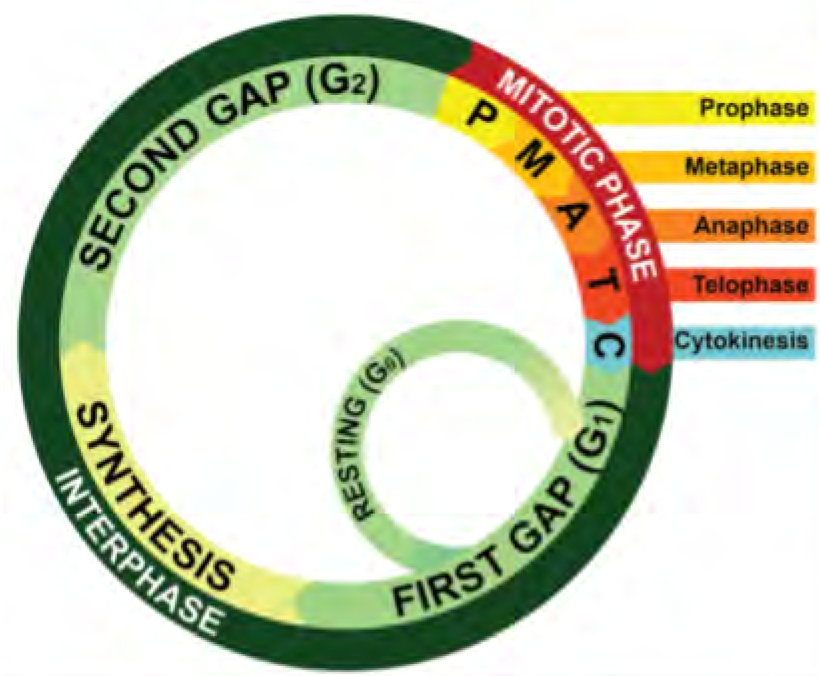


Image by Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation, CC-BY-NC 3.0

This diagram shows the parts of the cell cycle. It is not important to memorize the names of the phases, but it is important to understand the cycle that cells go through. During interphase, the cell grows, replicates its DNA, and prepares to divide. During the mitotic phase, the nucleus and DNA are divided and the cell splits into two daughter cells. Each daughter cell will repeat the cycle.

Mitosis Leads to New Cells

Mitosis is the part of cell division that takes place in the cell nucleus, resulting in the formation of two new nuclei. Both of the new nuclei have the same number of chromosomes as the parent nucleus. Mitosis ensures that the new cells have the same genetic information as the original cell. The main role of mitosis is to allow the organism to grow and to replace cells that are worn out or damaged.

Prior to actually dividing, all the DNA in the cell is replicated. Its organelles are also duplicated. When the cell divides, it occurs in two major steps:

1. The first step is mitosis, a multi-phase process in which the nucleus of the cell divides. During mitosis, the nuclear membrane breaks down and later reforms. The chromosomes are sorted and separated to ensure that each daughter cell receives a diploid number (2 sets) of chromosomes. In humans, that number of chromosomes is 46 (23 pairs).
2. The second major step is cytokinesis. The cytoplasm must divide. Cytokinesis is the division of the cytoplasm, resulting in two genetically identical daughter cells.

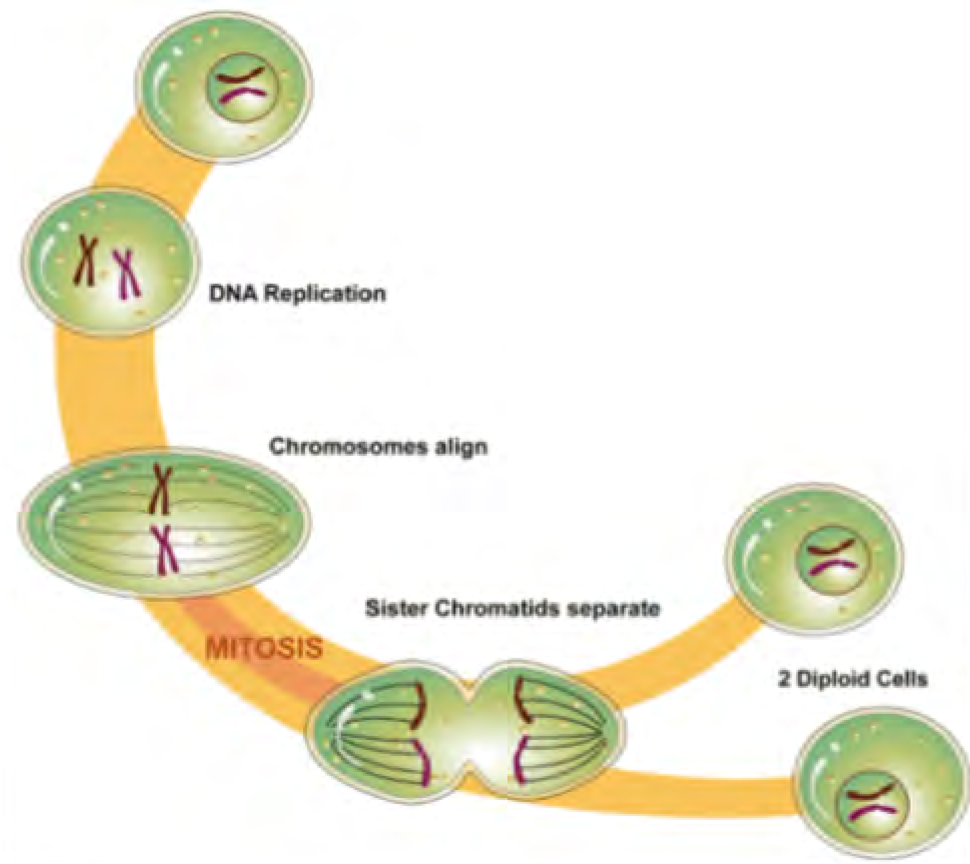


Image by Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation, CC-BY-NC 3.0

Mitosis is the phase of the cell cycle that occurs between DNA replication and the formation of two daughter cells. What happens during mitosis?

Differentiation

Every cell in the body originates from a single fertilized egg called a zygote. The zygote divides repeatedly to produce an embryo. These embryonic cells continue to divide. If the DNA is replicated and every daughter cell has the same DNA as the parent cell, how is it possible to have so many different cell types?

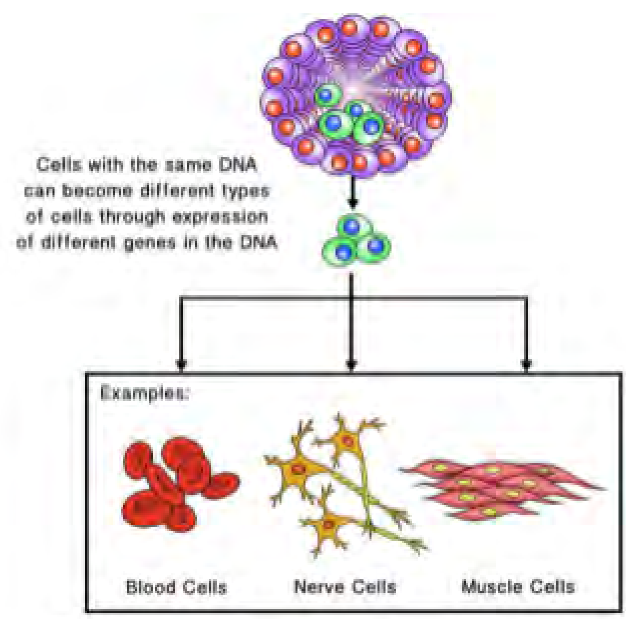


Image by Laura Guerin for CK-12 Foundation, CC-BY-NC 3.0

Differentiation is the process by which an unspecialized cell, such as a fertilized egg cell, divides many times to produce specialized cells. During differentiation, certain genes are turned on, or become activated, while other genes are switched off, becoming inactivated. This process is regulated by the cell. A differentiated cell will develop specific structures and perform certain functions.

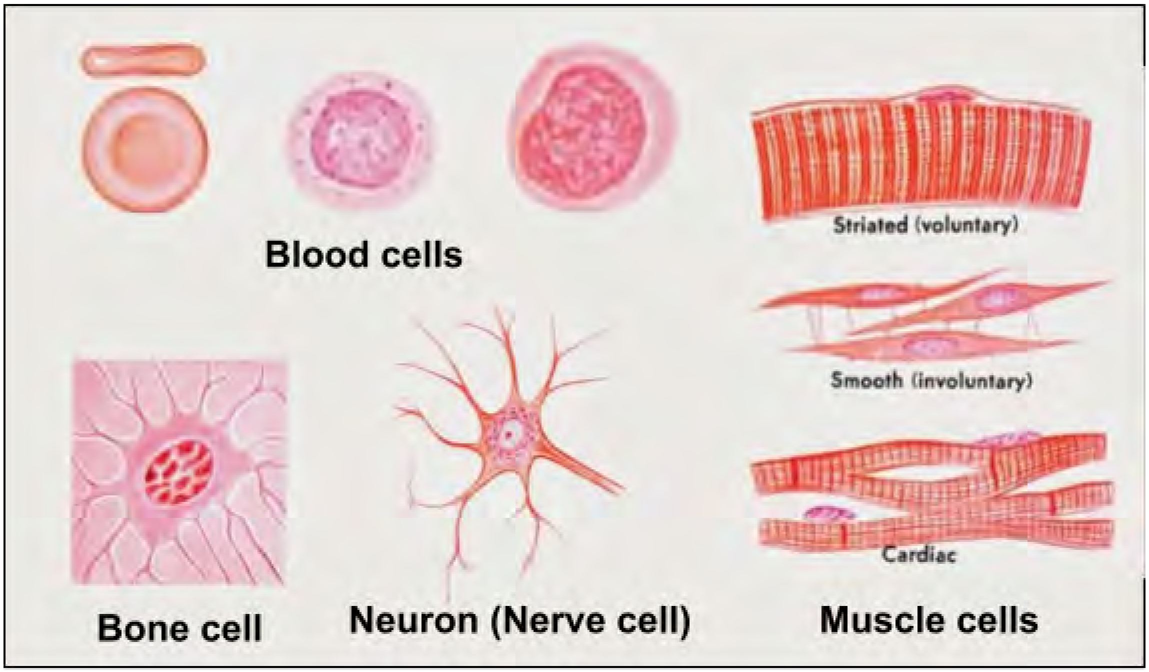
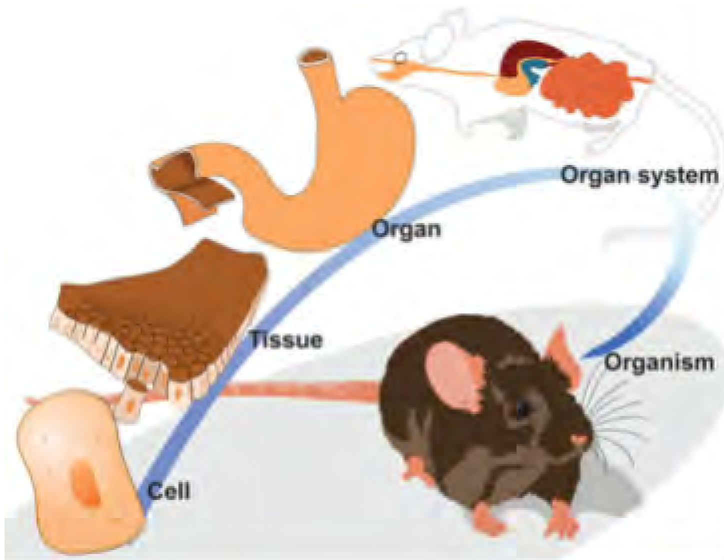


Image adapted from
https://commons.wikimedia.org/wiki/File:Figure_1._Exemples_de_diff%C3%A9rents_types_de_cellules_issues_de_la_diff%C3%A9renciation_cellulaire6.jpg, *CC-BY-SA*

Different types of cells in the human body are specialized for specific jobs. Do you know the functions of any of the cell types shown here?

Levels of Organization

Cells are the most basic units of life in your body, and each cell is specialized, with a specific function. Nerve cells transmit electrical messages around the body, and white blood cells attack invading bacteria throughout the body. Other cells include specialized cells in the kidney (such as kidney glomerulus parietal cells), brain (such as astrocytes), stomach (such as parietal cells), and muscles (such as red and white skeletal muscle fibers). Specialized cells that work together form tissues. Different tissues work together to form organs, and organs work together in organ systems. For example, the heart, lungs, and blood vessels are some of the organs that work together in the cardiovascular system.



An individual mouse is made up of several organ systems. The system shown here is the digestive system, which breaks down food into a form that cells can use. One of the organs of the digestive system is the stomach. The stomach, in turn, consists of different types of tissues. Each type of tissue is made up of cells of the same type.

Cell division and differentiation make and maintain specialized cells, which are needed to create the tissues, organs, and organ systems that carry out necessary functions for life. organisms. Thanks to cell division and differentiation, organisms have systems of tissues and organs that work together to meet its needs.

Putting It Together

Axolotl by Mike Licht, https://flic.kr/p/jVDiJX, CC-BY

Axolotls are amphibians that can regenerate almost any body part. If they lose a limb, it will grow back. The new limb will have the same structure and function as the original.

1. Revisit your original ideas about how an axolotl can regenerate a lost limb. Use your understanding of cell division and differentiation to revise your explanation.
2. What might be different in the cell cycle and differentiation of axolotl cells that allow them to regenerate limbs?

2.6 Organ Systems and Homeostasis (Bio.2.6)

Explore this Phenomenon

a spider bite by Marshal Hedin, https://flic.kr/p/8B9D5W, CC-BY-SA

Though not often deadly to a human, many spiders are able to inject poison when they bite something.

Many spiders are able to inject venom when they bite their victims, resulting in a red, swollen, and/or itchy spot on the skin.

1. Your body must maintain homeostasis to stay alive. How do you think your body responds to the spider's venom to maintain homeostasis?
2. What are three questions you could investigate to learn more about how your body maintains homeostasis in the presence of changing conditions, like a spider bite?

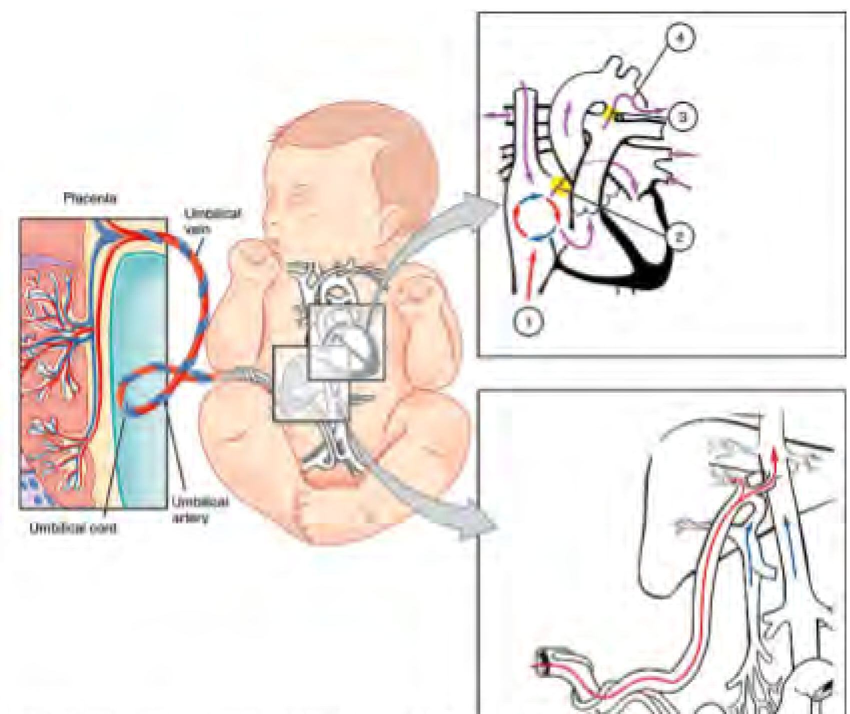
Bio.2.6 Interacting Systems

Ask questions to **develop an argument** for how the <u>structure and function</u> of interacting organs and organ systems, that make up multicellular organisms, contribute to homeostasis within the organism. Emphasize the interactions of organs and organ systems with the immune, endocrine, and nervous systems. (LS1.A)

Multicellular organisms are made of systems that interact with each other to help maintain homeostasis. As you read this chapter, pay attention to how the structure of different organs and organ systems affects their functions and ability to help maintain homeostasis.

Organs and Organ Systems

In section 2.4 you learned about homeostasis, and in section 2.5 you learned about the different levels of organization of life. In this section, you will be learning how organs and organ systems work together to help your body maintain homeostasis.



Adapted from https://commons.wikimedia.org/wiki/File:2916_Fetal_Circulatory_System-02.jpg, Openstax, CC-BY

Remember that organisms are made of many different parts called organs. Organs are made of one or more types of tissues. Human organs include the brain, stomach, kidney, and liver. Plant organs include roots, stems, and leaves.

Organs work together to perform a specific function forming an organ system. Organ systems also work together to perform tasks. Examples of organ systems in a human include the skeletal, nervous, and reproductive systems. Organ systems in a plant include the root and reproductive systems.

The previous figure shows how multiple organs work together to transport blood around the body. The heart and blood vessels are two of the organs that work together and form the circulatory system.

The Nervous System

The nervous system, together with the endocrine system, controls all the other organ systems. The nervous system sends one type of signal around the body, and the endocrine system sends another type of signal around the body.

The nervous system works by sending and receiving electrical signals. The main organs of the nervous system are the brain and the spinal cord. The signals are carried by nerves in the body, similar to the wires that carry electricity all over the house. The signals travel from all over the body to the spinal cord and up to the brain, as well as moving in the other direction. The messages released by the nervous system traveled through nerves.Similar to the electricity that travels through wires, nerves quickly carry electrical messages around the body.

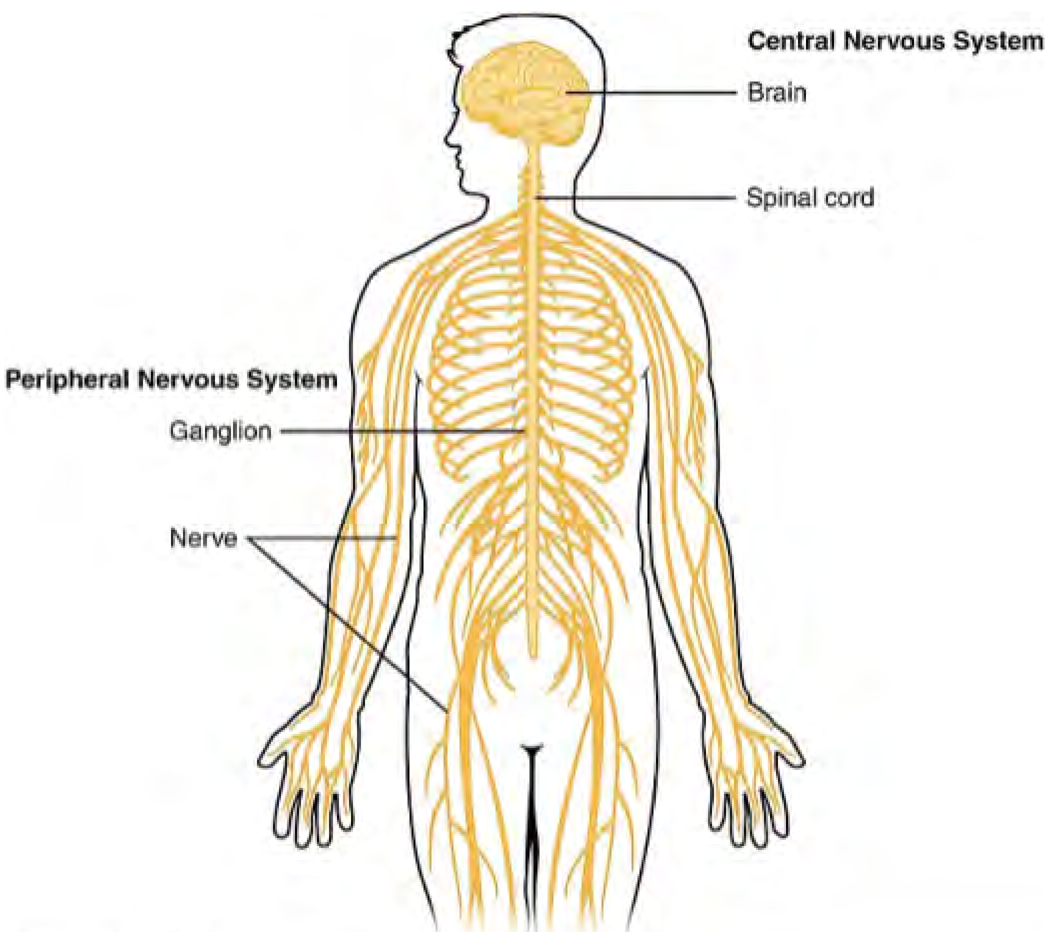


Image adapted from https://commons.wikimedia.org/wiki/File:1201_Overview_of_Nervous_System.jpg, Openstax, CC-BY

The Endocrine System

The endocrine system is a system of organs that releases chemical messenger molecules, called hormones, into the blood. The endocrine system is important in controlling metabolism, growth and development, reproduction, and salt, water, and nutrient balance in blood and other tissues.

Organs of the Endocrine System

The endocrine system is made up of many glands that are located in different areas of the body. Hormones are chemical messenger molecules that are made by cells in one part of the body and cause changes in cells in another part of the body. Hormones regulate the many and varied functions that keep you alive.

Hormones are made and secreted by cells in endocrine glands. Endocrine glands are organs that secrete hormones directly into the blood or the fluid surrounding a cell rather than through a duct. The primary function of an endocrine gland is to make and secrete hormones. The endocrine glands collectively make up the endocrine system. The major glands of the endocrine system are shown below. Many other organs, such as the stomach, heart, and kidneys, secrete hormones and are considered to be part of the endocrine system.

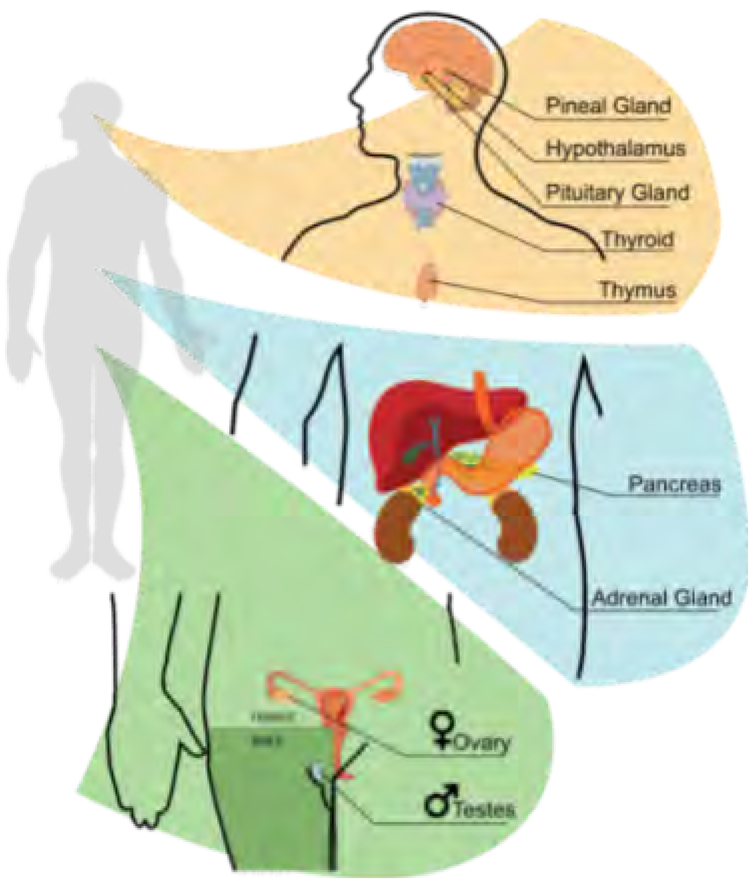


Image by Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation, CC-BY-NC-SA 3.0

The glands of the endocrine system are the same in males and females, except for the testes, which are found only in males, and the ovaries, which are found only in females.

Unlike the nervous system, whose actions help the body react immediately to change, the endocrine system controls changes that happen to the body over long periods of time, which can be minutes, hours, or even years. The endocrine system is more like starting up an oil or gas powered water-heating system. You flick on the switch to heat up water for a bath, but it takes a certain length of time for the result - hot water - to occur.

