SUPERCHARGED SCIENCE

Unit 16:
Life Science Part 1

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Appropriate for Grades:
Grades K-8 (see notes on each lesson)
Duration: 3-25 hours, depending on how many activities you do!

In this unit, you will learn about cells, which are the tiny things that everything is made of. We'll start off by talking about the scientists who first observed and described cells. We'll learn about things even smaller than cells that are inside of them, and what they do to help cells survive and do their jobs. We'll also talk about how things get in and out of cells.

All of this is important because cells make up all living things. In order to understand how living things like animals, plants, and bacteria live and grow, we must understand cells. In this unit we will also cover the basics of genetics. We will begin with the beginning of genetics as a science (Mendelian genetics) and continue through to modern genetics.

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Key Vocabulary

Lesson 1: Living Organisms

Autotroph – organism that can create its own energy

Cell – the smallest part of an organism still considered to be alive

Classification – organizing things into groups

Control Group – group that receives a no change in an experiment

Data – Information collected during an experiment

Ecology – branch of life science that studies the interaction of living things with other living things and non-living things

Evidence – an observation of a thing, group of things, or a process that takes time

Experimental Group – group that receives a change that is being tested during an experiment

Food Web – model showing what living things eat what in a certain area

Heterotroph – organism that must eat other organisms to get its energy

Homeostasis – process of maintaining a stable internal environment in an organism

Hypothesis – a possible answer to a scientific question

Life Science – the study of living things and how they interact with their environment

Model – a representation of something else

Observation – anything noticed using the five senses

Organism – a living thing

Placebo – inactive substance looking similar to the medication being tested

Reproduction – process of creating new organisms

Scientific method –a series of steps that can be used to answer questions and solve problems

Key Vocabulary

Lesson 2: Cells

Active Transport – Movement of materials into or out of a cell that requires the use of energy

ATP – Molecule used for energy in cells

Cell – The smallest objects that can do all the things needed for life

Cell Division – Process in which one cell becomes two cells

Cell Membrane – Structure on the edge of a cell that determines what does or doesn't go into a cell

Cell Wall – Organelle found in plant cells that provides support and protection

Cellular Respiration – Process in which chemical energy stored in glucose is changed to chemical energy stored in ATP

Chloroplast – Organelle found in plant cells that allows sunlight to be used to make food

Concentration – The amount of a substance in a certain area

Cytoplasm – Material inside the cell membrane

Daughter Cells – The cells at the end of cell division

DNA – Genetic material that has all the information about a cell

Endoplasmic Reticulum – Organelle that transports lipids and proteins around the cell

Energy – The ability to cause a change

Eukaryote – A cell with a nucleus

Golgi Apparatus – Organelle that receives proteins and prepares them to be sent to other places in the cell or the body

Lipid – Fat molecule

Mitochondrion – Organelle that makes energy available for the cell

Nuclear Membrane – Structure that surrounds and protects the nucleus

Nucleus – Organelle that determines which proteins will be made

Nutrient – Substances that are helpful to living things

Organ – A group of tissues working to do the same job

Organelle – Tiny structures found in the cytoplasm of a cell

Osmosis – Movement of water through passive transport

Parent Cell – The cell at the start of cell division

Passive Transport – Movement of materials into or out of a cell without the use of energy

Photosynthesis – Process in which light from the sun is changed into chemical energy

Prokaryote – A cell without a nucleus

Ribosome – Organelle that makes proteins

Theory – A group of ideas that explains why or how something happens

Tissue – A group of cells working together to do the same job

Vacuole – Organelles similar to vesicles, but larger in size

Vesicle – Organelle that stores and transports materials in the cell

Key Vocabulary

Lesson 3: Genetics

Alleles - Any of several forms of a gene, usually arising through mutation, that are responsible for hereditary variation.

Chromosomal disorders - Genetic disorders caused by defects to entire chromosomes.

Codominance - Of or pertaining to two different alleles that are fully expressed in a heterozygous individual.

DNA - An extremely long macromolecule that is the main component of chromosomes and is the material that transfers genetic characteristics in all life forms, constructed of two nucleotide strands. The genetic information of DNA is encoded in the sequence of the bases and is transcribed as the strands unwind and replicate.

Dominant Trait - A trait that will appear in the offspring if one of the parents contributes it.

Environment - The external factors surrounding and affecting an organism at any given time.

F1 generation - The offspring of the P generation.

F2 generation - The offspring of the F1 generation.

Gene therapy - The application of genetic engineering to the transplantation of genes into human cells in order to cure a disease caused by a genetic defect.

Gene - The basic physical unit of heredity; a linear sequence of nucleotides along a segment of DNA that provides the coded instruction for synthesis of proteins.

Genetic disorders - Inherited genetic defects.

Genetics - The science of heredity, dealing with resemblances and differences of related organisms resulting from the interaction of their genes and the environment.

Genotype - The genetic makeup of an organism or a group of organisms with reference to a single trait, set of traits, or entire complex of traits.