The Immune System

The immune system is a

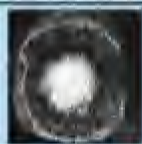
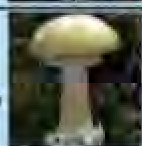
defense system. It comprises many biological structures, including individual white blood cells and entire organs. The function of the immune system is to protect the host from bacteria and viruses, and other causes of disease, such as tumor cells. To function properly, the immune system must be able to detect a wide variety of bacteria and viruses, and be able to distinguish pathogens from the body's own cells, so that it doesn't destroy cells of the body. The immune system must also be able to distinguish cancerous or damaged cells from healthy cells.

Image by Bruce Wetzel/Harry Schaefer/National Cancer Institute, colorized by Sam McCabe
http://visualsonline.cancer.gov/details.cfm?imageid=1762
License: Public Domain

Does this organism look like a space alien? A scary creature from a nightmare?

In fact, it's a 1-cm long worm that lives in the human body and causes serious harm. It enters the body through a hair follicle of the skin when it's in a much smaller stage of its life cycle. Like this worm, many other organisms can make us sick if they manage to enter our body. Fortunately for us, our immune system is able to keep out most such invaders.

The body's first line of defense consists of different types of barriers that keep most pathogens out of the body. Pathogens are disease-causing agents, such as bacteria and viruses. These and other types of pathogens are described in the next table. Regardless of the type of pathogen, however, the first line of defense is always the same.

Type of pathogen	Description	Human diseases caused by pathogens of that type
Bacteria *Escherichia coli* 	Single-celled organisms without a nucleus	Strep throat, staph infections, tuberculosis, food poisoning, tetanus, pneumonia, syphilis
Viruses *Herpes simplex* 	Thread-like particles that reproduce by taking over living cells	Common cold, flu, genital herpes, cold sores, measles, AIDS, genital warts, chiken pox, small pox
Fungi *Death cap mushroom* 	Simple organisms, including mushrooms and yeasts, that grow as single cells or thread like filaments	Ringworm, athlete's foot, tinea, candidiasis, histoplasmosis, mushroom poisoning
Protozoa *Giardia lamblia* 	Single-celled organism with a nucleus	Malaria, "traveler's diarrhea" giardiasis, trypanosomiasis ("sleeping sickness")

Credit: E coli: Rocky Mountain Laboratories, NIAID, NIH; Herpes simplex: CDC/Dr. Erskine Palmer; Death cap: GLJIVARSKO DRUSTVO NIS; Giarda lamblia: CDC/Janice Carr
Source: E coli: http://commons.wikimedia.org/wiki/File:EscherichiaColi_NIAID.jpg; Herpes simplex: http://commons.wikimedia.org/wiki/File:Herpes_simplex_virus_TEM_B82-0474_lores.jpg; Death cap: http://www.flickr.com/photos/ressaure/6580918185/; Giarda lamblia: http://commons.wikimedia.org/wiki/File:Giardia_lamblia_SEM_8698_lores.jpg

Types of pathogens that commonly cause human diseases include bacteria, viruses, fungi, and protozoa. Which type of pathogen causes the common cold? Which type causes athlete's foot?

Mechanical Barriers

Mechanical barriers physically block pathogens from entering the body. The skin is the most important mechanical barrier. In fact, it is the single most important defense the body has. The outer layer of the skin is tough and very difficult for pathogens to penetrate.

Mucous membranes provide a mechanical barrier at body openings. They also line the respiratory, GI, urinary, and reproductive tracts. Mucous membranes secrete mucus, a slimy substance that traps pathogens. The membranes also have hair-like cilia. The cilia sweep mucus and pathogens toward body openings where they can be removed from the body. When you sneeze or cough, pathogens are removed from the nose and throat. Tears wash pathogens from the eyes, and urine flushes pathogens out of the urinary tract.

Chemical Barriers

Chemical barriers destroy pathogens on the outer body surface, at body openings, and on inner body linings. Sweat, mucus, tears, and saliva all contain enzymes that kill pathogens. Urine is too acidic for many pathogens, and semen contains zinc, which most pathogens cannot tolerate. In addition, stomach acid kills pathogens that enter the GI tract in food or water.

Biological Barriers

Biological barriers are living organisms that help protect the body. Millions of harmless bacteria live on the human skin. Many more live in the GI tract. The harmless bacteria use up food and space so harmful bacteria cannot grow.

Organ Systems Work Together to Maintain Homeostasis

In section 2.4 you learned how the cell membrane helps a cell maintain homeostasis. Organs and organ systems work together to help your body maintain homeostasis.

One example of an organ working to maintain homeostasis is the way your pancreas works to keep the sugar in your blood relatively stable. When blood sugar is high, the pancreas releases the hormone insulin. The insulin signals cells to take in more sugar, lowering the amount of sugar in the blood. When blood sugar is low, the pancreas releases a different hormone, called glucagon. The glucagon signals cells and the liver to release sugar into the bloodstream.

The nervous, endocrine, and immune systems work together to help your body maintain homeostasis. For example, your nervous system can sense when you are in a dangerous situation. Your nervous system detects danger through sight, smell, or sound, and will send a signal to your endocrine system. Your endocrine system will respond to the signal by releasing adrenaline. The adrenaline travels to different cells in your body. The release of adrenaline causes your heart to beat faster, the release of glucose into your bloodstream, and the relaxing of muscle tissue in your lungs to allow for increased breathing. These changes are referred to as the fight or flight response, because they prepare your body to either fight or run away from danger.

You can learn more about the fight or flight response and how your nervous and endocrine systems work together by watching this video:

https://learn.genetics.utah.edu/content/cells/cellcom/.

Putting It Together

a spider bite by Marshal Hedin, https://flic.kr/p/8B9D5W, CC-BY-SA

Though often not deadly to a human, many spiders are able to inject poison when they bite something.

Many spiders are able to inject venom when they bite their victims, resulting in a red, swollen, and/or itchy spot on the skin.

1. How has your understanding of how your body can maintain homeostasis changed?
2. Use what you have learned about how organs and organ systems can work together to maintain homeostasis to explain how your body can recover from changing conditions, such as a spider bite.

2.7 Feedback Mechanisms (Bio.2.7)

Explore this Phenomenon

Resting Heart Rate by Eli Christman,
https://flic.kr/p/vsYttD,

Your heart rate changes throughout the day.

1. Create a model to show how and why your heart rate changes throughout the day.
2. How would you set up an investigation to find out what causes your heart rate to change?
3. What are three questions you could investigate to determine the effects of increased or decreased heart rate on other organs in your body?

Bio.2.7 Homeostasis

Plan and carry out an investigation to provide evidence of homeostasis and that feedback mechanisms maintain stability in organisms. Examples of investigations could include heart rate response to changes in activity, stomata response to changes in moisture or temperature, or root development in response to variations in water level. (LS1.A)

Organisms must be able to maintain stability, or homeostasis to survive. As you read this chapter, pay attention to how organisms use feedback loops to maintain homeostasis.

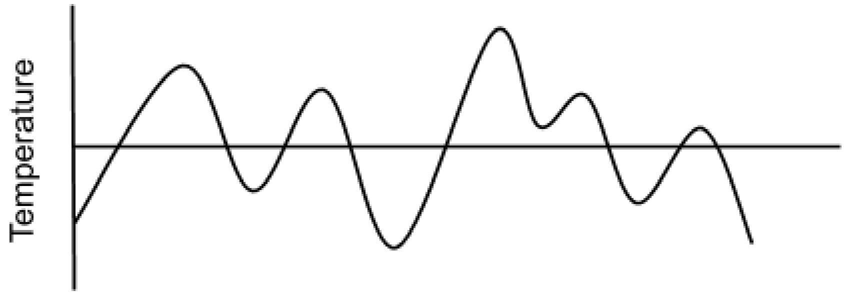
Feedback Maintains Homeostasis

In sections 2.4 and 2.6, you learned about homeostasis. Recall that your organs and organ systems work together to help your body maintain homeostasis. Cells, organs, and organ systems often rely on feedback loops to maintain homeostasis.

Negative Feedback Leads to Homeostasis
There are two types of feedback: negative feedback and positive feedback. The regulation of your internal environment is done primarily through negative feedback. Negative feedback is sometimes called "balancing feedback," because it helps maintain stability.

A thermostat uses negative feedback to keep a room the same temperature. If the temperature increases too much, the air conditioner will turn on until it cools down. If the temperature decreases too much, the heater will turn on until the room warms up.

Your body has an internal thermostat. When body temperature rises, receptors in the skin and the brain sense the temperature change. The temperature change triggers a command from the brain. This command can cause several responses. If you are too hot, the skin makes sweat and blood vessels near the skin surface dilate. This response helps decrease body temperature. When your body temperature decreases, your body responds by shivering, which generates heat so that you warm up.



Negative feedback ensures that your body's temperature never gets too high or too low. Even though your temperature may change, the changes are small and hover around a set point.

In section 2.6, you read about how the pancreas regulates blood sugar. This is also a form of negative feedback. The pH of your blood, breathing rate, blood pressure, and metabolism are some of the other factors regulated by negative feedback.

Positive feedback is also known as reinforcing feedback, because instead of keeping conditions the same, positive feedback causes change in a system. Most of the time, positive feedback is not good for living organisms because it leads to change, but some processes in the body are regulated by positive feedback.

For more examples of how feedback helps maintain homeostasis, watch this video: https://www.youtube.com/watch?v=Iz0Q9nTZCw4.

Failure of Homeostasis

Many homeostatic mechanisms such as these work continuously to maintain stable conditions in the human body. Sometimes, however, the mechanisms fail. When they do, cells may not get everything they need, or toxic wastes may accumulate in the body. If homeostasis is not restored, the imbalance may lead to disease or even death.

Negative Feedback and Respiration

Deep breath in…now blow out those candles. We've all done that. Taking that deep breath in is an active process. You can usually feel your chest move. Why? Obviously, muscles in your chest are doing the work.

To understand how breathing is regulated, you first need to understand how breathing occurs.

Inhaling is an active movement that results from the contraction of a muscle called the diaphragm. The diaphragm is a large, sheet-like muscle below the lungs. When the diaphragm contracts, the ribcage expands and the contents of the abdomen move downward. This results in a larger chest volume, which decreases air pressure inside the lungs. With lower air pressure inside than outside the lungs, air rushes into the lungs. When the diaphragm relaxes, the opposite events occur. The volume of the chest cavity decreases, air pressure inside the lungs increases, and air flows out of the lungs, like air rushing out of a balloon.

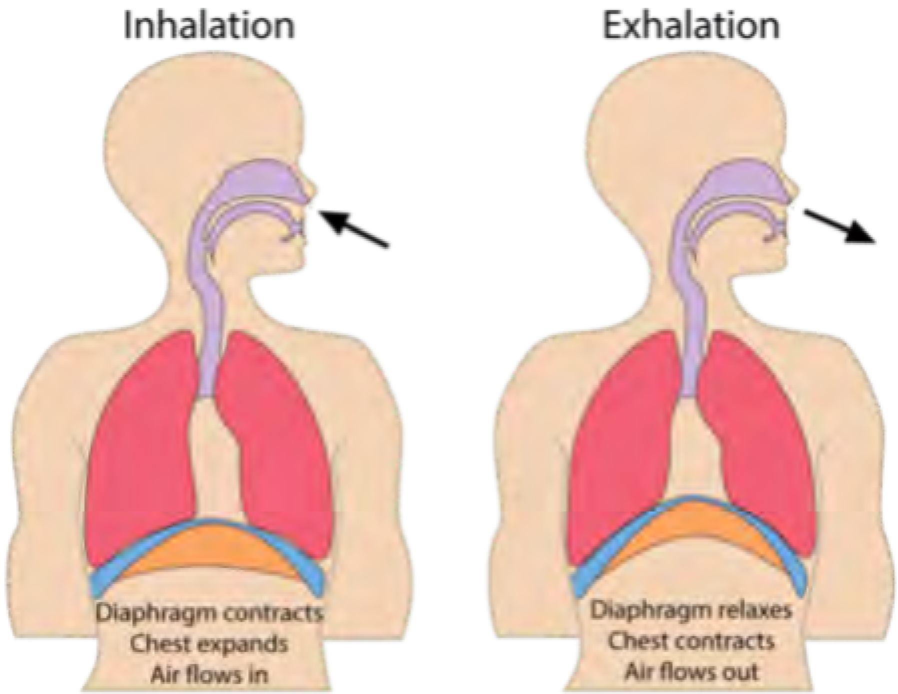


Image by Zachary Wilson, Hana Zavadska, CK-12 Foundation, CC-BY-NC 3.0

The regular, rhythmic contractions of the diaphragm are controlled by the brain stem. It sends nerve impulses to the diaphragm through the autonomic nervous system. The brain stem monitors the level of carbon dioxide in the blood. If the level becomes too high, it "tells" the diaphragm to contract more often. Breathing speeds up, and the excess carbon dioxide is released into the air. The opposite events occur when the level of carbon dioxide in the blood becomes too low. In this way, the concentration of CO_2 in your blood never gets too high.

Adapted from image by Mabel Amber, pixabay.com, CC0

Muscle cells use less energy when they are resting than when they are active. When muscle cells are active, they need more oxygen to produce energy, and they also produce more carbon dioxide. Think about how increased carbon dioxide production will affect respiration rate. How does negative feedback ensure that your muscle cells get the oxygen they need when they are active?

Guard Cells Help Plants Maintain Homeostasis

Plants also use negative feedback to maintain homeostasis. Plant leaves contain tiny openings, called stomata, that allow carbon dioxide (CO_2) to enter the leaf. Water can also diffuse out of the leaf through the stomata. The plant needs carbon dioxide for photosynthesis, but it also needs to retain water. Negative feedback allows the plant to keep the stomata open to obtain carbon dioxide, and to close the stomata before too much water is lost.

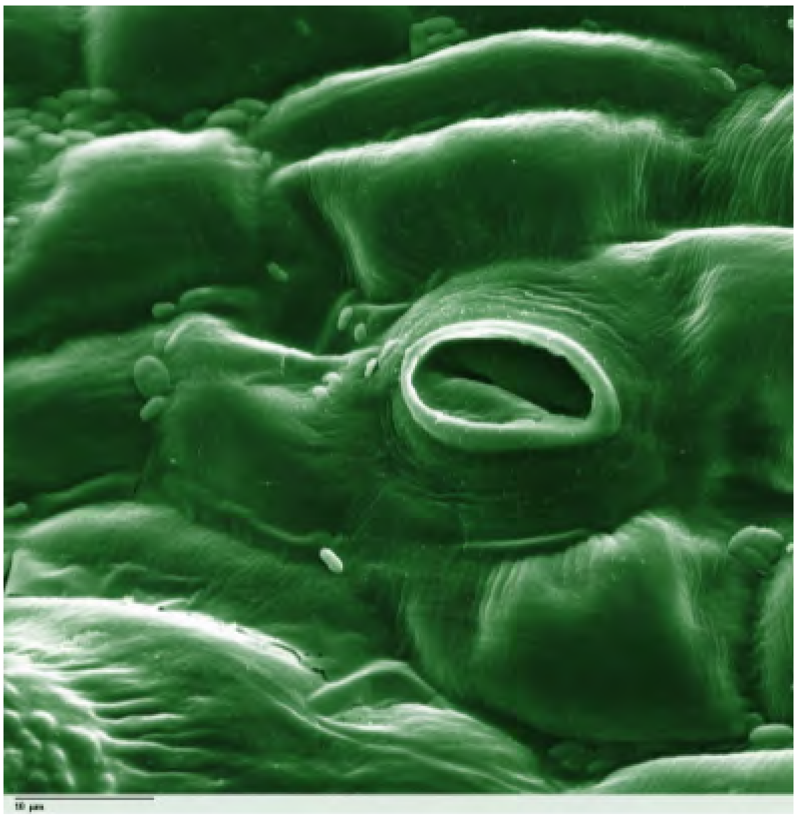


Image from https://en.wikipedia.org/wiki/Stoma#/media/File:Tomato_leaf_stomate_1-color.jpg, public domain

Guard cells surround the stomata. When there is a high concentration of water in the leaf, water diffuses into the guard cells, and their shape changes to open the stomata. If the concentration of water decreases, water diffuses out of the guard cells, and their shape changes to close the stomata. With the stomata closed, the leaf can conserve water.

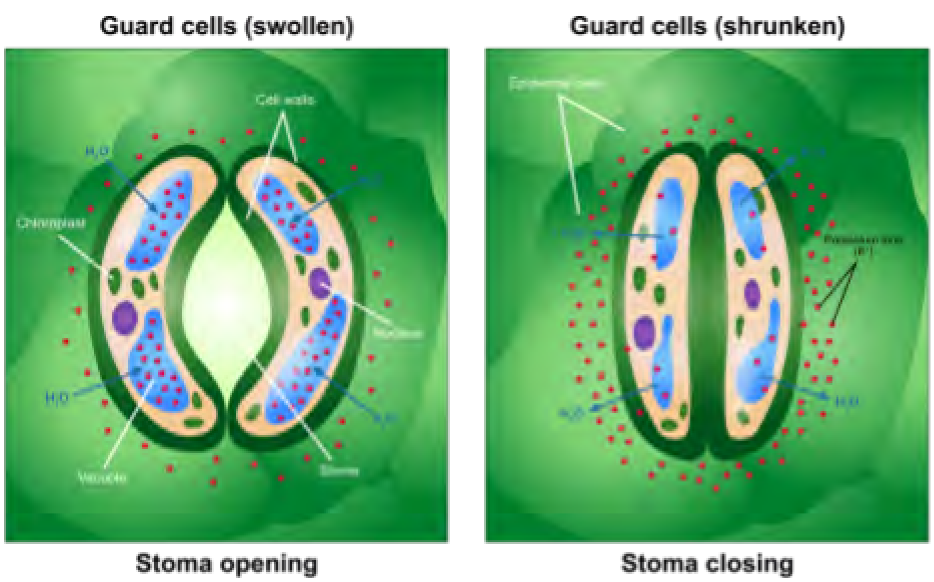


Image by Ali Zifan, https://commons.wikimedia.org/wiki/File:Opening_and_Closing_of_Stoma.svg, CC-BY-SA

Putting It Together

Resting Heart Rate by Eli Christman, https://flic.kr/p/vsYttD, CC-BY

Your heart rate changes throughout the day.

1. How has learning about feedback changed your understanding of what causes your heart rate to change throughout the day? Think about how your heart works with other organs in your body. Revise your model to include the role of feedback in regulating your heart rate.

CHAPTER 3

Strand 3: Genetic Patterns

Chapter Outline

image source: https://svgsilh.com/image/371983.html, public domain

Heredity is a unifying biological principle that explains how information is passed from parent to offspring through deoxyribonucleic acid (DNA) molecules in the form of chromosomes. Distinct sequences of DNA, called genes, carry the code for specific proteins, which are responsible for the specific traits and life functions of organisms. There are predictable patterns of inheritance; however, changes in the DNA sequence and environmental factors may alter genetic expression. The variation and distribution of traits observed in a population depend on both genetic and environmental factors. Research in the field of heredity has led to the development of multiple genetic technologies that may improve the quality of life but may also raise ethical issues.

3.1 DNA, RNA, and Proteins (Bio.3.1)

Explore this Phenomenon

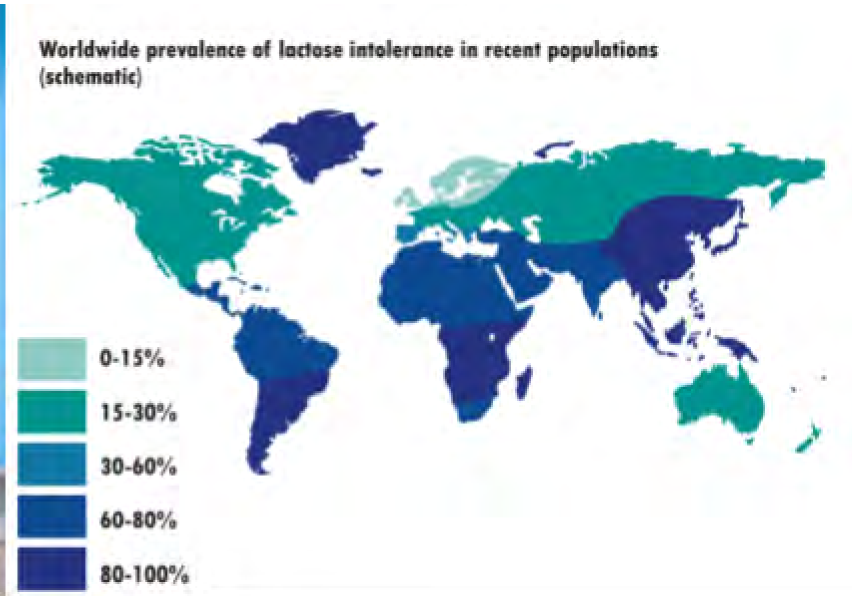


image by Daria-Yakovleva, pixabay.com, CC0
image by by NmiPortal, https://commons.wikimedia.org/wiki/File:Worldwide_prevalence_of_lactose_intolerance_in_recent_populations.jpg, CC-BY-SA

Globally, about two thirds of the adult population is lactose intolerant. This means that after infancy, they have reduced ability to digest lactose, which is a sugar that occurs naturally in milk. People who are not lactose intolerant produce an enzyme that breaks down lactose. People who are lactose intolerant can experience stomach pain, bloating, diarrhea, and other gastrointestinal distress if they drink milk.

1. Use the map to identify patterns in the location of people who are lactose intolerant. Propose an explanation for these patterns.
2. Develop a model to show what causes lactose intolerance.
3. What are three questions you could investigate to explain the patterns we see in the locations of people who are lactose intolerant.

Bio.3.1 Coding for Traits

Construct an explanation for how the structure of DNA is replicated, and how DNA and RNA code for the structure of proteins which regulate and carry out the essential functions of life and result in specific traits. Emphasize a conceptual understanding that the sequence of nucleotides in DNA determines the amino acid sequence of proteins through the processes of transcription and translation. (LS1.A, LS3.A)

The structure of DNA allows it to function as hereditary material and instructions for building proteins. The structure of proteins allow them to perform specific functions. As you read this chapter, pay attention to how the structure of DNA affects the way it functions.

DNA Replication

In section 2.1, you learned about four macromolecules that are in cells, including nucleic acids and proteins. Recall that nucleic acids include DNA and RNA. DNA serves as the hereditary material that is passed from parent cell to daughter cell. It also provides instructions for building proteins. RNA is a nucleic acid that is needed to build proteins.

DNA

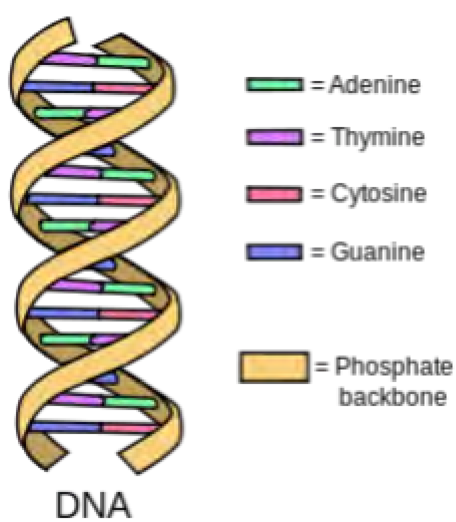


Image by: https://commons.wikimedia.org/wiki/File:DNA_simple2.svg, CC0

A molecule of DNA has a double helix shape. It looks like a ladder that has been twisted.

The DNA molecule is made of many smaller molecules, called nucleotides, that are bonded together. Each nucleotide includes a base. There are four different bases: adenine (A), thymine (T), cytosine (C), and guanine (G).

Notice that adenine and thymine are always bonded together, and cytosine is always bonded to guanine. This base pairing is important. The next diagrams show the atoms and nucleotides in a section of DNA. You can use this interactive to explore the structure of DNA and practice base pairing: https://learn.genetics.utah.edu/content/basics/builddna/.

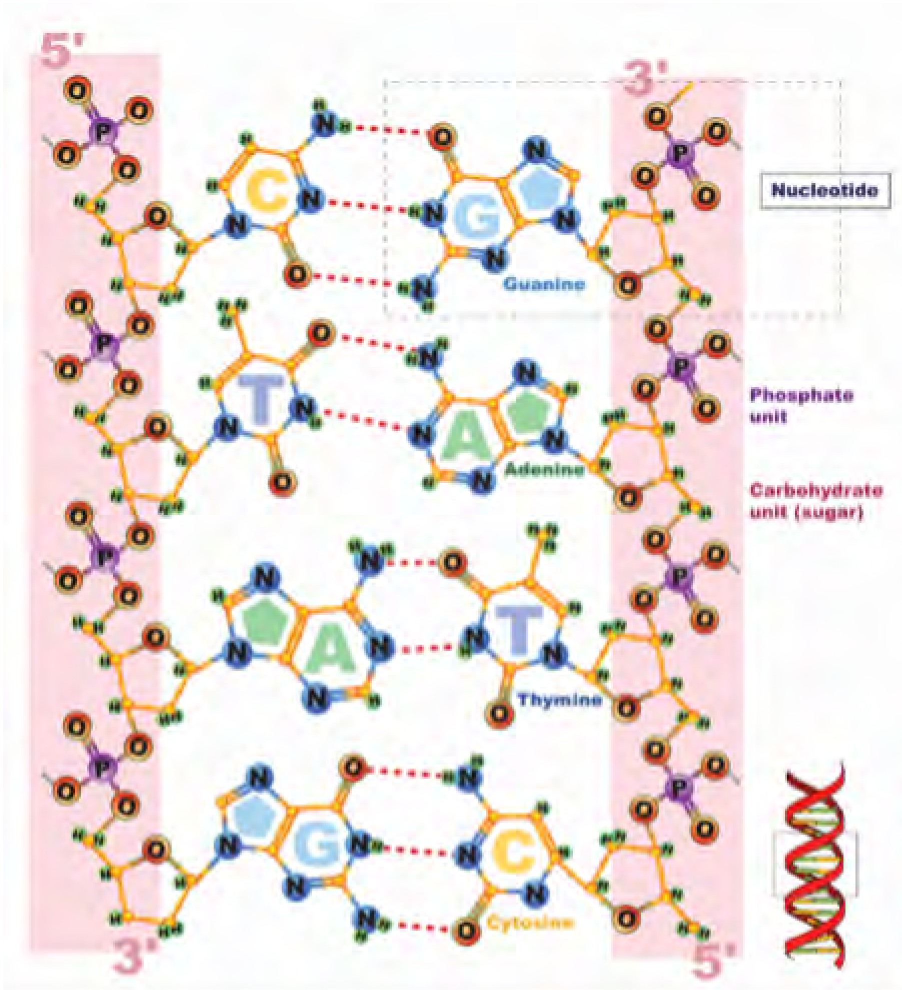


Image by Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation, CC-BY-NC-SA 3.0

So it is this four letter code, made of just A, C, G, and T, that determines what the organism will become and what it will look like. How can these four bases carry so much information? This information results from the order of these four bases in the chromosomes. This sequence carries the unique genetic information for each species and each individual. For example, the DNA sequences between two species of reptiles will be more similar than between a reptile and an elm tree.

Recall from section 2.5 that DNA is replicated before a cell divides. How is the cell able to make an exact copy of all of its DNA?

DNA replication starts when an enzyme splits the two sides of DNA apart. Each side of the DNA will end up becoming another complete molecule of DNA. New nucleotides are added, following the base pairing rules. As each DNA strand has the same genetic information, both strands of the double helix can serve as templates for the reproduction of a new strand. The two resulting double helices are identical to the initial double helix.

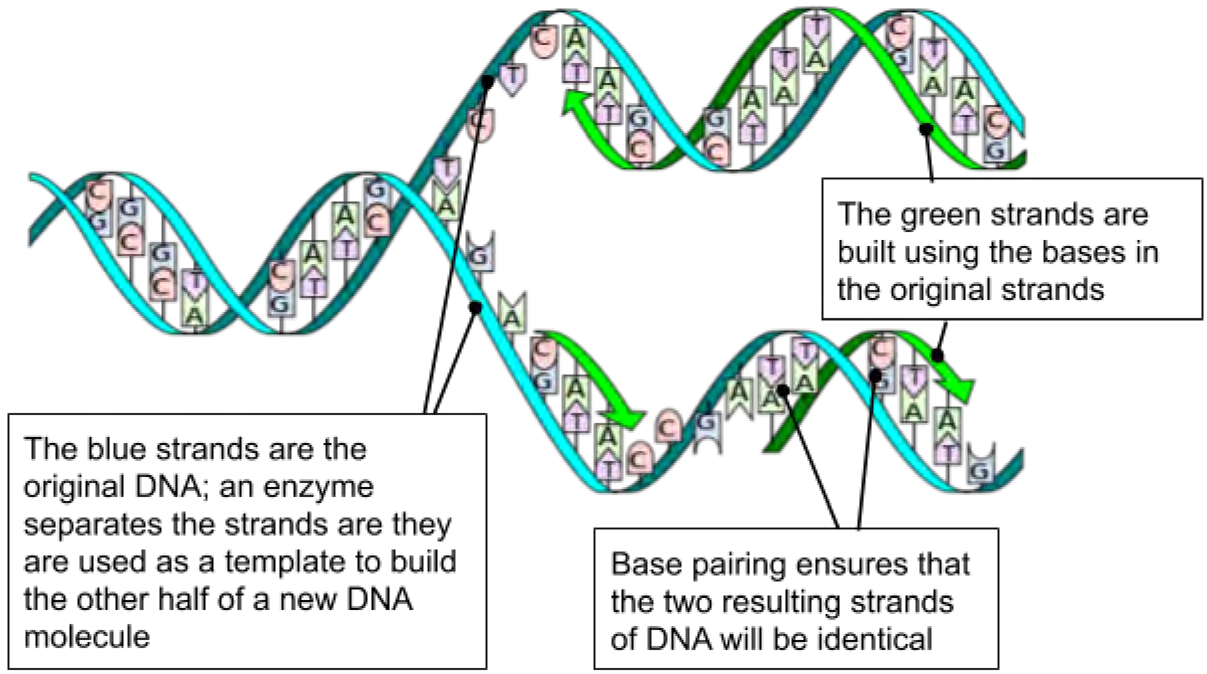


image adapted from *DNA replication split horizontal* by Madprime, https://commons.wikimedia.org/wiki/File:DNA_replication_split_horizontal.svg, CC-BY-SA

Once the DNA has been replicated, the cell can divide, and each of the daughter cells will have the same DNA.

RNA and Protein Synthesis

Your DNA, or deoxyribonucleic acid, contains the genes that determine who you are. How can this organic molecule control your characteristics? DNA contains instructions for all the proteins your body makes. Proteins, in turn, determine the structure and function of all your cells. What determines a protein’s structure? It begins with the sequence of amino acids that make up the protein. Instructions for making proteins with the correct sequence of amino acids are encoded in DNA.

DNA is found in chromosomes. The chromosomes in your cells always remain in the nucleus, but proteins are made at ribosomes in the cytoplasm. How do the instructions in DNA get to the site of protein synthesis outside the nucleus? Another type of nucleic acid is responsible. This nucleic acid is RNA, or ribonucleic acid. RNA is a small molecule that can squeeze through pores in the nuclear membrane. It carries the information from DNA in the nucleus to a ribosome in the cytoplasm and then helps assemble the protein.

The structure of RNA is similar to the structure of DNA, but they are not identical.

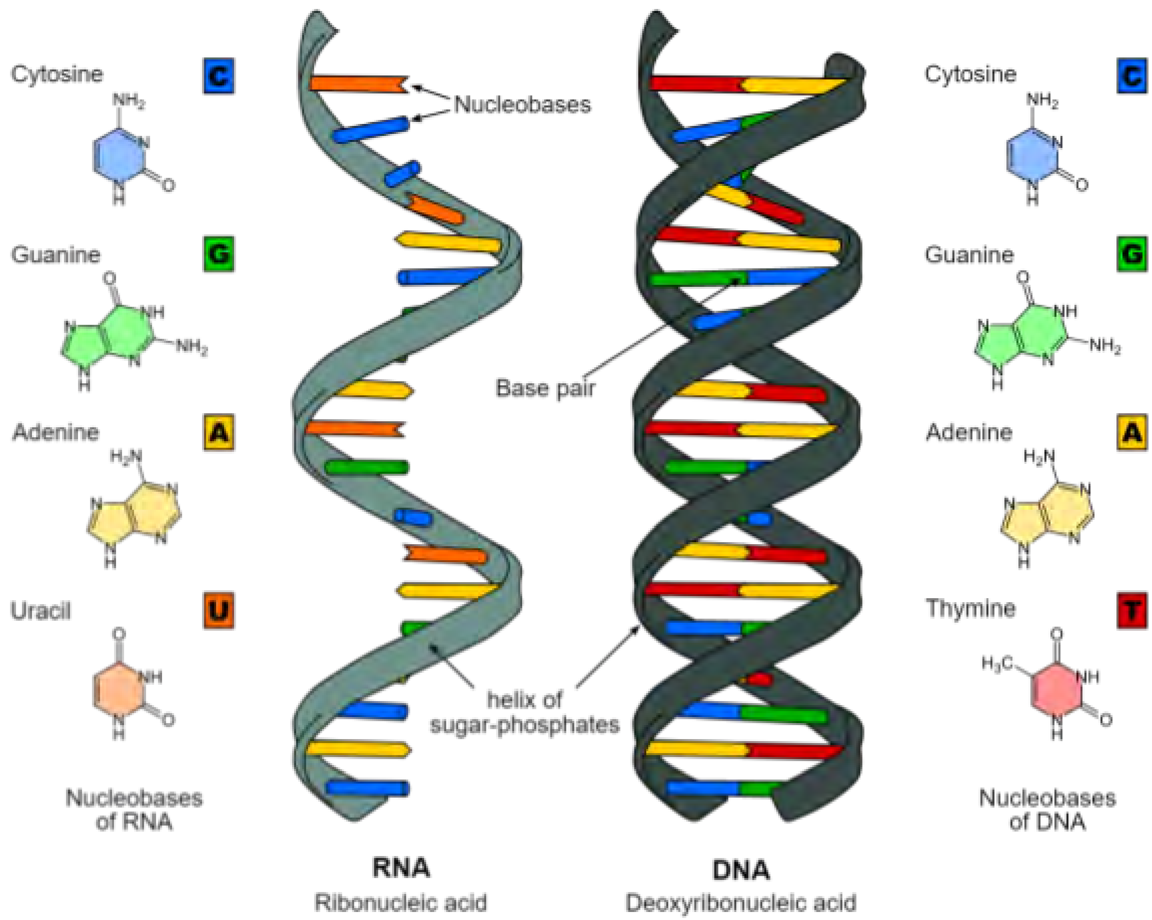


Image from https://commons.wikimedia.org/wiki/File:Difference_DNA_RNA-EN.svg, CC-BY-SA

RNA contains three of the same bases as DNA, but does not include thymine. Instead, RNA has the base uracil (U). The other major difference between DNA and RNA is that RNA is single stranded, instead of double stranded like DNA. This means that the bases of RNA are available to bond with other nucleotides. This part of RNA's structure is very important to its function in making proteins.

There are three types of RNA directly involved in protein synthesis:

- Messenger RNA (mRNA) carries the instructions from the nucleus to the cytoplasm. mRNA is produced in the nucleus, as are all RNAs.
- The other two forms of RNA, ribosomal RNA (rRNA) and transfer RNA (tRNA), are involved in the process of ordering the amino acids to make the protein. Ribosomal RNA becomes part of the ribosome, which is the site of protein synthesis, and tRNA brings an amino acid to the ribosome so it can be added to a growing chain during protein synthesis. There are numerous tRNAs, as each tRNA is specific for an amino acid. The amino acid actually attaches to the tRNA during this process.

The process of protein synthesis is summarized in the diagram below. DNA produces an RNA template which then directs the amino acids to be introduced into the growing protein chain in the proper sequence. A specific transfer-RNA (tRNA) attaches to each specific amino acid and brings the amino acid to the RNA for incorporation.

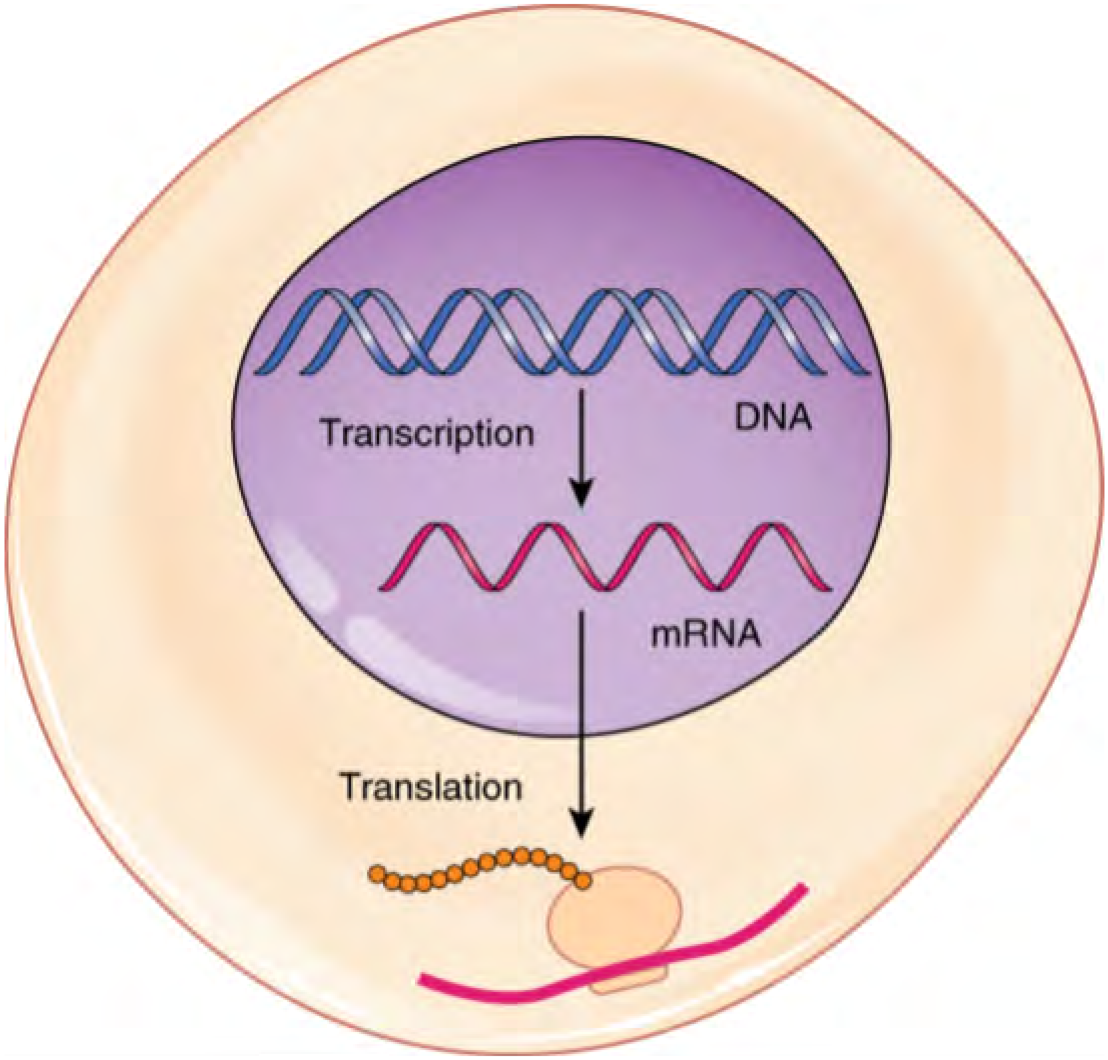


image by OpenStax, https://commons.wikimedia.org/wiki/File:0328_Transcription-translation_Summary.jpg, CC-BY

The first step in the process is transcription - the unfolding of DNA and the production of a messenger-RNA (mRNA) strand. This step takes place in the nucleus of the cell.

The DNA uncoils and provides the pattern for the formation of a single strand of mRNA. After production of the RNA, DNA refolds into the original double helix. The mRNA is exported to the cytoplasm (outside the nucleus).

Once the mRNA is in the cytoplasm, it is used to dictate the order of the amino acids in the protein. Recall from section 2.1 that the structure of a protein is important for it to perform its function. Proteins are made of smaller molecules, called amino acids. The order of amino acids determines the final shape of the protein, so it is important that the amino acids are in the right order. Use the figure below to study the relationship between the order of bases in the mRNA and the order of the amino acids.

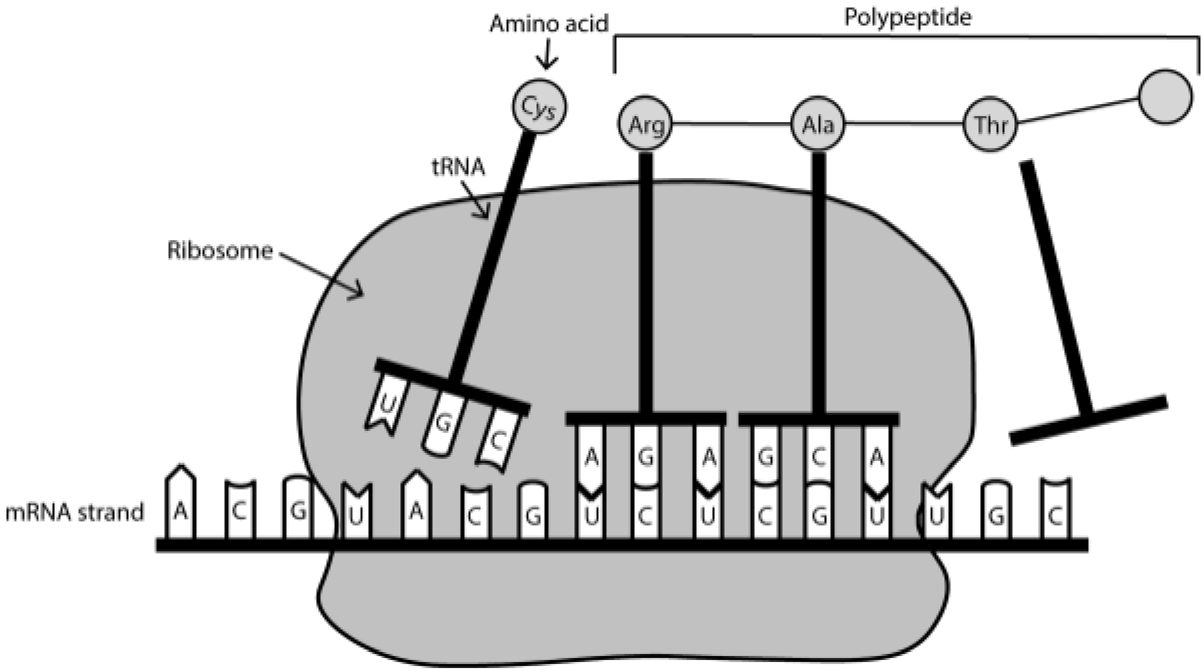


image by Sarah Greenwood, https://commons.wikimedia.org/wiki/File:Protein_Synthesis-Translation.png, CC-BY-SA

The process of protein synthesis is fairly fast. Amino acids are added to the growing protein at a rate of about 3-5 amino acids per second. A small protein (100-200 amino acids) can be produced in a minute or less. You can use this interactive to learn more about protein synthesis: https://learn.genetics.utah.edu/content/basics/txtl/

The End Product

Proteins are the final product of this process. They perform many functions and are the reason for the variation of all living things. The structure of a protein is vital to its function. Recall from section 2.1 that enzymes are proteins that speed up chemical reactions by building molecules or breaking molecules down. The substrate is the reactant and it must fit perfectly into the enzyme. If the enzyme is not shaped correctly then the substrate will not fit properly and the enzyme cannot do its job. This is true of all proteins, not just enzymes.

Cystic fibrosis, Parkinson's disease, and Huntington's disease are just a few examples of genetic disorders that result from proteins that have not been formed properly. The faulty structure prevents the protein from performing its function.

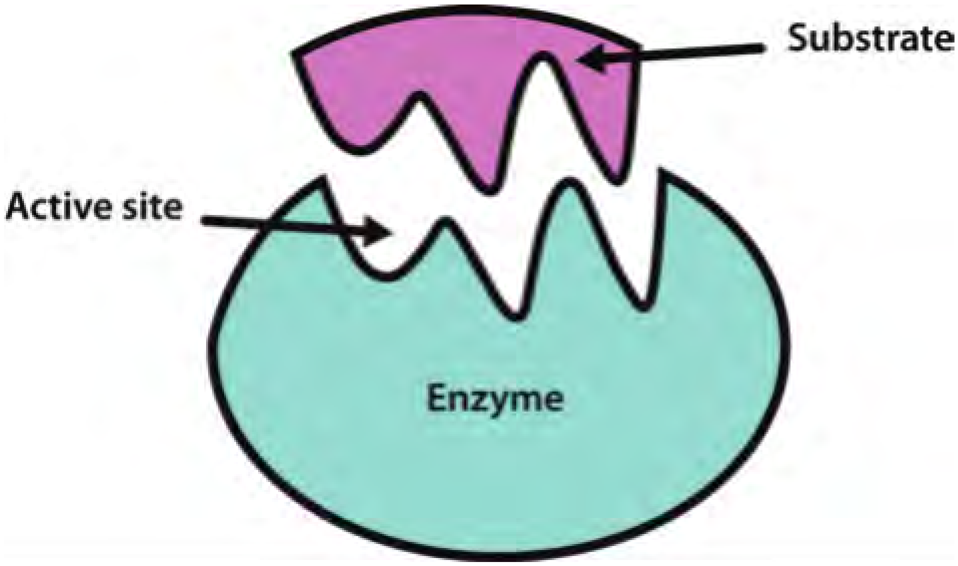


Image by Peter K. Robinson, https://www.researchgate.net/figure/Representation-of-substrate-binding-to-the-active-site-of-an-enzyme-molecule_fig14_283779912, CC-BY 3.0

Putting It Together

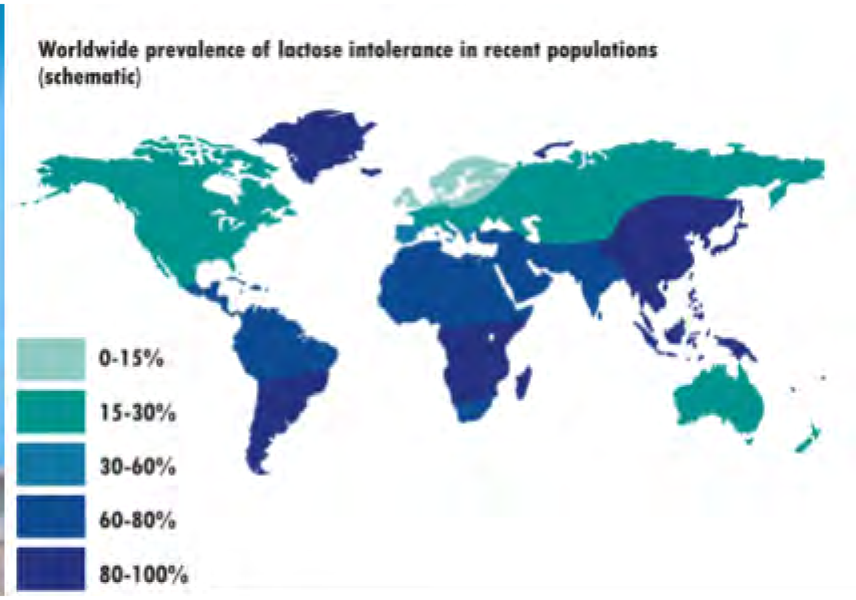


image by Daria-Yakovleva, pixabay.com, CC0
image by by NmiPortal, https://commons.wikimedia.org/wiki/File:Worldwide_prevalence_of_lactose_intolerance_in_recent_populations.jpg, CC-BY-SA

Globally, about two thirds of the adult population is lactose intolerant. This means that after infancy, they have reduced ability to digest lactose, which is a sugar that occurs naturally in milk. People who are not lactose intolerant produce an enzyme that breaks down lactose. People who are lactose intolerant can experience stomach pain, bloating, diarrhea, and other gastrointestinal distress if they drink milk.

1. Review the patterns you identified in the location of people who are lactose intolerant. What role does DNA play in causing these patterns?
2. Review your model to show what causes lactose intolerance. Use what you have learned about DNA and proteins to revise your model. What additional information can you add to explain what causes lactose intolerance?

3.2 Patterns of Inheritance (Bio.3.2)

Explore this Phenomenon

Choux types variés.jpg by Arn, https://commons.wikimedia.org/wiki/File:Choux_types_vari%C3%A9s.jpg, CC-BY-SA

Cruciferous vegetables, like those pictured, can have a bitter taste. PTC is a chemical that tastes bitter, and is similar to the chemicals in cruciferous vegetables. Most people can taste the chemical PTC, but there are people who can't taste it at all. If your parents can't taste PTC, you are less likely to be able to taste PTC than someone whose parents can taste it.

1. Explain how your parents' ability to taste PTC is a factor in your ability to taste PTC.
2. What are three questions we could investigate to better understand why a parent's ability to taste PTC affects their children's ability to taste it.
3. What other phenomena might be explained using the same science concepts as those you used to explain why only some people can taste PTC?

Bio.3.2 Trait Inheritance

Use computational thinking and patterns to make predictions about the expression of specific traits that are passed in genes on chromosomes from parents to offspring. Emphasize that various inheritance patterns can be predicted by observing the way genes are expressed. Examples of tools to make predictions could include Punnett squares, pedigrees, or karyotypes. Examples of allele crosses could include dominant/recessive, incomplete dominant, codominant, or sex-linked alleles. (LS3.A)

We use patterns to make predictions about what traits offspring could inherit. As you read this chapter, look for ways that patterns can be used to predict which traits are passed on and expressed.

Genes and Proteins

In the previous section, you learned that DNA contains instructions to build the proteins that your cells need to function. An individual's DNA is arranged in chromosomes. Each chromosome includes a section of DNA wrapped around proteins, which keeps the DNA organized.

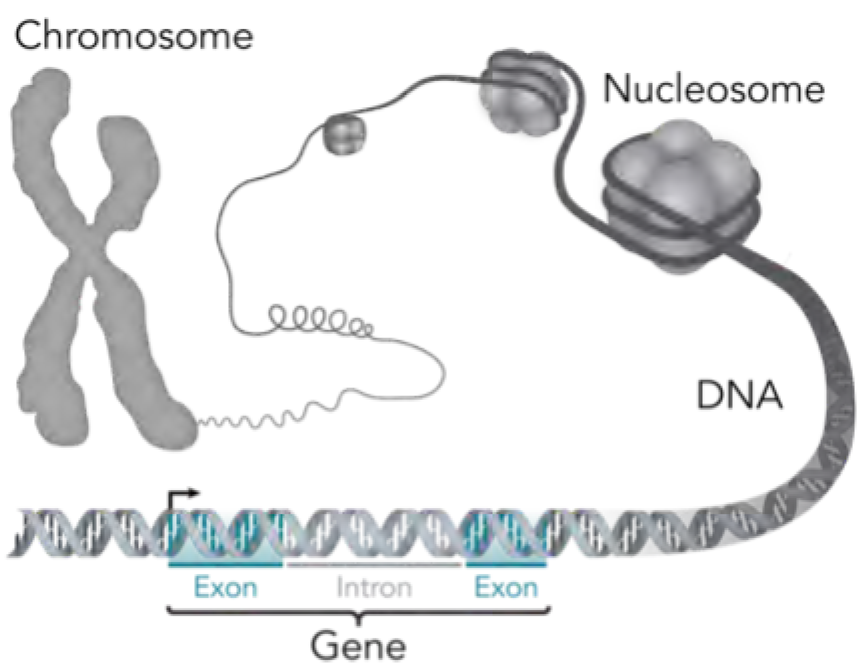


Image by Thomas Splettstoesser, https://commons.wikimedia.org/wiki/File:Chromosome-DNA-gene.png, CC-BY-SA

A section of DNA that codes for a protein is called a gene. Most genes contain the instructions for a single protein. There may be hundreds or even thousands of genes on a single chromosome. Humans have about 22,000 genes. Everyone has the same genes, but due to small differences in the sequence of DNA bases, the proteins produced from each gene may not be the same. The proteins that are made affect the traits that an individual has.

We can use observable patterns and our understanding of how DNA is passed from parent to offspring to make predictions about the likelihood of a trait being passed to and expressed in an offspring.

Meiosis and Sexual Reproduction

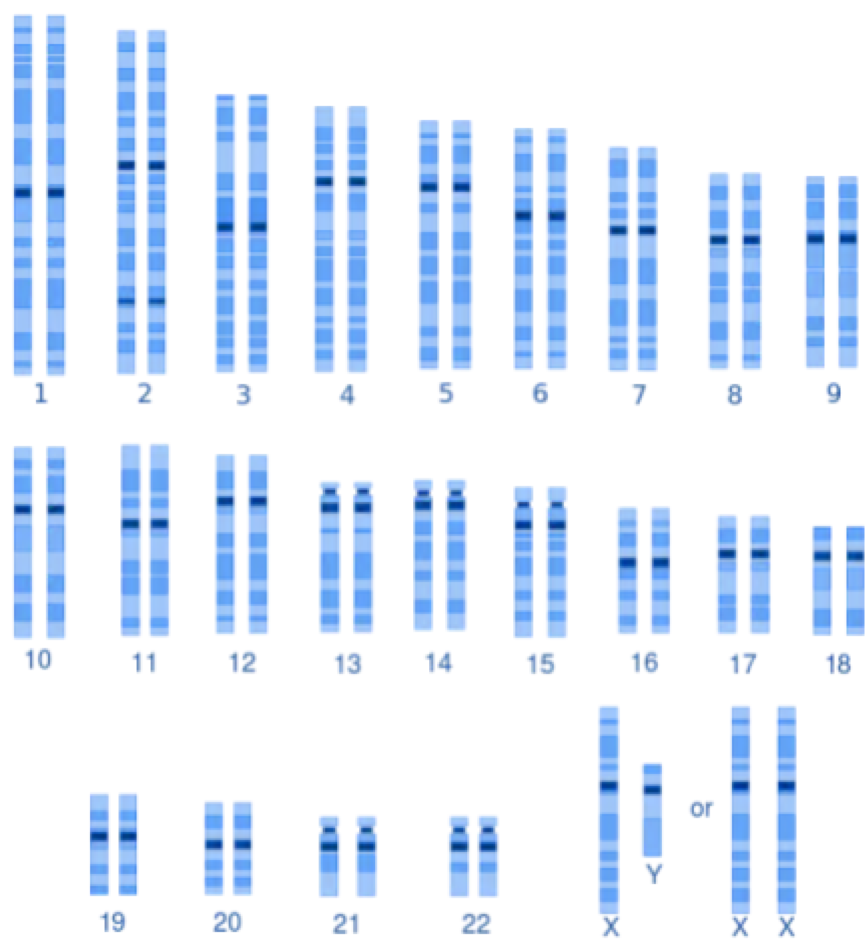
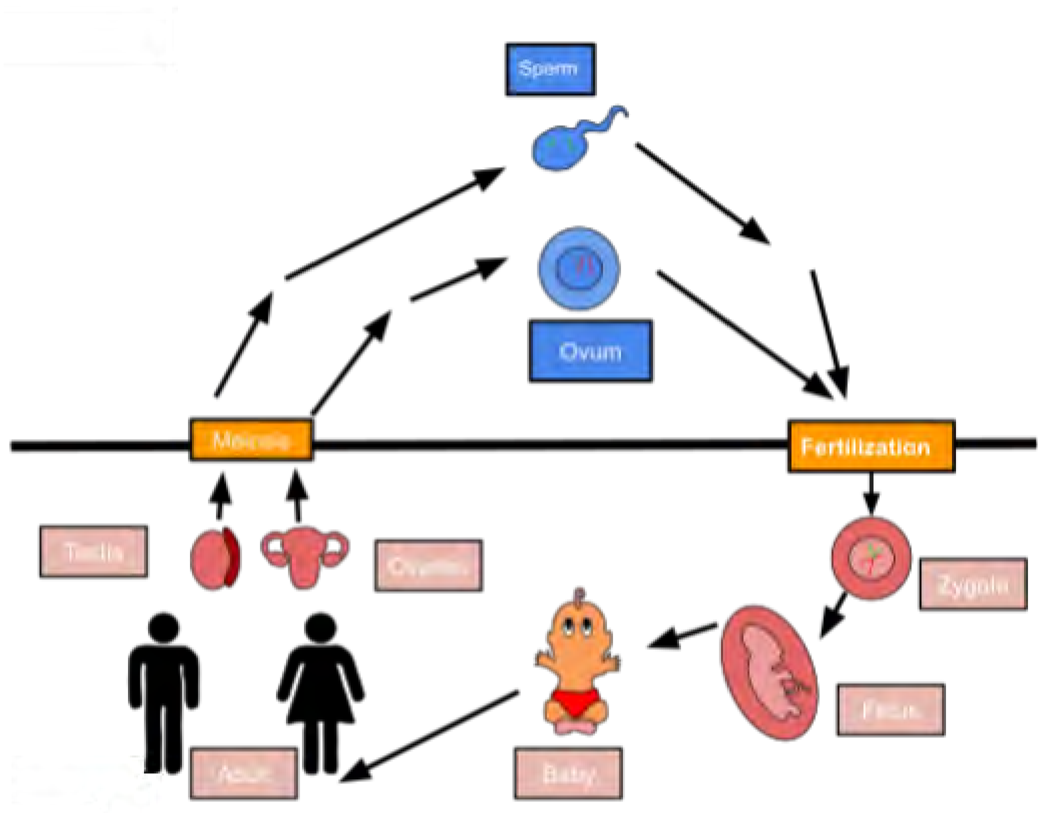


Image by Mikael Häggström, https://a.wikipedia.org/wiki/File:Human_karyotype.svg, CC0

This diagram represents the 23 pairs of chromosomes in a human. Pairs 1-22 are labeled. These chromosomes are called autosomes. The 23rd pair could include an X chromosome and a Y chromosome (for males), or two X chromosomes (for females). The 23rd pair of chromosomes determines the sex of the individual, and is called the sex chromosomes.

One chromosome from each pair was inherited from the individual's mother and the other chromosome was inherited from the individual's father. Except for the Y chromosome in males, the genes on each pair of chromosomes are the same. This means that an individual inherits two copies of each gene; one copy from their mother and one copy from their father.

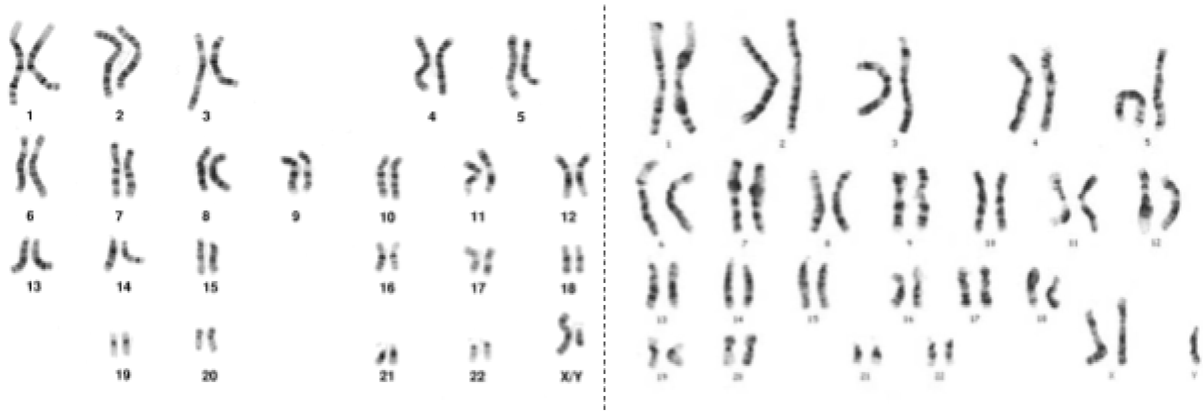
Organisms that reproduce sexually will only pass half of their DNA to their offspring. During a process called meiosis, cells with only half of the DNA are produced. Each daughter cell contains one chromosome from each chromosome pair. The daughter cells are called gametes; male gametes are sperm and female gametes are eggs. When a sperm cell fertilizes an egg cell, the resulting cell will have 23 pairs of chromosomes.



Adapted from image by Aiden cormier, https://en.wikipedia.org/wiki/File:Biological_Life_Cycle_of_Humans.svg, CC-BY-SA

Karyotypes

A karyotype is a picture of a set of chromosomes , a "portrait of the chromosomes in a cell." A karyotype is useful in helping diagnose, learn about, and explain many genetic diseases. Sometimes during meiosis the chromosomes do not divide evenly or they are broken, and the offspring can inherit an abnormal number of chromosomes. Karyotypes allow us to see these abnormalities, and can be used to identify extra, defective, or missing chromosomes. Compare the two karyotypes below to determine which has the normal number of chromosomes and which has an abnormal number of chromosomes.



Images from https://commons.wikimedia.org/wiki/File:Karyotype_(normal).jpg, CC0 (CC0) and https://lt.m.wikipedia.org/wiki/File:47,XXY.jpg, CC-BY-SA

Genes and Alleles

The chromosomes that make a pair are called homologous, because they contain the same genes. Even though the chromosomes contain the same genes, they are not identical . The majority of human genes have two or more possible alleles, which are alternative forms of a gene. For example, there are different versions, or alleles, of the gene that codes for the protein hemoglobin. Although each gene will produce the hemoglobin, small differences in the DNA can cause the hemoglobin protein to have a different shape. One allele for hemoglobin has one different base, and the changes to the protein result in sickle cell anemia.

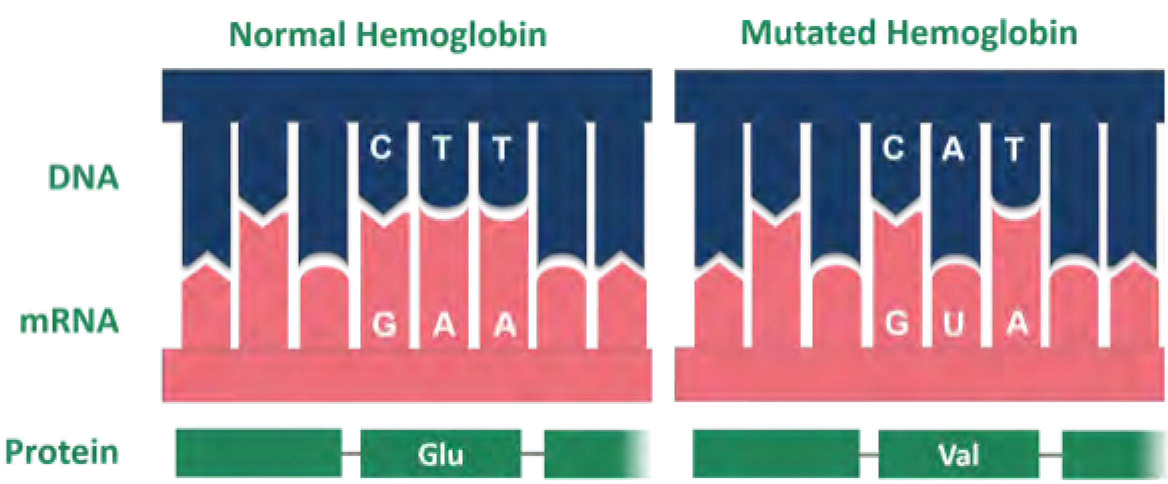
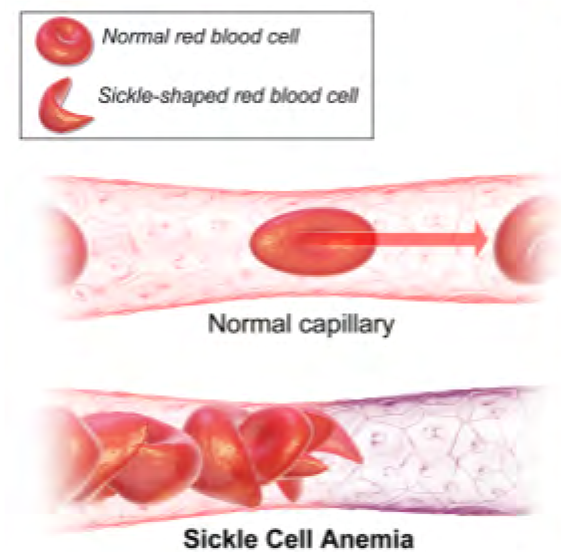
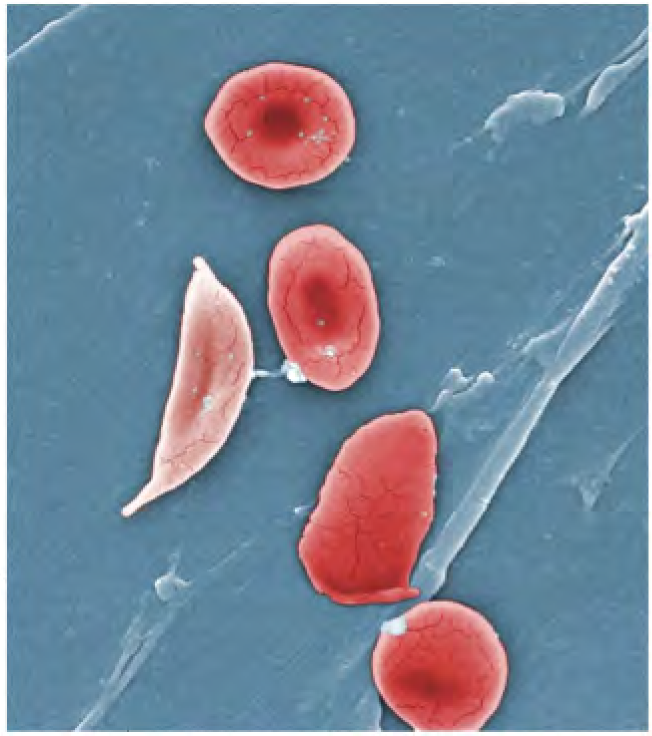


Image by Thomas Samuel for ACC-BioinnovationLab, https://commons.wikimedia.org/wiki/File:Point-Mutation-Sickle-Cell-Normal_and_Mutated-Hemoglobin.png, CC-BY-SA

People with sickle cell anemia can experience a range of symptoms, including reduced blood flow to tissues, pain, and the death of cells. The differently-shaped hemoglobin protein causes red blood cells to change to a sickle shape. The images show normal and sickle shaped cells, and how the sickle shaped cells can interrupt the flow of blood. People with two copies of the sickle cell allele will have sickle cell anemia, but people who inherit one or two copies of the normal allele will not have sickle cell anemia.





(Top) Image by BruceBlaus,
https://en.wikipedia.org/wiki/Sickle_cell_disease#/media/File:Sickle_Cell_Anemia.png, *CC-BY-SA*
(Right) Image by OpenStax,
https://en.wikipedia.org/wiki/Sickle_cell_disease#/media/File:1911_Sickle_Cells.jpg, *CC-BY*

Most human genetic variation is the result of differences in individual DNA bases within alleles. The combination of alleles that an individual inherits from their parents determines what traits they have. Some alleles are always expressed, meaning that the trait associated with the allele will be present. These alleles are sometimes called "dominant" alleles, and they are represented using a capital letter. Other alleles may not be expressed. These alleles are sometimes called "recessive" alleles, and they are represented using a lower case letter. Even though an individual has a recessive allele, they will not have the trait that the allele codes for, but they could pass the allele to their offspring, and their offspring could have the trait. The terms "dominant" and "recessive" can be misleading. Dominant alleles are not necessarily more common than recessive alleles, and they are not more likely to be passed on than recessive alleles. Recessive alleles are not always hidden. There are cases when alleles do not follow a dominant-recessive pattern.

Patterns of Inheritance

We can use patterns in the expression of traits to learn if an allele is dominant, recessive, or neither, and to make predictions about the likelihood of a particular trait being expressed in the offspring.

Before using patterns to make predictions, it is important to understand the relationship between the alleles an individual has and the traits they express. The combination of alleles an individual has is their genotype, and the expression of traits is their phenotype. As an example, assume that the allele for brown fur (A) is dominant to the allele for gray fur (a). The table below shows the possible combinations of alleles that an individual could have, and the traits associated with each allele combination.

Genotype (allele combination)	Phenotype (expressed trait)
AA	brown
Aa	brown
aa	gray

What is the possibility of two brown individuals having a gray offspring? Or of brown and gray parents having brown offspring? We can use observable patterns to make predictions about the possible genotype and phenotype of the offspring. This is important when it comes to breeding animals and plants. Gregor Mendel is known as the Father of Genetics, because his work established a foundation for understanding genetics. Mendel studied inheritance patterns in pea plants from 1856 to1853.

Mendelian inheritance refers to the inheritance of traits controlled by a single gene with two alleles, one of which may be dominant to the other. Mendel discovered that genes come in pairs, and that these gene pairs are separated and only one gene from each pair is passed to an offspring.

A Punnett square is a chart that allows you to easily determine the expected percentage of different genotypes in the offspring of two parents. An example of a Punnett square for pea plants is shown. In this example, both parents have the genotype Bb for flower color. This means that the homologous chromosomes that include the gene for color have different alleles. These chromosomes will be separated during meiosis, and the parent will only pass one chromosome along to each offspring. The gametes produced by the male parent are at the top of the chart, and the gametes produced by the female parent are along the side. The different possible combinations of alleles in their offspring are determined by filling in the spaces of the Punnett square with the correct alleles.

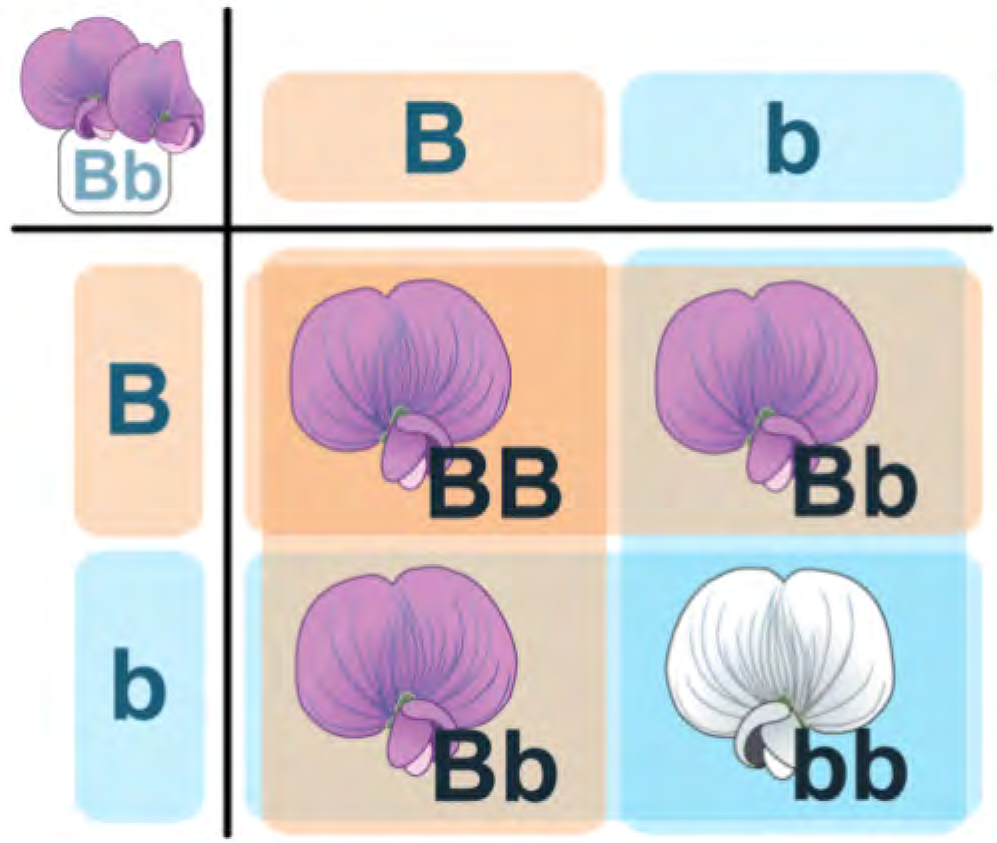


Image by Jodi So;Sam McCabe, CK-12 Foundation, CC BY-NC 3.0

Predicting Offspring Genotypes

In the cross shown in the figure, you can see that one out of four offspring (25 percent) has the genotype *BB*, one out of four (25 percent) has the genotype *bb*, and two out of four (50 percent) have the genotype *Bb*. These percentages of genotypes are what you would expect in any cross between two heterozygous parents. If these parents only had four offspring, they won't necessarily have one offspring with genotype BB, two with Bb, and one with bb. Each offspring has the same chance of being BB (or Bb or bb). However, if you considered hundreds of such crosses and thousands of offspring, you would get very close to the expected results, just like tossing a coin.

Predicting Offspring Phenotypes

You can predict the percentages of phenotypes in the offspring of this cross from their genotypes. *B* is dominant to *b*, so offspring with either the *BB* or *Bb* genotype will have the purple-flower phenotype. Only offspring with the *bb* genotype will have the white-flower phenotype. Therefore, in this cross, you would expect three out of four (75 percent) of the offspring to have purple flowers and one out of four (25 percent) to have white flowers. These are the same percentages that Mendel got when experimenting with pea plants.

You can learn more about how and why to use Punnett Squares in this video:

https://www.youtube.com/watch?v=i-0rSv6oxSY&list=PLwL0Myd7Dk1FVxYPO_bVbk8oOD5EZ2o5W&index=6

Determining Missing Genotypes

A Punnett square can also be used to determine a missing genotype based on the other genotypes involved in a cross. Suppose you have a parent plant with purple flowers and a parent plant with white flowers. Because the *b* allele is recessive, you know that the white-flowered parent must have the genotype *bb*. The purple-flowered parent, on the other hand, could have either the *BB* or the *Bb* genotype. The Punnett square below shows this cross. The question marks (?) in the chart could be either *B* or *b* alleles.

		White Flowered Parent	
	Parents	**b**	**b**
Purple Flowered Parent	**B**	Bb	Bb
	?	?b	?b

Punnett Square: Cross Between White-Flowered and Purple-Flowered Pea Plants. This Punnett square shows a cross between a white-flowered pea plant and a purple-flowered pea plant. Can you fill in the missing alleles? What do you need to know about the offspring to complete their genotypes?

Can you tell what the genotype of the purple-flowered parent is from the information in the Punnett square? No; you also need to know the genotypes of the offspring in row 2. What if you found out that two of the four offspring have white flowers? Now you know that the offspring in the second row must have the *bb* genotype. One of their *b* alleles obviously comes from the white-flowered (*bb*) parent, because that’s the only allele this parent has. The other *b* allele must come from the purple-flowered parent. Therefore, the parent with purple flowers must have the genotype *Bb*.

Not many human traits are controlled by a single gene with two alleles, but this type of inheritance is a good starting point for understanding human heredity. How Mendelian traits are inherited depends on whether the traits are controlled by genes on autosomes or the sex chromosomes.

Autosomal Traits

Autosomal traits are controlled by genes on one of the 22 human autosomes. Consider earlobe attachment. A single autosomal gene with two alleles determines whether you have attached earlobes or free-hanging earlobes. The allele for free-hanging earlobes (*F*) is dominant to the allele for attached earlobes (*f*). Other single-gene autosomal traits include widow's peak and hitchhiker's thumb. The dominant and recessive forms of these traits are shown in the image. Which form of these traits do you have? What are your possible genotypes for the traits?

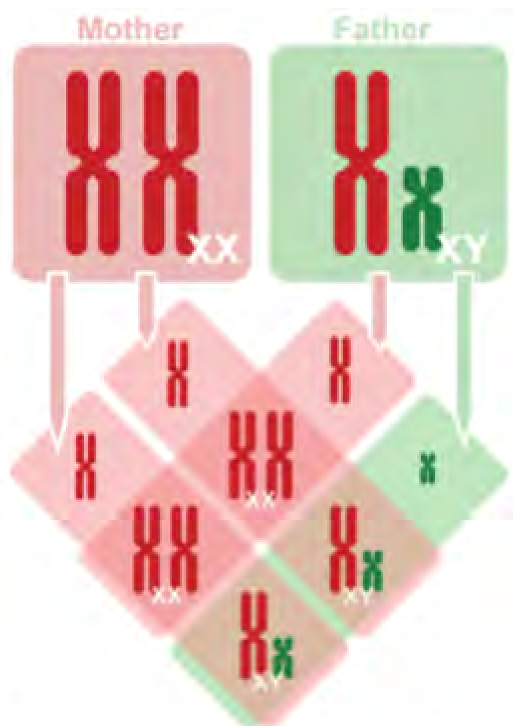
Single Gene Autosomal Traits

Widow's Peak | No Widow's Peak | Hitchhiker's Thumb | No Hitchhiker's Thumb

Adapted from images on pixabay.com, CC0

Sex-Linked Traits

Traits controlled by genes on the sex chromosomes are called sex-linked traits. Single-gene X-linked traits have a different pattern of inheritance than single-gene autosomal traits. Do you know why? It's because males only have one X chromosome. In addition, they always inherit their X chromosome from their mother, and they pass it on to all their daughters but none of their sons.



Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation, CC-BY-NC 3.0

Inheritance of Sex Chromosomes. Mothers pass on only X chromosomes to their children. Fathers always pass their X chromosome to their daughters and their Y chromosome to their sons. Can you explain why fathers always determine the sex of the offspring?

Because males have only one X chromosome, they have only one allele for any X-linked trait. Therefore, a recessive X-linked allele is always expressed in males. Because females have two X chromosomes, they have two alleles for any X-linked trait. Therefore, they must inherit two copies of the recessive allele to express the recessive trait. This explains why X-linked recessive traits are less common in females than males. Red-green color blindness is an example of a recessive X-linked trait. People with this trait cannot distinguish between the colors red and green. More than one recessive gene on the X chromosome codes for this trait, which is fairly common in males but relatively rare in females. About 1 in 10 men have some form of color blindness, however, very few women are color blind.

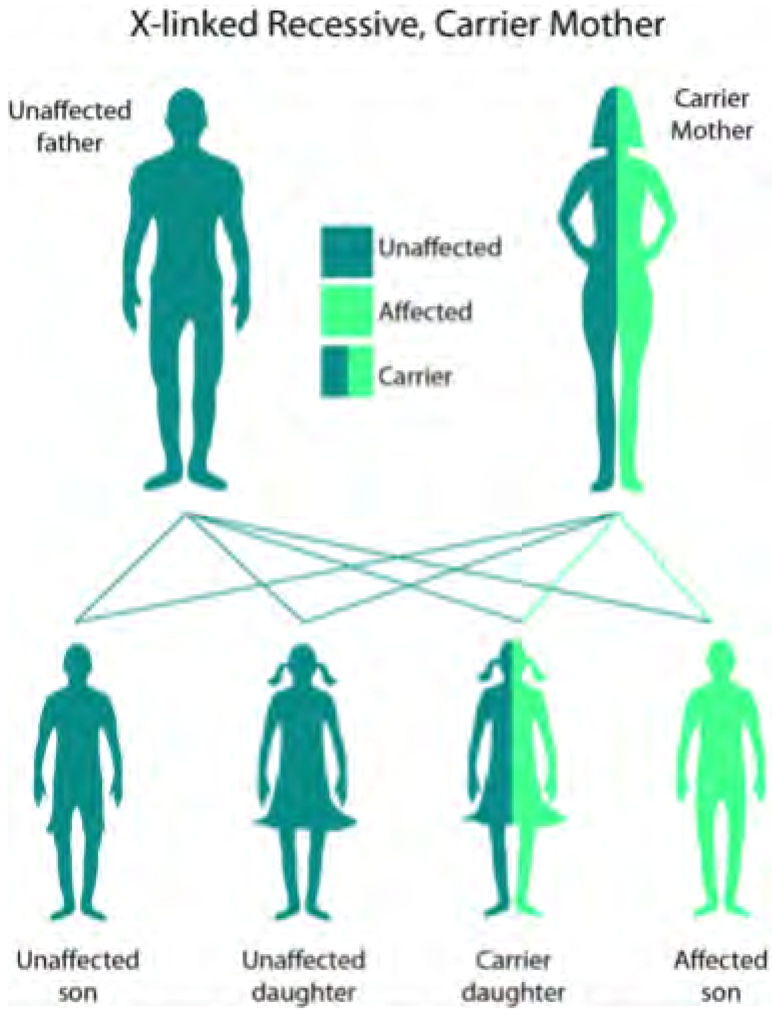


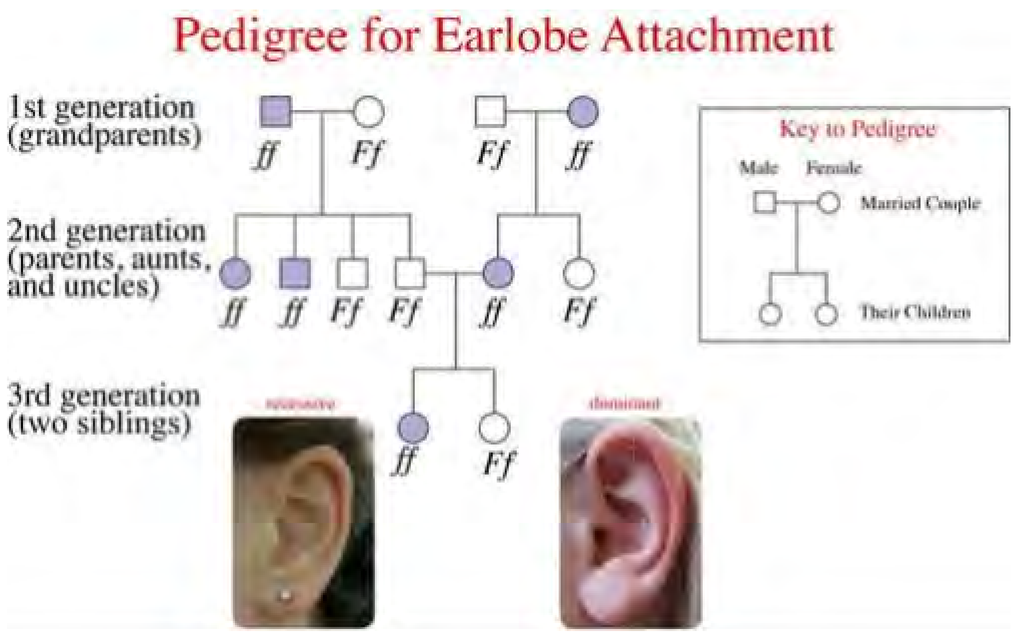
Image by CK-12 Foundation, CC-BY-NC 3.0

Pedigree Charts

Image by Zachary Wilson, CK-12 Foundation, CC BY-NC 3.0

When you are talking about a pedigree dog, it means the dog is purebred. Through selective breeding, the dog has all the traits of that particular breed. When talking about genetics, however, a pedigree is a chart that helps show family relationships.

The chart in the image is called a pedigree. It shows how the earlobe trait was passed from generation to generation within a family.



Adapted from images by Covalent/Wikipedia and Claire P.; pedigree created by Sam McCabe (CK-12 Foundation)
http://commons.wikimedia.org/wiki/File:Earcov.JPG (public domain); and
http://www.flickr.com/photos/rockinfree/4939042632 (CC-BY 2.0)

Having free-hanging earlobes is an autosomal dominant trait. This figure shows the trait and how it was inherited in a family over three generations. Shading indicates people who have the recessive form of the trait. Look at (or feel) your own earlobes. Which form of the trait do you have? Can you tell which genotype you have?

A pedigree is a chart that shows the inheritance of a trait over several generations. It is a useful tool for studying inheritance patterns. A pedigree is commonly created for families, and it outlines the inheritance patterns of genetic disorders and traits. A pedigree can help predict the probability that offspring will inherit a genetic disorder.

Pictured next is a pedigree displaying recessive inheritance of a disorder through three generations. From studying a pedigree, you can determine the following:

- If the trait is sex-linked (on the X or Y chromosome) or autosomal (on a chromosome that does not determine sex).
- If the trait is inherited in a dominant or recessive fashion.

Sometimes pedigrees can also help determine individuals' genotypes. Some points to keep in mind when analyzing a pedigree are:

1. With autosomal recessive inheritance, all affected individuals will be homozygous recessive.
2. With dominant inheritance, all affected individuals will have at least one dominant allele. They will be either homozygous dominant or heterozygous.
3. With sex-linked inheritance, more males (XY) than females (XX) usually have the trait. Sex-linked inheritance is usually recessive.

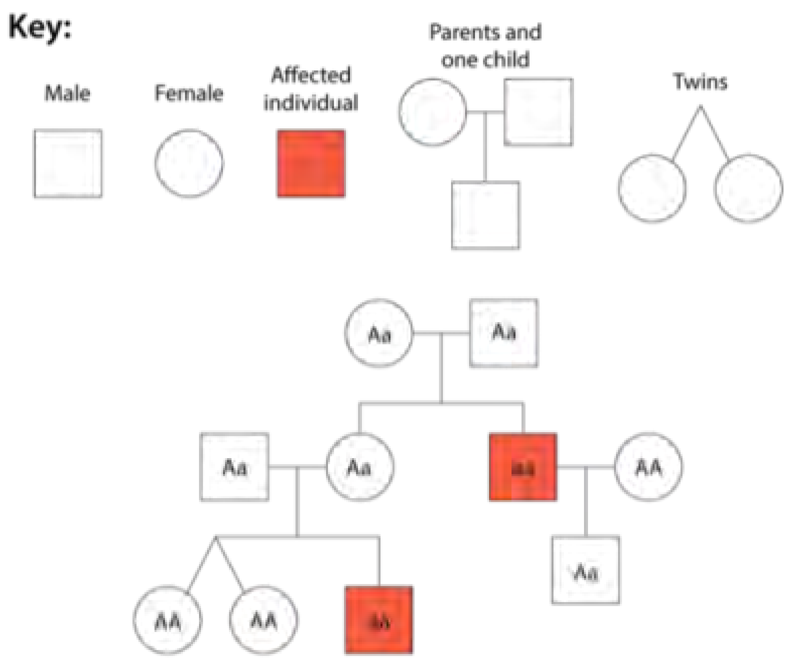


Image by Zachary Wilson, CK-12 Foundation, CC BY-NC 3.0

In a pedigree, squares symbolize males, and circles represent females. A horizontal line joining a male and female indicates that the couple had offspring. Vertical lines indicate offspring which are listed left to right, in order of birth. Shading of the circle or square indicates an individual who has the trait being traced. In this pedigree, the inheritance of the recessive trait is being traced. A is the dominant allele, and a is the recessive allele.

Non-Mendelian Inheritance

Of course human eyes do not come in multi-color, but they do come in many colors. How do eyes come in so many colors? That brings us to complex inheritance patterns, known as non-Mendelian inheritance. Many times inheritance is more complicated than the simple patterns observed by Mendel.

Each characteristic Mendel investigated was controlled by one gene that had two possible alleles, one of which was completely dominant to the other. This resulted in just two possible phenotypes for each characteristic. Each characteristic Mendel studied was also controlled by a gene on a different (nonhomologous) chromosome. As a result, each characteristic was inherited independently of the other characteristics. We now know that inheritance is often more complex than this.

A characteristic may be controlled by one gene with two alleles, but the two alleles may have a different relationship than the simple dominant-recessive relationship that you have read about so far. For example, the two alleles may have a codominant or incompletely dominant relationship.

Codominance

Codominance occurs when both alleles are expressed equally in the phenotype of the heterozygote. The red and white flower in the figure has codominant alleles for red petals and white petals.

Codominance. The flower has red and white petals because of the codominance of red-petal and white-petal alleles.

Image by darwin cruz, https://commons.wikimedia.org/wiki/File:Co-dominance_Rhododendron.jpg, CC BY 2.0

Incomplete Dominance

Incomplete dominance occurs when the phenotype of the offspring is somewhere in between the phenotypes of both parents; a completely dominant allele does not occur. For example, when red snapdragons are crossed with white snapdragons, the offspring are all pink. The pink color is an intermediate between the two parent colors. When two plants with pink flowers are crossed, they will produce red, pink, and white flowers. The genotype of an organism with incomplete dominance can be determined from its phenotype.

		White Flower	
		c^W	c^W
Red Flower	c^R	c^Rc^W	c^Rc^W
	c^R	c^Rc^W	c^Rc^W

Images by Sandy Schultz, http://www.flickr.com/photos/chatblanc1/4788366795/,CC BY 2.0 and Jodi So (punnett square), ; CK-12 Foundation, CC BY-NC 3.0

Incomplete Dominance. The flower has pink petals because of incomplete dominance of a red-petal allele and a recessive white-petal allele.

Putting It Together

Choux types variés.jpg by Arn,
https://commons.wikimedia.org/wiki/File:Choux_types_vari%C3%A9s.jpg, CC-BY-SA

Cruciferous vegetables, like those pictured, can have a bitter taste. PTC is a chemical that tastes bitter, and is similar to the chemicals in cruciferous vegetables. Most people can taste the chemical PTC, but there are people who can't taste it at all. If your parents can't taste PTC, you are less likely to be able to taste PTC than someone whose parents can taste it.

1. Revise your explanation for how an individual's ability to taste PTC is affected by their parents.
2. What other information about the PTC gene would you need to make predictions about the possible phenotype of an offspring? Describe why this information would be needed to predict the possible phenotypes of the offspring.

3.3 Genetic Variation (Bio.3.3)

Explore this Phenomenon

Image by Michelle Maria, pixabay.com, CC0

These puppies look similar to each other, but they are not identical, even though they all inherited DNA from the same parents.

1. Propose an explanation for why the puppies have different traits, even though they inherited DNA from the same parents.
2. What are three questions that you could investigate to better understand why the puppies share some, but not all, traits.

3.3 Genetic Variation

Engage in argument from evidence that inheritable genetic variation is <u>caused</u> during the formation of gametes. Emphasize that genetic variation may be caused by epigenetics, during meiosis from new genetic combinations, or viable mutations. (LS3.B)

Different factors can cause changes in the genes that are passed from parent to offspring. As you read this chapter, look for different processes that can result in genetic variation.

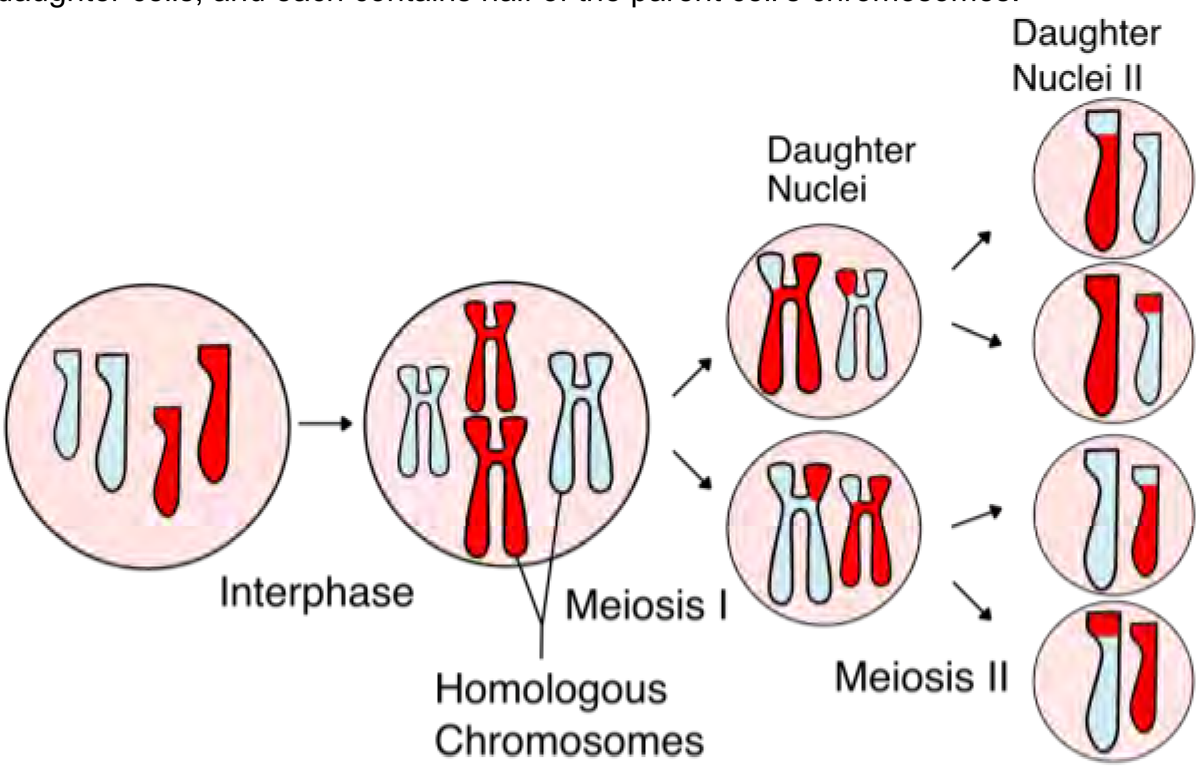
Meiosis and Fertilization Create Genetic Variation

Image from US National Library of Medicine, http://ghr.nlm.nih.gov/handbook/illustrations/mitosismeiosis, Public Domain

Have you ever heard that our differences make us stronger? When it comes to the survival of a species, this is true! When the individuals of a species have very different traits, we say that the species has a high level of genetic variation. Species that have a lot of genetic variation are more likely to survive changes in their environment or the breakout of a deadly disease. In this chapter, you will be learning about factors that cause genetic variation, starting with variation that occurs due to meiosis.

Sexual reproduction results in a population with higher variation than asexual reproduction. In the previous section, you learned about meiosis. Recall that meiosis creates cells that only have half of the DNA of the parent cell. These cells are called gametes. When a gamete from a female (egg) is fertilized by a gamete from a male (sperm), an offspring with a new combination of DNA is formed. Through the process of meiosis and fertilization, the genetic variation of a species is increased.

Two rounds of cell division occur during meiosis. Homologous chromosomes, which contain alleles for the same genes, are separated during the first division. Sister chromosomes are separated during the second division. At the end, there are four daughter cells, and each contains half of the parent cell's chromosomes.



Meiosis Overview new by Rdbickel,
https://commons.wikimedia.org/wiki/File:Meiosis_Overview_new.svg, CC-BY-SA 4.0

Independent Assortment During Meiosis Increases Genetic Variation

Remember from section 3.2 that individuals have two copies of each gene. During meiosis, the copies of each gene are separated into different daughter cells. Unless they are located close together on the same chromosome, the way the alleles for one gene separate do not affect the way that alleles from other genes separate. In other words, the chromosomes follow the law of independent assortment. This means that there are over eight million different combinations of alleles that could be produced by the same person! These different combinations ensure that offspring are genetically different from their parents and siblings.

Crossing-Over During Meiosis Increases Genetic Variation

Crossing-over happens during meiosis, and increases the possible combinations of alleles that can be passed to the offspring. Before the homologous chromosomes separate, they can swap sections of DNA. This results in new combinations of alleles on a chromosome that can be passed onto the offspring.

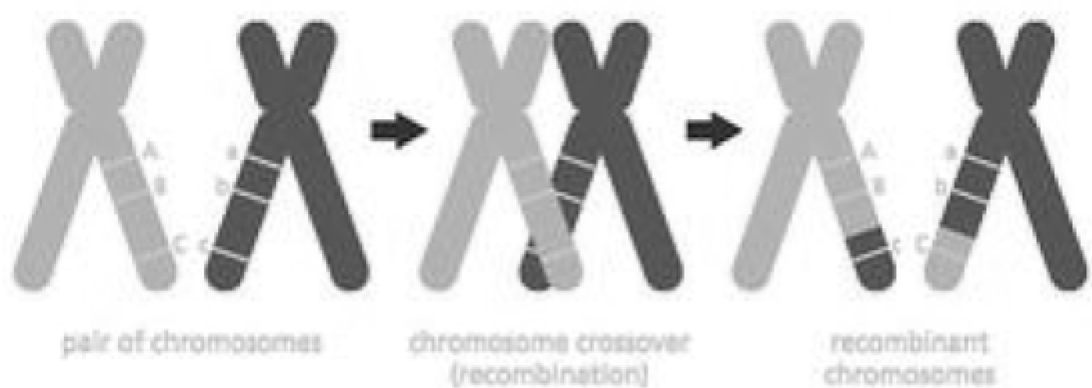


Image by yourgenome (Genome Research Limited), https://flic.kr/p/H1twqU, CC-BY-NC-SA

Mutations Increase Genetic Variation

Mutations are changes to the original DNA. Many mutations don't have any effect on the final protein, but some mutations can cause the protein to be nonfunctional, or to work better or even have a new function. If a mutation is passed from parent to offspring and stays in the population, it increases the amount of genetic variation.

Causes of Mutations

During meiosis, the DNA is replicated. The process of DNA replication is not always 100% accurate. Sometimes the wrong base is inserted in the new strand of DNA. This mutation could become permanent. Once DNA has a mutation, that mutation will be copied each time the DNA replicates. After cell division, each resulting cell will carry the mutation.

A mutation in the DNA may have a positive, negative, or no effect on the protein it codes for. If the mutation has a negative effect that makes it so the offspring can't survive, it won't be passed on. However, if the offspring survives, it is a viable mutation and can increase the genetic variation in the species.

Mutations can also be caused by environmental factors. Factors such as UV radiation from the sun, chemicals in cigarette smoke, and x-rays can cause mutations in DNA.

Epigenetics Leads to Variations in Expressed Traits

Chromosomes consist of strands of DNA, proteins, and other molecules. The proteins and molecules are like packaging for the DNA. This “packaging” surrounding the DNA is called the epigenome. Some of the DNA is exposed, but some of it is covered by the epigenome. The image below shows the structure of the DNA, proteins, and other molecules in a chromosome.

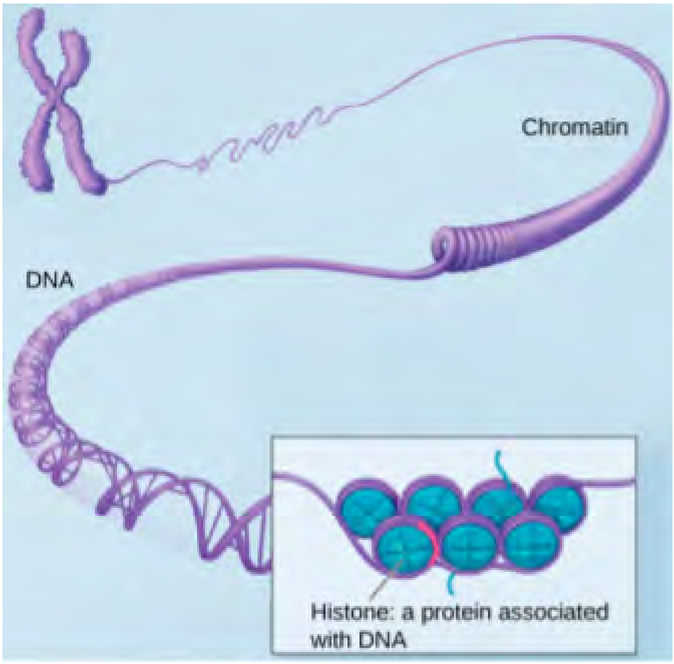


Image by CNX OpenStax, https://commons.wikimedia.org/wiki/File:Figure_04_03_05a.jpg, CC-BY

The epigenome affects which sections of DNA can be expressed. Genes covered by the epigenome (proteins and other molecules associated with the DNA) aren’t expressed. Proteins can’t be made from these genes, because the DNA is covered and cannot be read to make mRNA. The diagram below shows how the epigenome interacts with the DNA, and includes factors that affect the epigenome.

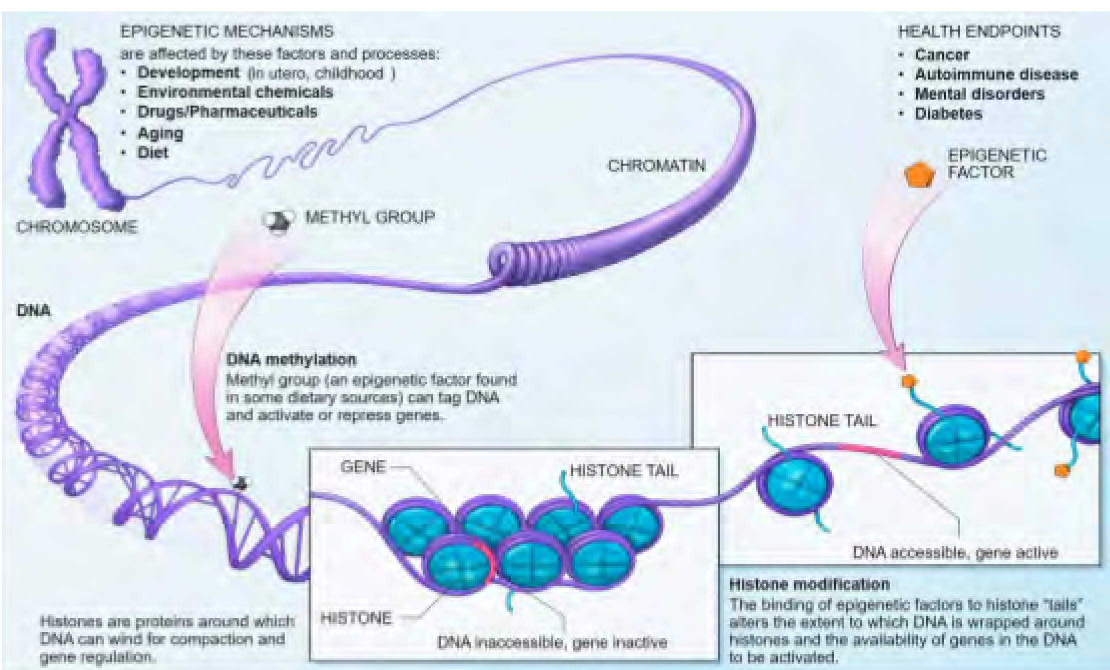


Image by National Institutes of Health, https://commons.wikimedia.org/wiki/File:Epigenetic_mechanisms.jpg, *public domain*

Even though an individual has a gene for a specific trait, the epigenome can keep this trait from being expressed. Since the epigenome helps determine which genes are expressed, it affects the variation of expressed traits we see in a population. Environmental factors can affect an individual's epigenome.

To learn more about how the epigenome affects gene expression, see this video (https://learn.genetics.utah.edu/content/epigenetics/intro/).

You can also use this simulation to see how the care that a mother rat gives her pups affects their epigenomes (https://learn.genetics.utah.edu/content/epigenetics/rats/).

Putting It Together

Image by Michelle Maria, pixabay.com, CC0

These puppies look similar to each other, but they are not identical, even though they all inherited DNA from the same parents.

1. Revise your explanation for why the puppies have different traits, even though they inherited DNA from the same parents. Which factors most likely account for the differences we see in the puppies?
2. Extend your explanation to other species. Compare the genetic variation you observe in several species, and explain what causes higher or lower levels of genetic variation in different species.

3.4 Trait Distribution (Bio 3.4)

Explore this Phenomenon

Image by USFWS, https://www.fws.gov/refuge/willapa/wildlife_and_habitat/clams.html, public domain

Clams, like those pictured above, live along the coasts of the United States. Recently, there have been large growths of algae that release toxins that can harm the clams, but some populations include individuals who are resistant to the toxin. Scientists have found that the distribution of the resistant trait is not uniform. Areas further north have fewer resistant clams, and populations on the east coast tend to have more resistant clams than populations on the west coast.

1. Explain why the resistant trait would not be evenly distributed among all populations of clams. Why do some areas have more clams that are resistant to the toxin than others?
2. What are three questions we could investigate to better understand the distribution patterns of the resistant trait?
3. What additional information would be helpful in explaining this phenomenon?

Bio.3.4 Trait Distribution

Plan and carry out an investigation and **use computational thinking** to explain the variation and patterns in the distribution of the traits expressed in a population. Emphasize the distribution of traits as it relates to both genetic and environmental influences on the expression of those traits. Examples of variation and patterns in the distribution of traits could include sickle-cell anemia and malaria, hemoglobin levels in humans at high elevation, or antibiotic resistance. (LS3.B)

We observe patterns in the way traits are distributed in populations. As you read this chapter, look for the genetic and environmental factors that lead to patterns in trait distribution.

Traits are not Distributed Evenly

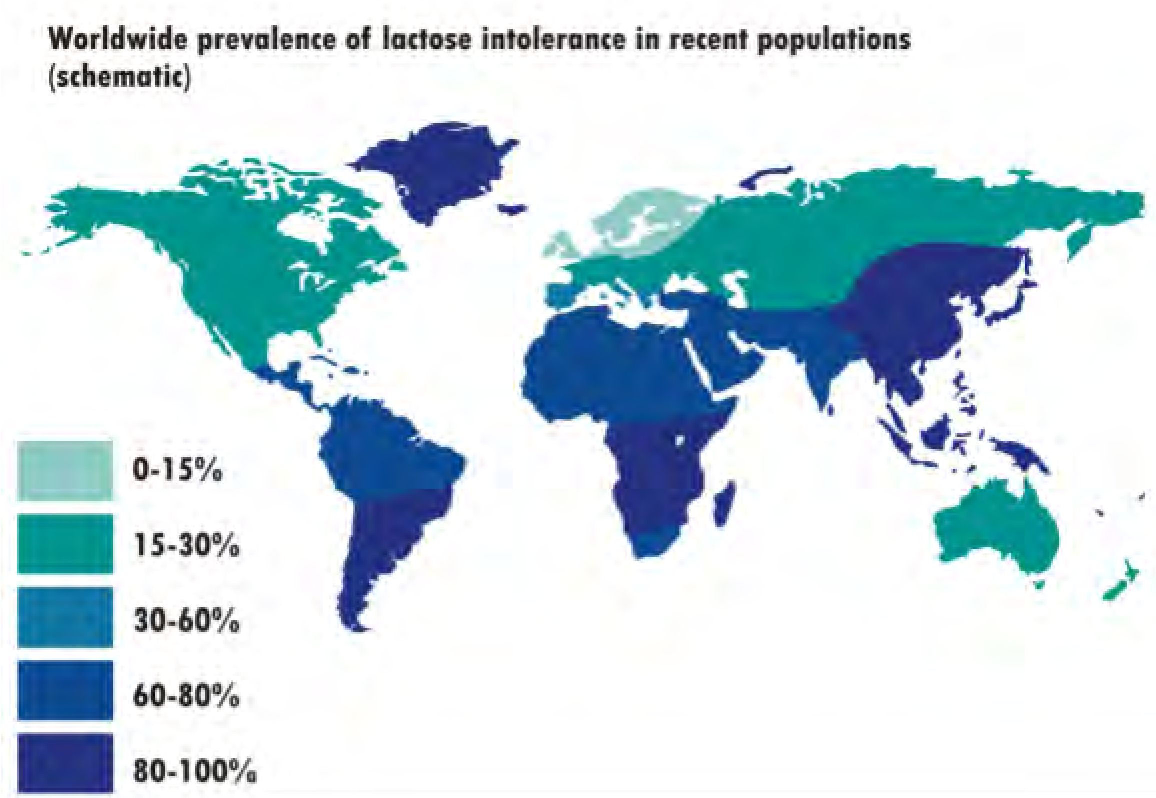
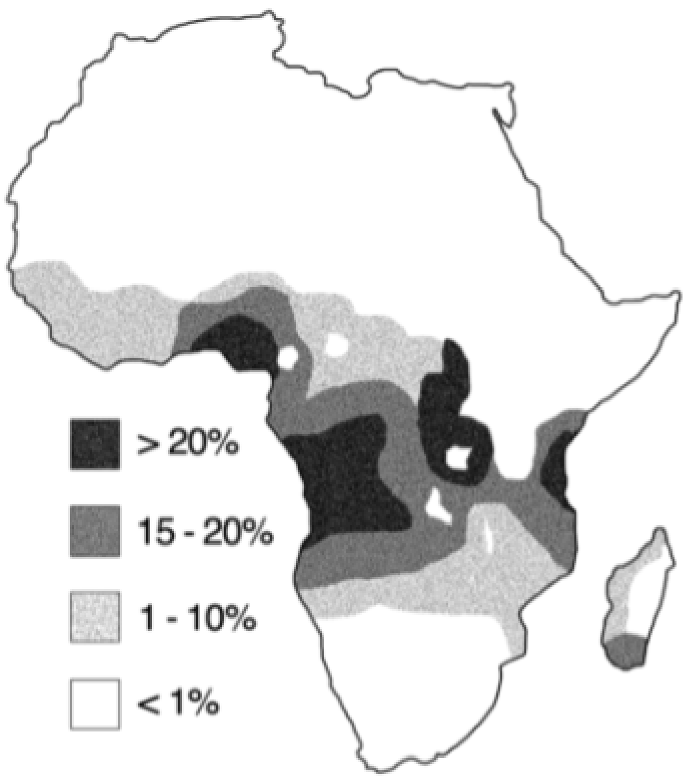


Image by Nmiportal, https://commons.wikimedia.org/wiki/File:Worldwide_prevalence_of_lactose_intolerance_in_recent_populations.jpg, CC-BY-SA

In the previous section, you learned about some of the factors that cause genetic variation. However, different genetic traits are not always spread evenly throughout a population. For example, the percentage of a population that is lactose tolerant is not the same everywhere in the world. Recall from section 3.1 that this trait is more common in some areas than others:

In this section, we will be focusing on some of the factors that cause uneven distribution of traits. We will begin by revisiting sickle cell anemia, which is a trait you learned about in section 3.2.

Sickle Cell Anemia
The map below shows the percentage of the population affected by sickle cell anemia on the continent of Africa. What patterns in the distribution of the sickle cell trait can you identify?



Adapted from image by Anthony Alison, https://commons.wikimedia.org/wiki/File:Malaria_versus_sickle-cell_trait_distributions.png, CC0

What would cause a trait like sickle cell anemia to affect over one in five people in some areas, and be almost nonexistent in other areas?

Recall from section 3.2 that a mutation in the DNA causes a change to the hemoglobin protein. This mutation in the DNA can be passed from parent to offspring. Individuals with two copies of the sickle cell allele will have sickle cell anemia. The inheritance pattern of the trait is the same no matter where you are, so what causes the uneven distribution of the sickle cell trait? To answer this question, we need to also consider environmental factors related to the trait.

The shaded areas on the map below indicate areas where malaria is present in Africa:

Adapted from image by Anthony Alison, https://commons.wikimedia.org/wiki/File:Malaria_versus_sickle-cell_trait_distributions.png, CC0

Compare the malaria map to the map showing the distribution of the sickle cell trait. What pattern do you notice?

There is a correlation between the sickle cell trait and malaria. Areas where a higher percentage of the population have sickle cell anemia are also areas where malaria is present. Malaria is a disease caused by a parasite and transmitted by mosquitoes. A person infected with malaria can experience fever, chills, and can even die. It turns out that people with the sickle cell trait are protected against malaria. Normally, the parasite that causes malaria infects red blood cells, but it can't infect the sickle shaped cells. People living in areas where malaria is present have an advantage if they have the sickle cell allele.

In this case, both genetic factors and environmental factors affect the distribution of the trait in question. Why isn't the sickle cell trait present in areas where malaria is not present?

Putting it Together

Image by USFWS, https://www.fws.gov/refuge/willapa/wildlife_and_habitat/clams.html, public domain

Clams, like those pictured above, live along the coasts of the United States. Recently, there have been large growths of algae that release toxins that can harm the clams, but some populations include individuals who are resistant to the toxin. Scientists have found that the distribution of the resistant trait is not uniform. Areas further north have fewer resistant clams, and populations on the east coast tend to have more resistant clams than populations on the west coast.

1. Use what you learned about environmental influences on trait distribution to revise your original explanation about why the resistant trait is not evenly distributed among the clam populations.
2. What additional information about the clam's environment would be helpful in explaining this phenomenon? Describe how this information would be helpful in developing an explanation.
3. What other phenomenon could be explained using these science concepts about genetic and environmental influences on trait distribution?

3.5 Biotechnology (Bio.3.5)

Explore this Phenomenon

Image by Jim Clark, USFWS, https://en.wikipedia.org/wiki/Endangered_species#/media/File:Mexican_Wolf_2_yfb-edit_1.jpg, CC0

The Mexican Wolf is one of many endangered animals.

1. We currently change the DNA of many species; would altering the DNA of an endangered species be a possible solution for helping them recover?
2. What factors should we consider before altering the DNA of other species?

Bio.3.5 Biotechnology

Evaluate **design solutions** where biotechnology was used to identify and/or modify genes in order to solve (effect) a problem. *Define the problem, identify criteria and constraints, analyze available data on proposed solutions, and determine an optimal solution.* Emphasize arguments that focus on how effective the solution was at meeting the desired outcome. (LS3.B, ETS1.A, ETS1.B, ETS1.C)

We have developed many biotechnology solutions to problems related to genes. As you read this chapter, focus on the effects of different biotechnologies on genes.

Biotechnologies can Modify Genes

What is involved in Engineering Design?
Engineering is a creative process where each new version of a design is tested and then modified, based on what has been learned up to that point. This process includes a number of stems:

5. Identifying the problem and defining criteria and constraints.
6. Generating ideas for how to solve the problem. Engineers can use research, brainstorming and collaboration with others to come up with ideas for solutions and designs.
7. Build and then test the prototypes. Using data collected, the engineer can analyze how well the various prototypes meet the given criteria and constraints.
8. Evaluate what is needed to improve the leading design or devise a better one.

Recall from the beginning of this section that the Mexican Wolf is an endangered species. Different biotechnologies could be used to modify the Mexican Wolf's genes in order to help restore the species.

In this section, you will be learning about different biotechnologies used to modify genes. As you learn about each biotechnology, take note about how it is used, the effects of using it, and any questions you have. After learning about the different biotechnologies, evaluate each as a possible solution for restoring the Mexican Wolf population.

Evaluating solutions includes identifying criteria and constraints of the problem. You may also want to determine how a solution could be improved.

In this chapter, you have learned about some disorders caused by mutations in DNA. Scientists are interested in treating disorders caused by mutations in genes. They are also interested in finding ways to modify genes in other organisms to make those organisms more useful or less harmful to people. For example, modifying the genes of plants could lead to crops that produce more food or are drought resistant. In this section, you will be learning about some of the biotechnologies that scientists are using to modify genes. As you learn about each technology, consider problems that the technology could solve, and the various effects that implementing the technology could have.

CRISPR/Cas9
This technology was actually discovered in bacterial cells. Cas9 is an enzyme and CRISPR is a strand of nucleotides. Together, they can cut DNA in specific locations. Bacterial cells use the CRISPR/Cas9 system to cut the DNA of invading viruses. Scientists have adapted the system to edit DNA. We can now use CRISPR/Cas9 to turn off genes, change the sequence of bases in a gene, and even to increase the amount of proteins made from a specific gene.

Watch this video to see how CRISPR/Cas9 is used to edit DNA:
https://www.youtube.com/watch?v=UKbrwPL3wXE.

The use of CRISPR/Cas9 has been controversial in some cases. Questions remain about what problems CRISPR/Cas9 should be used to address, and which species it should be used on.

Genetically Modified Organisms
Any organism that has had its DNA modified can be considered a Genetically Modified Organism, or GMO. For years, we have been able to modify the genes of plants to make them resistant to disease, insects, drought, herbicides, or have other traits that can increase the amount of food we grow.

Gene Drive
Recently, scientists have been able to add something called a “gene drive” to genetically modified organisms. The gene drive ensures that a particular allele will be passed on to the offspring. Recall from section 3.2 that during meiosis, homologous chromosomes are separated and only one chromosome is passed to the offspring. If the homologous chromosomes contain different alleles, there is a 50% chance of each allele being passed on to the next generation. With the gene drive technology, only one of the alleles will be passed on. This ensures that a particular allele will spread through the population.

Using CRISPR/Cas9 and a gene drive together would allow humans to change the traits in other species. This type of system has been proposed as a solution to stop the spread of malaria. Normally, mosquitoes spread malaria; however, scientists have been able to use CRISPR/Cas9 to insert a gene into mosquitoes that makes them reject the parasite so that they can't spread it. If mosquitoes with this gene and a gene drive were released into the wild, it would ensure that they would pass on the malaria-resistant gene, and this gene would spread through the population. There are many concerns about changing the DNA of other species this way. Getting rid of malaria would be good, but what are some other possible consequences of introducing these genetically-altered mosquitoes into the wild?

Putting It Together

Image by Jim Clark, USFWS, https://en.wikipedia.org/wiki/Endangered_species#/media/File:Mexican_Wolf_2_yfb-edit_1.jpg, CC0

The Mexican Wolf is one of many endangered animals.

1. Now that you know about a few different technologies we use to modify genes in other organisms, how have your ideas about altering the DNA of endangered species as a solution for helping them recover changed?
2. What factors should we consider before altering the DNA of other species?
3. What type of problems would it be appropriate to use biotechnologies to alter DNA to solve, and what type of problems would it be inappropriate to use biotechnologies to alter DNA to solve? Explain your criteria for using DNA alteration to solve a problem.

CHAPTER 4

Strand 4: Evolutionary Change

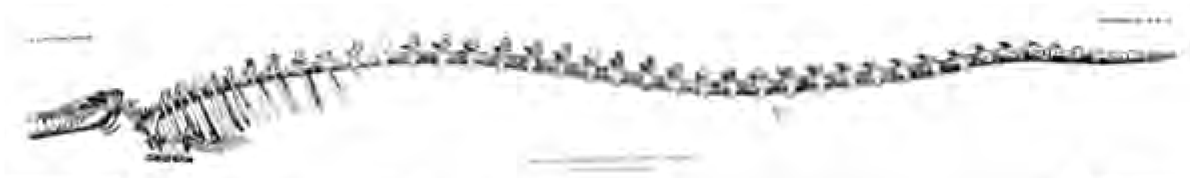
Chapter Outline

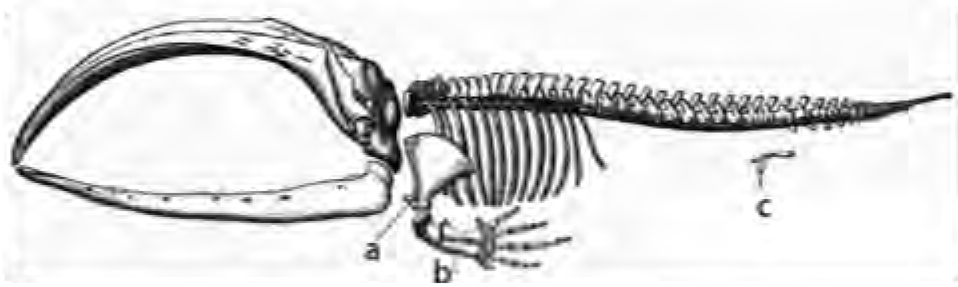
Image from PublicDomainPictures, pixabay.com, CC0

The unity among species, as evidenced in the fossil record, similarities in DNA and other biomolecules, anatomical structures, and embryonic development, is the result of evolution. Evolution also explains the diversity within and among species. Evolution by natural selection is the result of environmental factors selecting for and against genetic traits. Traits that allow an individual to survive and reproduce are likely to increase in the next generation, causing the proportions of specific traits to change within a population. Over longer periods of time, changes in proportions of traits due to natural selection and changes in selective pressures can cause both speciation and extinction. Changes in environmental conditions impact biodiversity in ecosystems and affect the natural selection of species.

4.1 Evidence of Evolution (Bio.4.1)

Explore this Phenomenon





(Top) Image by James William Gidley, https://commons.wikimedia.org/wiki/File:Gidley-1913-Basilosaurus-skeleton-reconstruction.JPEG, public domain
(Bottom) Image by Meyers Konversionlexikon, https://commons.wikimedia.org/wiki/File:Whale_skeleton.png, public domain

The top image is of a fossil of an animal named Basilosaurus that lived approximately 41.3 to 33.9 million years ago. The bottom image is the skeleton of a modern whale.

1. What evidence would be required to establish that the Basilosaurus is the ancestor of modern whales? Explain why each piece of evidence could be used to establish the relationship between Basilosaurus and modern whales.
2. What are three questions we could investigate to determine the relationship between Basilosaurus and modern whales?

Bio.4.1 Support of Evolution

Obtain, evaluate, and communicate information to identify the patterns in the evidence that support biological evolution. Examples of evidence could include DNA sequences, amino acid sequences, anatomical structures, the fossil record, or order of appearance of structures during embryological development. (LS4.A)

Biological evolution is supported by many different lines of evidence. As you read this chapter, look for patterns in the evidences that support evolution.

Evidence From Living Species

Image by Stuart Rankin, *https://flic.kr/p/Spg4un, CC-BY-NC*

If you look closely at a skeleton, you might notice a triangular bone at the end of the spinal column. This is your tailbone. Why would you have a tailbone when you don't have a tail? You have a tailbone because your ancient ancestors *did* have a tail. These sorts of "left-over" structures support the theory of evolution.

Just as Darwin did many years ago, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

Structural Evidence

Even though two different species may not look similar, they may have similar internal structures that suggest they have a common ancestor. That means both evolved from the same ancestor organism a long time ago. Common ancestry can also be determined by looking at the structure of the organism as it first develops.

Vestigial Structures

Some of the most interesting kinds of evidence for evolution are body parts that have lost their use through evolution. For example, most birds need their wings to fly. But the wings of an ostrich have lost their original use. Structures that have lost their use through evolution are called vestigial structures. They provide evidence for evolution because they suggest that an organism changed from using the structure to not using the structure, or using it for a different purpose.

Penguins do not use their wings, known as flippers, to fly in the air. However, they do use them to move in the water. The theory of evolution by natural selection suggests that penguins evolved to use their wings for a different purpose. A whale's pelvic bones, which were once attached to legs, are also vestigial structures. Whales are descended from land-dwelling ancestors that had legs.

Moles live underground where they do not need eyes to find their way around. This mole's eyes are covered by skin. Body parts that do not serve their original function are vestigial structures.

Comparative embryology

Some of the oldest evidence of evolution comes from embryology, the study of how organisms develop. An embryo is an animal or plant in its earliest stages of development. This means looking at a plant or animal before it is born or hatched. Centuries ago, people recognized that the embryos of many different species have similar appearances. The embryos of some species are even difficult to tell apart. Many of these animals do not differ much in appearance until they develop further.

Some unexpected traits can appear in animal embryos. For example, human embryos have gill slits just like fish! In fish they develop into gills, but in humans they disappear before birth. The presence of the gill slits suggests that a long time ago humans and fish shared a common ancestor.

The similarities between embryos suggests that these animals are related and have common ancestors. For example, humans did not evolve from chimpanzees. But the similarities between the embryos of both species suggest that we have an ancestor in common with chimpanzees. As our common ancestor evolved, humans and chimpanzees went down different evolutionary paths and developed different traits.

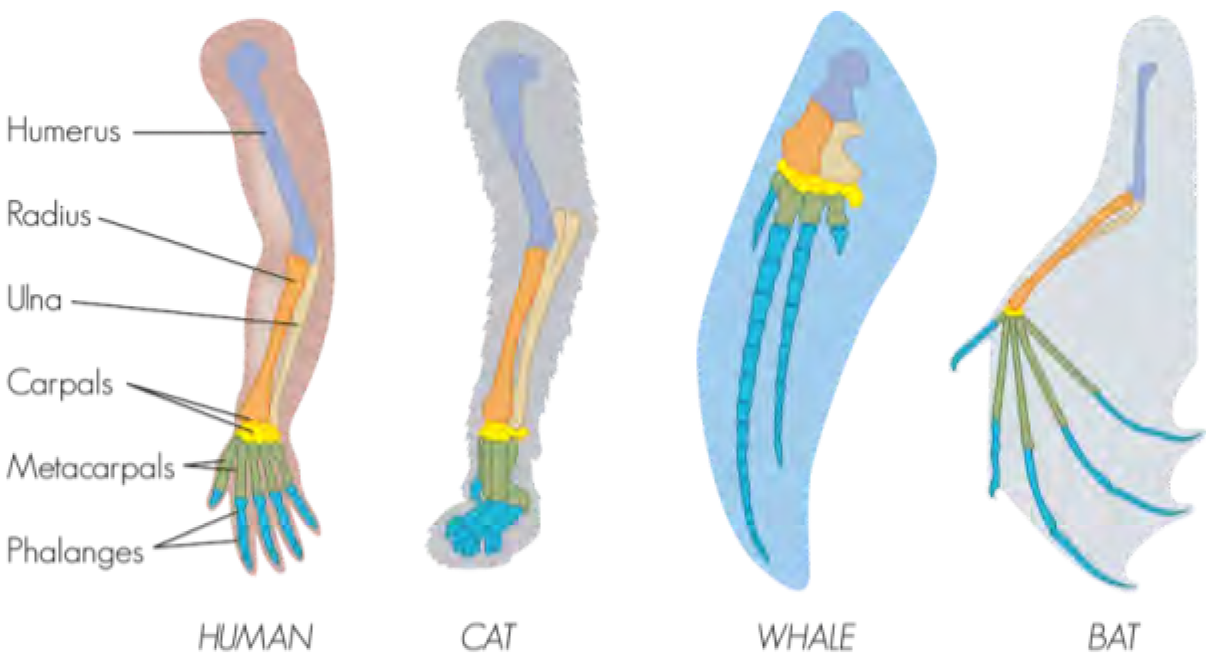
Image by Peter Miller, https://flic.kr/p/eH7aZN, CC-BY-NC-ND

Comparative Anatomy

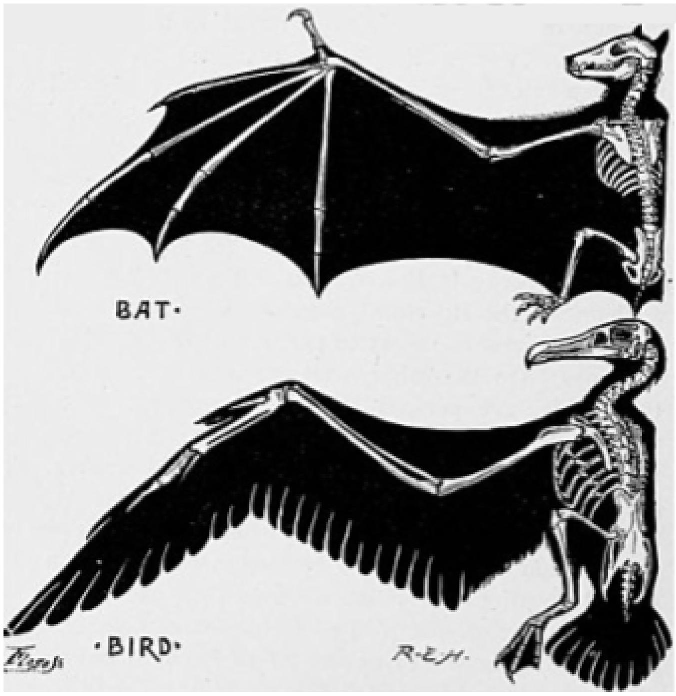
Take a close look at this gorilla hand. The similarities to a human hand are remarkable. Comparing anatomy, and characterizing similarities and differences, provides evidence of evolution.

Comparative anatomy is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

Homologous structures are structures that have a common function and suggest common ancestry. For example, homologous structures include the limbs of mammals, such as bats, lions, whales, and humans, which all have a common ancestor. Different mammals may use their limbs for walking, running, swimming or flying. The method the mammal uses to move is considered a common function. The diagram shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.



The forelimbs of all mammals have the same basic bone structure.
Image by Christopher Auyeung, CK-12 Foundation, CC-BY-NC 3.0



Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.
Image by John Romanes, public domain

Analogous structures are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

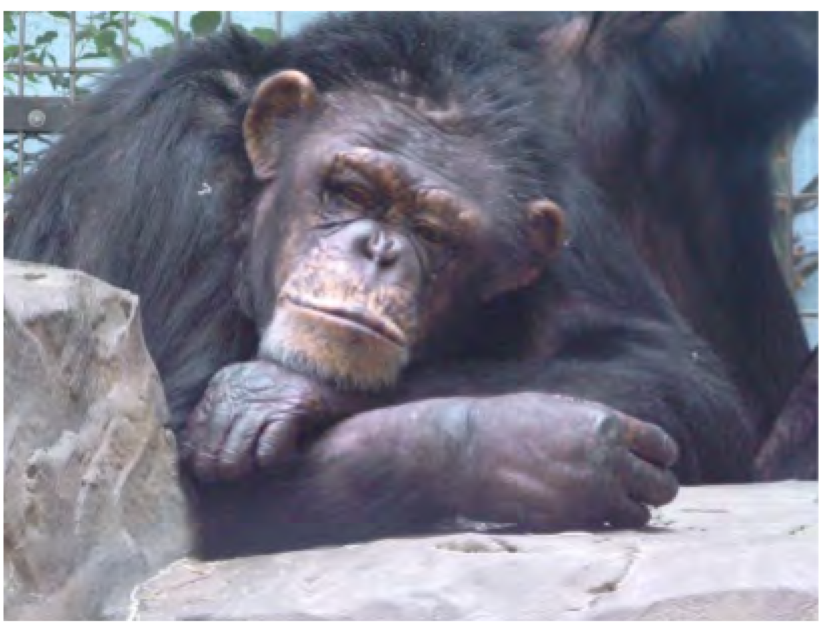


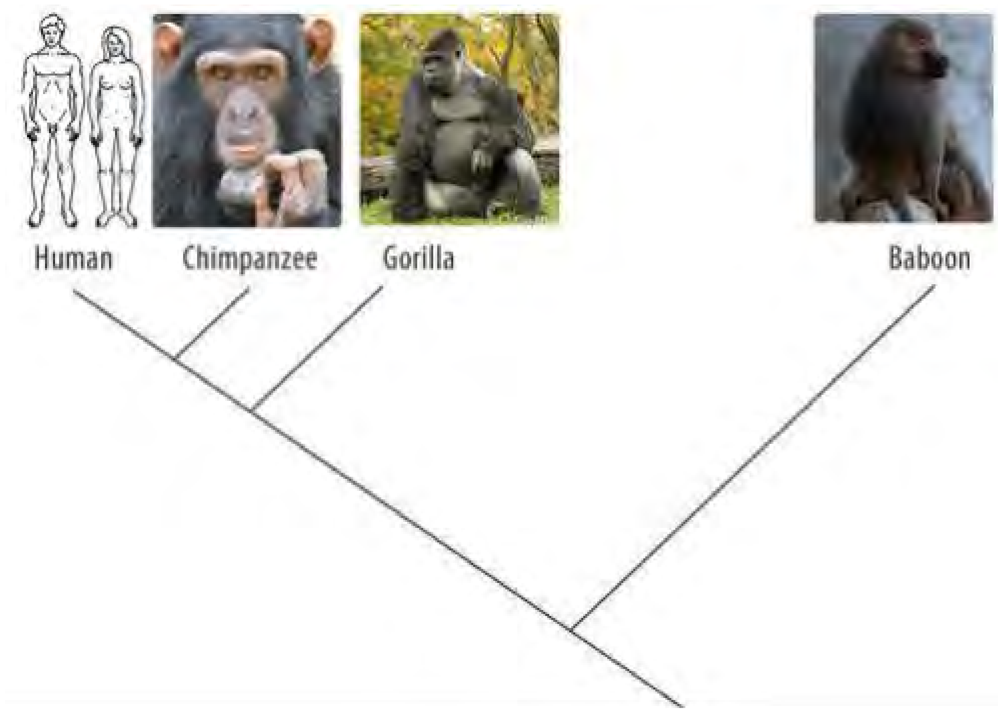
Image by Chippy, https://flic.kr/p/k8YR7, CC-BY-NC-ND

Molecular Evidence for Evolution

Chimpanzees and humans turn out to be very similar—if you look at their DNA. When scientists determined the entire genetic code of both humans and chimpanzees, they found that we have over 98% identical DNA.

Arguably, some of the best evidence of evolution comes from examining the molecules and DNA found in all living things.

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. More similarities in the DNA sequence is evidence for a closer evolutionary relationship. The diagram below shows how humans and apes are related based on their DNA sequences.



Human: MrKimm, http://commons.wikimedia.org/wiki/File:Human-gender-neutral.png, public domain
Chimpanzee: Afrika Force, http://www.flickr.com/photos/afrikaforce/5187391191, CC-BY 2.0
Gorilla: Roger Luijten, http://www.flickr.com/photos/66555186@N02/6312198231, CC-BY 2.0
Baboon: Birdseye Maple, http://www.flickr.com/photos/26198976@N04/4007297452, CC-BY 2.0

Beginning in the 1940s, scientists studying molecules and DNA have confirmed conclusions about evolution drawn from other forms of evidence. Molecular clocks are used to determine how closely two species are related by calculating the number of differences between the species' DNA sequences or amino acid sequences. These clocks are sometimes called gene clocks or evolutionary clocks. The fewer the differences, the less time since the species split from each other and began to evolve into different species.

A chicken and a gorilla will have more differences between their DNA and amino acid sequences than a gorilla and an orangutan. That means the chicken and gorilla had a common ancestor a very long time ago, while the gorilla and orangutan shared a more recent common ancestor. This provides additional evidence that the gorilla and orangutan are more closely related than the gorilla and the chicken. Which pair of organisms would have more molecular differences, a mammal and a bird, a mammal and a frog, or a mammal and a fish?

On the other hand, animals may look similar but can have very different DNA sequences and evolutionary ancestry. Which would have more DNA sequences in common, a whale and a horse, or a whale and a shark?

The genomes, or all the DNA sequences of all the genes of an organism, have been determined for many different organisms. The comparison of genomes provides new information about the relationships among species and how evolution occurs.

Molecules besides DNA provide evidence for evolution. The same biochemical building blocks, such as amino acids and nucleotides, are found in all organisms, from bacteria to plants and animals. Recall that amino acids are the building blocks of proteins, and nucleotides are the building blocks of DNA and RNA. Also, DNA and RNA determine the development of all organisms. We can use the patterns in both molecules and anatomy to determine the evolutionary relationships among species.

Evidence from Fossils

This rock contains a fossilized fern. Scientists study fossils of plants, animals, and other organisms in order to better understand what life was like on Earth many years ago and how it has changed over time. Fossils are important evidence for the theory of evolution by natural selection.

Image by James St. John, https://flic.kr/p/2fFQxAv, CC-BY

Fossils are the preserved remains of animals, plants, and other organisms from the distant past. Examples of fossils include bones, teeth, and impressions. By studying fossils, evidence for evolution is revealed. Paleontologists are scientists who study fossils to learn about life in the past. Fossils allow these scientists to determine the features of extinct species. Paleontologists compare the features of species from different periods in history. With this information, they try to understand how species have evolved over millions of years.

The image next shows how the fossil record has informed our understanding of how horses evolved.

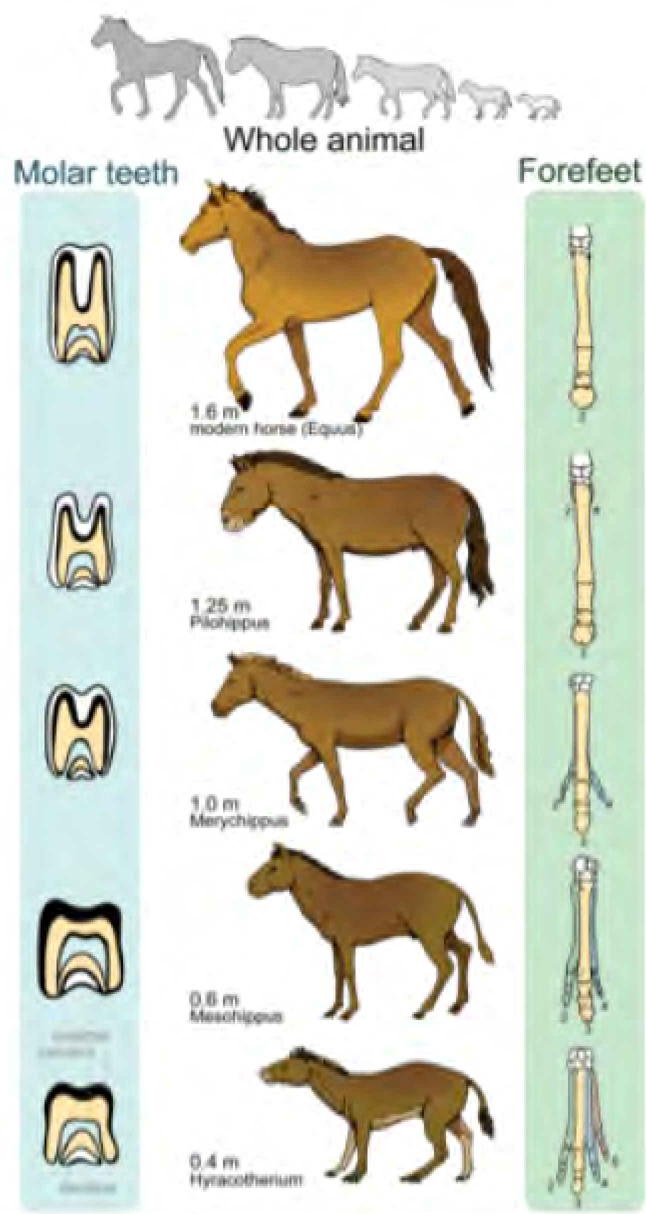


Image by LadyofHats, CK-12 Foundation, CC BY-NC 3.0

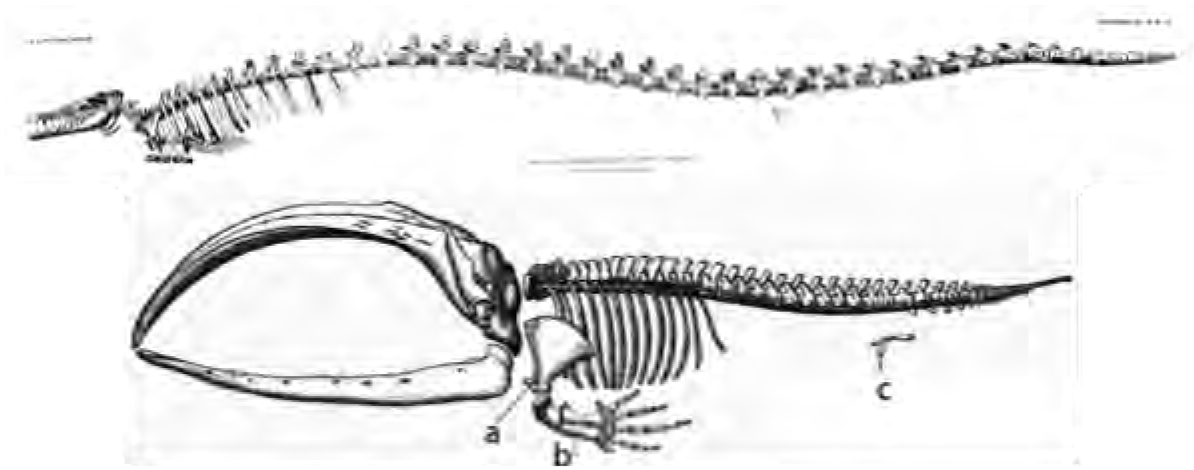
Until recently, fossils were a main source of evidence for evolution. Through studying fossils, we now know that today's organisms look much different in many cases than those that were alive in the past. Scientists have also shown that organisms were spread out differently across the planet. Earthquakes, volcanoes, shifting seas, and other movements of the continents have all affected where organisms live and how they adapted to their changing environments.

Rock Layers and the Age of Fossils

There are many layers of rock in the Earth's surface. Newer layers form on top of the older layers; the deepest rock layers are the oldest. Therefore, you can tell how old a fossil is by observing in which layer of rock it was found. The fossils and the order in which fossils appear is called the fossil record. The fossil record provides evidence for when organisms lived on Earth, how species evolved, and how some species have gone extinct. Geologists use a method called radiometric dating to determine the exact age of rocks and fossils in each layer of rock. This technique, which is possible because radioactive materials decay at a known rate, measures how much of the radioactive materials in each rock layer have broken down.

We can use the patterns from multiple lines of evidence when determining evolutionary relationships. When evidence from biological molecules, the fossil record, anatomy, and development of embryos all suggest the same evolutionary relationships, we can be more certain about how species are related.

Putting It Together



(Top) Image by James William Gidley, https://commons.wikimedia.org/wiki/File:Gidley-1913-Basilosaurus-skeleton-reconstruction.JPEG, public domain
(Bottom) Image by Meyers Konversionlexikon, https://commons.wikimedia.org/wiki/File:Whale_skeleton.png, public domain

The top image is of a fossil of an animal named Basilosaurus that lived approximately 41.3 to 33.9 million years ago. The bottom image is the skeleton of a modern whale.

1. What evidence could we use to establish the relationship between Basilosaurus and modern whales?
2. How could information from all the different types of whales that exist today help establish their relationship to Basilosaurus? What information could we gather to establish these relationships?

4.2 Natural Selection (Bio.4.2)

Explore this Phenomenon

Collage by Kiwi Rex, https://commons.wikimedia.org/wiki/File:Darwin%27s_finches.png, *CC-BY-SA*

The finches pictured all have beaks of different sizes and shapes.

1. Create an explanation of what caused the finches to all have different beaks.
2. What are three questions we could investigate to understand what caused the finches to have different beaks?

Bio.4.2 Natural Selection

Construct an explanation based on evidence that natural selection is a primary cause of evolution. Emphasize that natural selection is primarily <u>caused</u> by the potential for a species to increase in number, the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, competition for limited resources, and the proliferation of those organisms that are better able to survive and reproduce in the environment. (LS2.D, LS4.B, LS4.C)

In this chapter, you will be learning about natural selection, which causes evolution. As you read, identify four factors that cause natural selection.

Natural Selection

Image by USFWS, https://flic.kr/p/aNW87t, CC-BY

Notice how this deer mouse's dark coloring would allow it to easily hide from predators on the darkened forest floor. On the other hand, deer mice that live in the nearby Sand Hills are a lighter, sand-like color. What caused the deer mice to be so well adapted to their unique environments?

Natural Selection

The theory of evolution by natural selection means that the inherited traits of a population change over time. Inherited traits are features that are passed from one generation to the next. Use sections 3.1 and 3.2 to review inherited traits.

Natural selection explains how organisms in a population develop traits that allow them to survive and reproduce. Natural selection means that traits that offer an advantage will most likely be passed on to offspring; individuals with those traits have a better chance of surviving. Evolution occurs by natural selection.

Take the giant tortoises on the Galápagos Islands as an example. If a short-necked tortoise lives on an island with fruit located at a high level, will the short-necked tortoise survive? No, it will not, because it will not be able to reach the food it needs to survive. If all of the short necked tortoises die, and the long-necked tortoises survive, then, over time, only the long-necked trait will be passed down to offspring. All of the tortoises with long-necks will be "naturally selected" to survive. Organisms that are not well-adapted, for whatever reason, to their environment, will naturally have less of a chance of surviving and reproducing.

Every plant and animal depends on its traits to survive. Survival may include getting food, building homes, and attracting mates. Traits that allow a plant, animal, or other organism to survive and reproduce in its environment are called adaptations.

Natural selection occurs when:

1. There is some variation in the inherited traits of organisms within a species. Without this variation, natural selection would not be possible.
2. Some of these traits will give individuals an advantage over others in surviving and reproducing.
3. There is a limited amount of resources in the environment so organisms must compete for available resources.
4. These individuals whose traits give them a competitive advantage will be likely to have more offspring.

Variation and Adaptation

There are variations in the traits of a population. For example, there are lots of variations in the color of human hair. Hair can be blonde, brown, black, or even red. Hair color is a trait determined by genes.

At some time in the past, a variation probably came from a mutation. A mutation is a random change in an organism's genes. Mutations are natural. Some are harmful, but many are neutral. Some may even be beneficial. If a mutation is harmful, the organism may not live to reproduce. If the mutation is beneficial, that organism may have a better chance to survive. An organism that survives is likely to have offspring. If it does, it may pass the mutation on to its offspring. The offspring may be more likely to survive.

Imagine how in the Arctic, dark fur makes a rabbit easy for foxes to spot and catch in the snow. Therefore, white fur is a beneficial trait that improves the chance that a rabbit will survive, reproduce, and pass the trait of white fur on to its offspring. Through this process of natural selection, dark fur rabbits will become uncommon over time. Rabbits will adapt to have white fur. In essence, the selection of rabbits with white fur - the beneficial trait - is a natural process.

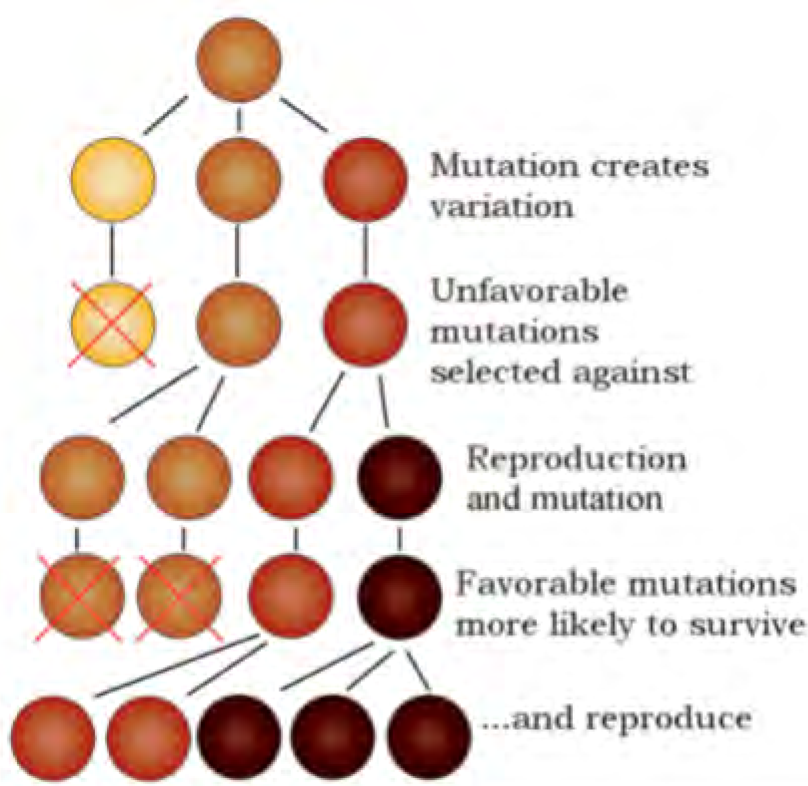


Image by Hana Zavadska and Christopher Auyeung, CK-12 Foundation, CC-BY-NC 3.0

Image by USFWS, https://commons.wikimedia.org/wiki/File:Arctic_Hare.jpg, public domain

The white fur of the Arctic hares may make it more difficult for foxes and other predators to locate hares against the white snow.

Evolution happens because of natural selection. Traits that provide an advantage in the environment become more common in a population. Traits that cause a disadvantage in the environment become less common in a population. We can see how evolution by natural selection has affected the deer mice in Nebraska. This mouse is typically brown, but in places where glaciers dropped lighter sand over the darker soil, the mice are light. Why? Because predators could more easily spot the dark mice on light sand. The lighter mice were more likely to survive and have offspring. Natural selection favored the light mice. Over time, the population became light colored. Enough changes may take place over time that the two types of mice become different species.

Putting It Together

Collage by Kiwi Rex, https://commons.wikimedia.org/wiki/File:Darwin%27s_finches.png, *CC-BY-SA*

The finches pictured all have beaks of different sizes and shapes.

1. Use the principles of natural selection to revise your explanation of what caused the finches to have different beaks.
2. What other phenomena could be explained using the same science concepts you used to explain what caused the finches' beaks to be different?

4.3 Advantageous Heritable Traits (Bio.4.3)

Explore this Phenomenon

Image by Roos Rojas, pixabay.com, CC0

Male crickets chirp by rubbing their wings together to attract mates. Some male crickets have wings that are shaped differently, so they cannot chirp. On the island of Kauai, almost all of the male crickets are silent. In less than 20 generations, this trait spread from almost no males having the silent trait to over 90% of the population having the silent trait.

1. Propose an explanation for the increase of the proportion of crickets having the silent trait.
2. What are three questions we could investigate to understand how this trait spread through the population?

Bio.4.3 Survival

Analyze and interpret data to identify patterns that explain the claim that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. Emphasize analyzing shifts in the numerical distribution of traits and using these shifts as evidence to support explanations. (LS4.B, LS4.C)

The proportions of traits in a population can change. As you read this chapter, look for evidence and patterns that show why the proportion of some traits increases while the proportion of other traits decreases.

Advantageous Traits

In chapter 3, you learned how traits are passed from parent to offspring. As natural selection operates on a population, some traits are more likely to be passed on than others. If one trait provides an advantage in a particular environment, it may be selected for. The trait will spread through the population as it is passed from parent to offspring, and eventually the proportion of individuals with the trait will increase.

Some examples of traits, or adaptations that help organisms survive include:

1. Camouflage: An organism that blends with its background is more likely to avoid predators. If it survives, it is more likely to have offspring. Those offspring are more likely to blend into their backgrounds and to have more offspring. Eventually the organisms with the advantageous trait will increase in proportion to the numbers of organisms with less advantageous traits.
2. Water retention: Cacti have thick, water-retaining bodies that help them conserve water in the desert. Individuals who are able to conserve water are able to live longer and have the possibility of having more offspring, who will also be able to conserve water.
3. Gathering food: Reindeer have sponge-like hooves that help them walk on snowy ground without slipping and falling, which helps them move and gather food. The individuals who are able to get away from predators and get to the most food have a better chance of surviving and reproducing, so they are more likely to pass their traits to the next generation. Eventually, the sponge-like hoof trait spreads through the population.

How Adaptations Develop
Adaptations develop this way. Think about a population of oak trees. Imagine that a fungus has arrived from Asia to North America. Most of the North American oak trees are killed by the fungus. But a few oak trees have a mutation that allows them to survive the fungus. Those oak trees are better adapted to the new environment than the others. Those trees have a better chance of surviving. They will probably reproduce. The trees may pass on the favorable mutation to their offspring. The other trees will die. Eventually, the population of oak trees will change. Most of the trees will have the trait to survive the fungus. This is an adaptation. Over time, traits that help an organism survive become more common. Traits that hinder survival eventually disappear.

Types of Natural Selection
Natural selection can change the proportion of individuals in a population who have a particular trait. Three ways that natural selection can affect phenotypes.

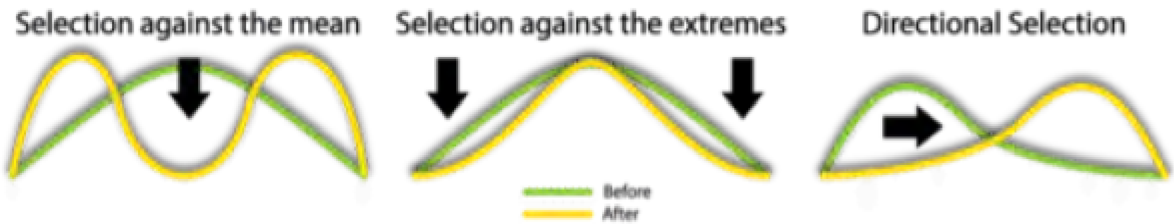


Image by Zachary Wilson, CK-12 Foundation, CC-BY-NC 3.0

1. Stabilizing selection occurs when phenotypes at both extremes of the phenotypic distribution are selected against. This narrows the range of variation. An example is human birth weight. Babies that are very large or very small at birth are less likely to survive. This keeps birth weight within a relatively narrow range.
2. Directional selection occurs when one of two extreme phenotypes is selected for. This shifts the distribution toward that extreme. This type of natural selection has been observed in the beak size of Galápagos finches.
3. Disruptive selection occurs when phenotypes in the middle of the range are selected against. This results in two overlapping phenotypes, one at each end of the distribution. An example is sexual dimorphism. This refers to differences between the phenotypes of males and females of the same species. In humans, for example, males and females have different heights and body shapes.

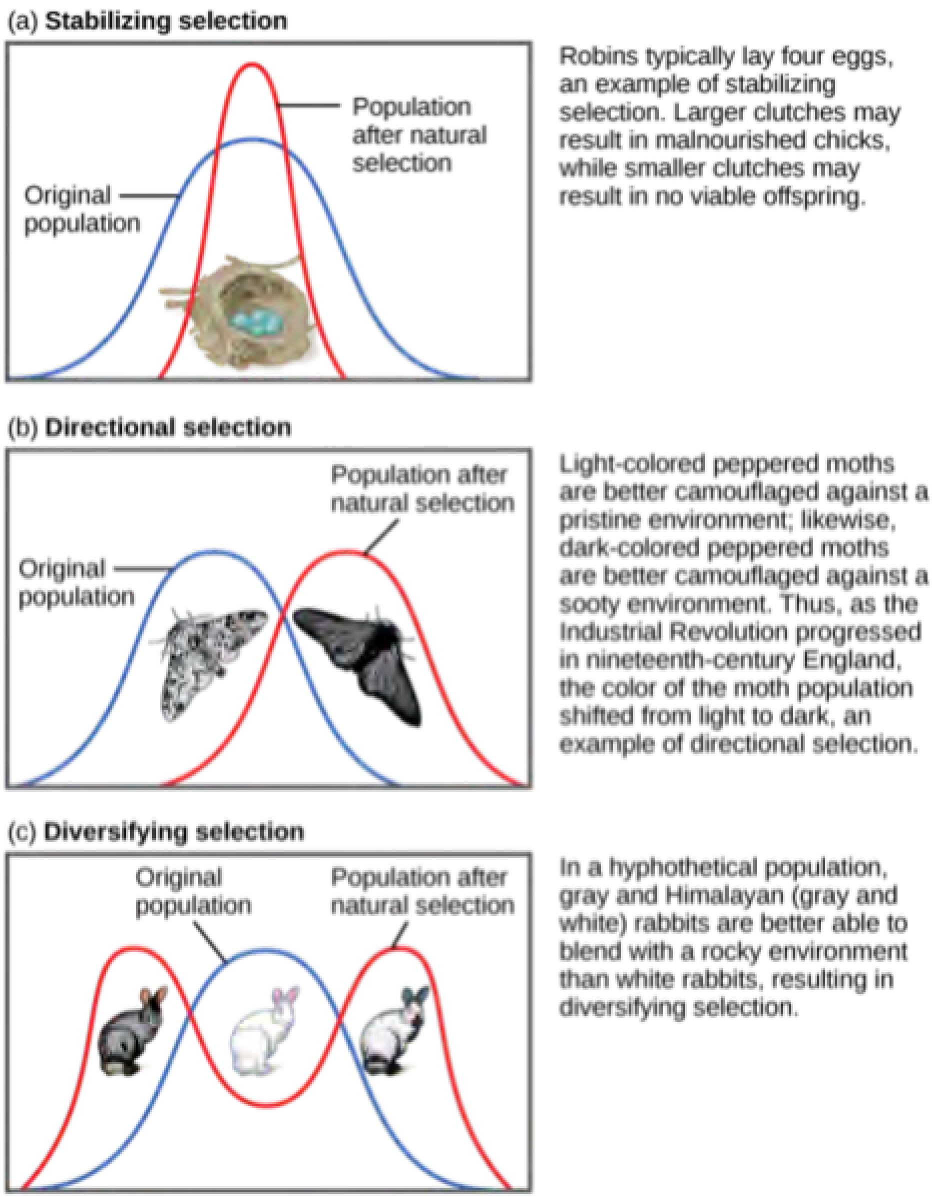


Image by CNX OpenStax, https://commons.wikimedia.org/wiki/File:Figure_19_03_01.png, CC-BY

Putting It Together

Image by Roos Rojas, pixabay.com, CC0

Male crickets chirp by rubbing their wings together to attract mates. Some male crickets have wings that are shaped differently, so they cannot chirp. On the island of Kauai, almost all of the male crickets are silent. In less than 20 generations, this trait spread from almost no males having the silent trait to over 90% of the population having the silent trait.

1. Use what you have learned to revise your explanation for the increase of the proportion of crickets having the silent trait. What additional information can you add to your original explanation?
2. What other phenomenon can you explain using your understanding of how natural selection can affect the proportion of individuals with a particular trait?

4.4 Emergence and Decline of Species (Bio.4.4)

Explore this Phenomenon

Image by USFWS, https://www.fws.gov/lodi/aquatic_invasive_species/quagga_and_zebra_mussels.htm, public domain

Zebra mussels, like those pictured, are showing up in places they are not native to. When zebra mussels are transported to a new location, their population tends to grow rapidly.

1. Use what you have learned about natural selection to propose an explanation for why the zebra mussel populations would grow rapidly in a new environment.
2. Use what you have learned about natural selection to predict how the rapid growth of a newly-introduced population of zebra mussels will affect the other species in the ecosystem.
3. What are three questions we could investigate to understand what causes the zebra mussel population to grow?

Bio.4.4

Engage in argument from evidence that changes in environmental conditions may cause increases in the number of individuals of some species, the emergence of new species over time, and/or the extinction of other species. Emphasize the cause and effect relationships for how changes and the rate of change to the environment affect distribution or disappearance of traits in a species. Examples of changes in environmental conditions could include deforestation, application of fertilizers, drought, or flood. (LS4.C)

Changes to the environment affect populations. As you read this chapter, look for evidence of how and why environmental changes have affected species. Pay special attention to how the rate of the environmental change affects the species.

Speciation

Image by Thajsko, https://commons.wikimedia.org/wiki/File:Huka_falls_-_panoramio.jpg, *CC-BY*

Imagine a group of small organisms, such as mice, that become separated by a mighty river. This group has now become isolated, and formed two separate groups. The groups are obviously no longer able to breed together. Over many generations, each group will evolve separately, eventually forming two completely new species of mice.

Evolution is change in organisms over time. If enough changes occur, a new species can evolve. The process by which a new species evolves is called speciation. How does speciation occur? How does one species evolve into two or more new species?

To understand how a new species forms, it's important to review what a species is.One way to define a species is as a group of organisms that can breed and produce fertile offspring together in nature. For a new species to arise, some members of a species must become reproductively isolated from the rest of the species. This means they can no longer interbreed with other members of the species. How does this happen? One way is that they become geographically isolated first.

Assume that some members of a species become geographically separated from the rest of the species. If they remain separated long enough, they may evolve genetic differences. If the differences prevent them from interbreeding with members of the original species, they have evolved into a new species.

(Left) Allyson Mathis/National Park Service, https://flic.kr/p/apkL9G, public domain
(Center) NASA, http://commons.wikimedia.org/wiki/File:Grand_Canyon_autumn_STS61A-48-91.jpg, public domain
(Right) Sally King/National Park Service, http://bandelier.areaparks.com/parkinfo.html?pid=1789, public domain
Composite created by CK-12 Foundation

Speciation in the Kaibab Squirrel. The Kaibab squirrel is in the process of becoming a new species.

Another way new species arises is without geographic separation. The following example shows one way this can occur.

1. Hawthorn flies lay eggs in hawthorn trees. The eggs hatch into larvae that feed on hawthorn fruits. Both the flies and trees are native to the U.S.

2. Apple trees were introduced to the U.S. and often grow near hawthorn trees. Some hawthorn flies started to lay eggs in nearby apple trees. When the eggs hatched, the larvae fed on apples.
3. Over time, the two fly populations—those that fed on hawthorn trees and those that preferred apple trees—evolved reproductive isolation. Now they are reproductively isolated because they breed at different times. Their breeding season matches the season when the apple or hawthorn fruits mature.
4. Because they rarely interbreed, the two populations of flies are evolving other genetic differences. They appear to be in the process of becoming separate species.

One group of hawthorn flies continues to lay eggs in hawthorn trees.

The other group lays eggs in apple trees.

The two groups now rarely interbreed.

(Top left) Hawthorn berries by Steph and Teddy Gravell, https://flic.kr/p/8y15hj, CC-BY-ND
(Top right) Apples by Jennifer C., https://flic.kr/p/cKFwL3, CC-BY
(Bottom) Hawthorn fly by Joseph Berger, http://www.invasive.org/browse/detail.cfm?imgnum=5402798, CC BY

Sympatric Speciation in Hawthorn Flies.
Hawthorn flies are diverging from one species into two. As this example shows, behaviors as well as physical traits may evolve and lead to speciation.

Extinction
Most of the species that have lived have also gone extinct. Extinction is a normal part of Earth's history.

Sometimes large numbers of species go extinct in a short amount of time. This is a mass extinction. The causes of different mass extinctions are different: collisions with comets or asteroids, massive volcanic eruptions, or rapidly changing climate are all possible causes of some of these disasters.

Over 99 percent of all species that ever lived on Earth have gone extinct. Five mass extinctions are recorded in the fossil record. They were caused by major geologic and climatic events. Evidence shows that a sixth mass extinction is occurring now. Unlike previous mass extinctions, the sixth extinction is due to human actions.

One example of extinction is happening now. Around the world, frogs are declining at an alarming rate due to threats like pollution, disease, and climate change. Frogs bridge the gap between water and land habitats, making them the first indicators of ecosystem changes. If the environment changes and there are no individuals with traits suitable to the new conditions, the species may not survive.

Humans can change environments, causing other species to go extinct. One example of human impacts is the introduction of new species. Scoop a handful of critters out of the San Francisco Bay and you'll find many organisms from far away shores. Invasive kinds of mussels, fish, and more are choking out native species.

Putting It Together

Image by USFWS, https://www.fws.gov/lodi/aquatic_invasive_species/quagga_and_zebra_mussels.htm, public domain

Zebra mussels, like those pictured, are showing up in places they are not native to. When zebra mussels are transported to a new location, their population tends to grow rapidly.

1. Use what you learned in the section to revise your original explanation, and predict how the zebra mussel populations will change in the future.
2. Develop a model to show what would have to happen for speciation of the zebra mussels to occur.

4.5 Design Solutions for Real-World Problems (Bio 4.5)

Explore this Phenomenon

Image by Dr Graham Beards, https://en.wikipedia.org/wiki/Antimicrobial_resistance#/media/File:Antibiotic_sensitvity_and_resistance.JPG, CC-BY-SA 4.0

Some of the bacteria in these Petri dishes are resistant to antibiotics. The white circles contain antibiotics. The disks with clear space around them are effective, and bacteria can't grow in their presence. The bacteria on the right are resistant to three of the antibiotics, as seen by the fact that the bacteria are growing next to three of the white disks.

1. Use what you have learned about natural selection to explain how the bacteria become resistant to antibiotics.
2. If we can't use antibiotics to kill bacteria, it will be hard to treat bacterial infections. What are some possible solutions to this problem?

Bio.4.5 Human Impacts

Evaluate **design solutions** that can best solve a real-world problem caused by natural selection and adaptation of populations. *Define the problem, identify criteria and constraints, analyze available data on proposed solutions, and determine an optimal solution.* Examples of real-world problems could include bacterial resistance to drugs, plant resistance to herbicides, or the effect of changes in climate on food sources and pollinators. (LS4.C, ETS1.A, ETS1.B, ETS1.C)

Human impacts on natural selection have caused various problems. As you read this chapter, think about solutions that could be used to mitigate effects of problems caused by natural selection.

Human Impacts on Natural Selection

What is involved in Engineering Design?

Engineering is a creative process where each new version of a design is tested and then modified, based on what has been learned up to that point. This process includes a number of stems:

9. Identifying the problem and defining criteria and constraints.
10. Generating ideas for how to solve the problem. Engineers can use research, brainstorming and collaboration with others to come up with ideas for solutions and designs.
11. Build and then test the prototypes. Using data collected, the engineer can analyze how well the various prototypes meet the given criteria and constraints.
12. Evaluate what is needed to improve the leading design or devise a better one.

Recall from the beginning of this section that some bacteria have become resistant to the drugs we depend on to kill them. This means that we are no longer able to treat some bacterial infections with drugs. In this section, you will be learning what caused this problem and a few things we can do to keep it from getting worse. After you read this section, evaluate the solutions proposed. Identify constraints and criteria, and determine which solutions will be most effective.

Human activities affect the natural selection of other species. Sometimes, the way we impact natural selection causes problems. As you read about some of the possible solutions to problems we have created, evaluate the solutions to determine which could be used to solve each problem.

Bacterial Resistance to Drugs

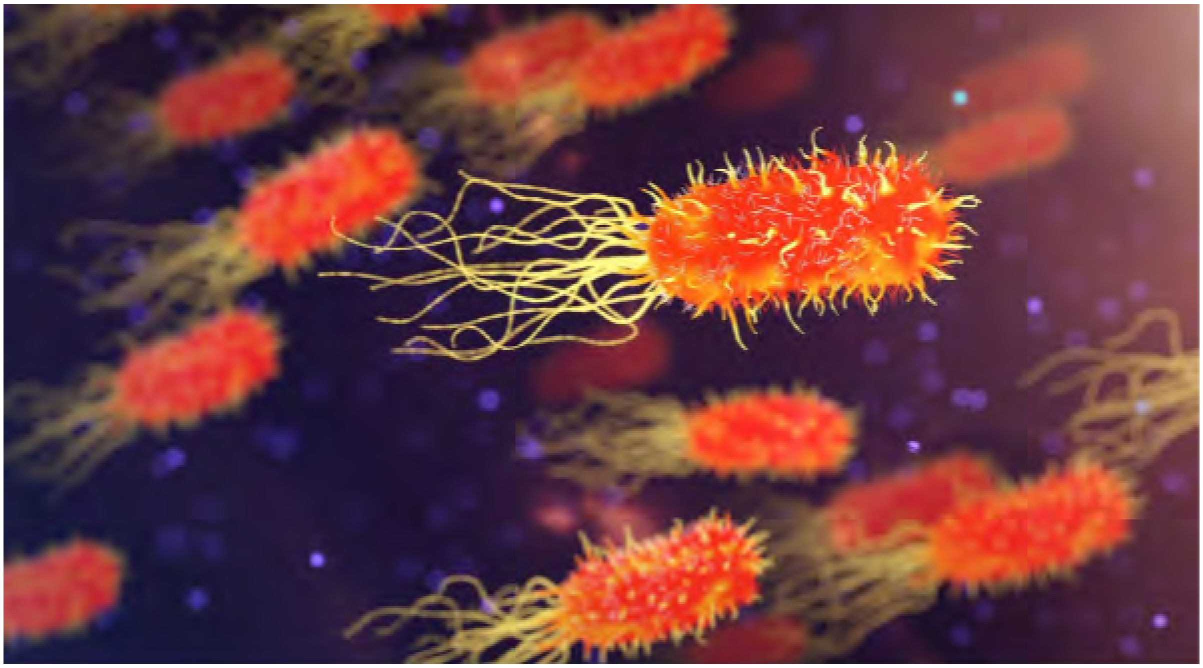


Image by Arek Socha (qimono), pixabay.com, CC0

A "superbug" is not a bug at all. It is a type of bacteria or other microorganism that no longer responds to treatment. These microorganisms are called "resistant" because they resist the effects of the drugs that were used to kill them in the past.

Microorganisms that do not respond to treatment are called "resistant." The evolution of resistance is a growing problem for many disease-causing bacteria and also for parasites, viruses, fungi, and cancer cells. The "miracle" of drug treatment which appeared to protect humans from disease may be short-lived. How does resistance happen? How can we prevent it?

Bacteria reproduce much more rapidly than humans, and therefore can evolve much more rapidly. Consider a population of bacteria infecting an individual with tuberculosis. Like all populations, individuals within that population show variation. Mutations add more variation. By chance, mutation may change the chemistry of one or a few bacteria so that they are not affected by a particular antibiotic. If the infected human begins to take antibiotics, they change the environment for the bacteria, killing most of them. However, the few bacteria which by chance have genes for resistance will survive this change in environment, and they will produce offspring which also carry the genes. More and more of the bacterial population will be resistant to antibiotics because the antibiotics select for resistance. The bacteria are merely evolving in response to changes in their habitats. If the resistant bacteria are transmitted to another human "habitat," their population continues to expand, and if the new "habitat" takes different drugs, natural selection may result in multi-drug resistance.

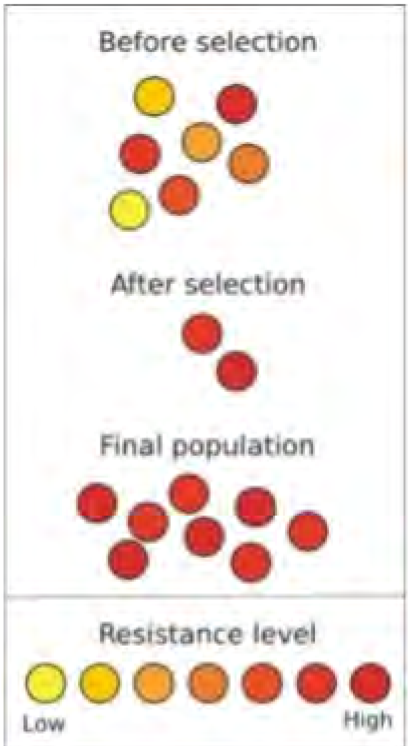


Image by Wykis, https://commons.wikimedia.org/wiki/File:Antibiotic_resistance.svg, CC0

The development of resistance to antibiotics is a classic example of natural selection. Before selection, a number of heritable variations in the level of resistance exist within the population, from low to high levels. After selection by antibiotics, only those bacteria resistant to antibiotics survive. Only these resistant bacteria reproduce; thus the final population contains a greater proportion of resistant bacteria.

What can we do about this particular instance of evolution which we have unwittingly encouraged? In general, we should reduce the use of antibiotics where possible and safe in order to lessen the selective pressure on bacteria. Here are some practices to keep in mind:

1. Don't take antibiotics for viral infections such as colds and flu; they act only on bacteria.
2. When antibiotics are appropriate, take them exactly as prescribed, and complete the entire course.
3. Never take antibiotics which are left over from an earlier illness or prescribed for someone else.
4. Consider purchasing meat and other animal products from animals not treated with antibiotics.

In much the same way that bacteria become resistant to antibiotics, weeds have become resistant to herbicides. Applying herbicides to their crops to kill weeds can make farming more profitable. However, some weeds have a mutation that allows them to survive in the presence of herbicides. The resistant weeds survive and pass their resistant trait along to their offspring, increasing the number of herbicide-resistant weeds in the next generation.

Humans have the potential to impact species anytime we change the environment they live in. When we introduce a new species, cause climate change, remove species from an ecosystem, or make other changes, we can influence natural selection. What other problems may arise from human impacts on natural selection? What are some possible solutions for these problems?

Putting It Together

Image by Dr Graham Beards, https://en.wikipedia.org/wiki/Antimicrobial_resistance#/media/File:Antibiotic_sensitvity_and_resistance.JPG, CC-BY-SA 4.0

Some of the bacteria in these Petri dishes are resistant to antibiotics. The white circles contain antibiotics. The disks with clear space around them are effective, and bacteria can't grow in their presence. The bacteria on the right are resistant to three of the antibiotics, as seen by the fact that the bacteria are growing next to three of the white disks.

1. After researching possible solutions to the problem of antibiotic-resistant bacteria, determine which solution best meets the criteria you established.

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