Gregor Mendel - An Austrian monk and biologist. He developed the fundamental laws of genetics through his experiments with pea plants.

Heredity - The transmission of genetic characters from parents to offspring.

Heterozygous - Having dissimilar pairs of genes for any hereditary characteristic.

Homozygous - Having similar pairs of genes for any hereditary characteristic.

Human Genome Project - A global effort, completed in 2003, to sequence and map all human genetic information.

Incomplete dominance - The appearance in a heterozygote of a trait that is intermediate between either of the trait's homozygous phenotypes.

Laws of heredity - The laws of the inheritance of genetic information.

P generation - The parent generation.

Pedigree analysis - A graphic showing the inheritance of a trait or traits throughout a lineage.

Phenotype - The appearance of an organism resulting from the interaction of the genotype and the environment.

Polygenic traits - Traits controlled by two or more genes.

Punnett Squares - Tables used to determine the probability of offspring inheriting traits from their parent(s).

Recessive Trait - A trait that must be contributed by both parents inorder to appear in the offspring.

Recombinant DNA - DNA combined from two or more sources.

Restriction enzymes - Enzymes used to cut DNA at specific points.

Sex-linked inheritance - Inheritance linked to the sex chromosomes (the X or Y chromosomes).

(Mendel's) Law of segregation - Mendel's law postulates that each organism receives two copies of its genes (what he called

"inheritance factors." Furthermore, when reproducing (sexually) they can only give one copy, such that each offspring receives one paternal and one maternal copy of the gene.

Traits - A genetically determined characteristic.

Wild-type - An organism having an appearance that is characteristic of the species in a natural breeding population. Or, the form or forms of a gene commonly occurring in nature in a given species.

Objectives

Lesson 1: Living Organisms

This section will introduce you do the special way of thinking and asking questions known as science. You will see that science investigations are sometimes carried out in a special way, called the scientific method. You will also learn about how models can be helpful to scientists. Next, we will talk about life. We will explore what makes something alive, how living things can be organized, and how we can name living things.

This section is important because it is the basis of everything else you will learn in science. Science has done many great things in our lives, from designing safety features for our cars to discovering medicines that are used to treat illnesses. But if we do not understand how science works, we cannot hope to make these kinds of discoveries. In order to study life science, we must know what make something alive, and what is the same and different about various living things.

Objectives

Lesson 2: Cells

How do lipids, carbohydrates, proteins, and nucleic acids come together to form a living organism? By forming a cell. These organic compounds are the raw materials needed for life, and a **cell** is the smallest unit of an organism that is still considered living. Cells are the basic units that make up every type of organism.

Some organisms, like bacteria, consist of only one cell. Other organisms, like humans, consist of trillions of specialized cells working together. Even if organisms look very different from each other, if you look close enough you'll see that their cells have much in common.

Most cells are so tiny that you can't see them without the help of a microscope. The microscopes that students typically use at school are light microscopes. Robert Hooke created a primitive light microscope in 1665 and observed cells for the very first time. Although the light microscope opened our eyes to the existence of cells, they are not useful for looking at the tiniest components of cells. Many structures in the cell are too small to see with a light microscope.

At the end of this unit, you will:

- Understand what cells are, how cells form the basis for all life
- Understand the development of the cell theory
- Know the function of the major cell organelles
- Understand how material enters and exits cells
- Understand the methods of cell division, and which types of organisms use each

Objectives

Lesson 3: Genetics

Why do families share similar features like eye and hair color? Why aren't they exact clones of each other? These questions and many more will be answered as well look into the fascinating world of **genetics**!

Genetics is defined as "the science of **heredity**[1], dealing with resemblances and differences of related organisms resulting from the interactions of their genes and the environment". That is to say, genetics asks *which* features are passed on from generation to generation in living things.

Genetics also tries to explain *how* those features are passed on (or not passed on). Which features are stay and leave depend on the **genes**[2] of the organism and the **environment**[3] the organism lives in.

So, that's the basic summary of Genetics. It's the study of how features move from generation to generation in living things. As you can see there's LOTS of vocabulary—don't be intimidated! Genetics is incredibly interesting, useful, and even, FUN!

Here are the key concepts:

The Beginning of Genetics—Mendel

- Genetics is the science of heredity.
- Gregor Mendel, an Austrian monk in the 19th century, identified laws of inheritance by experimenting with peas.
- The law of segregation, developed by Mendel, states that each organism receives two copies of each gene; one maternal copy, and one paternal copy.
- According to Mendel's observations, dominant traits are always expressed if present, and recessive traits are only expressed if both copies of the gene are recessive. Modern research has reviled exceptions to those rules.

[1] The transmission of (genetic) characteristics from parents to offspring.
[2] The codes found in the DNA to make protein. They serve as the basic unit of heredity.
[3] The external factors surrounding and affecting an organism at any given time.

Modern Genetics: Additions, Further Explanations, and Exceptions to Mendel's Laws

- Genes are the "inheritance factors "described in Mendel's laws.
- The genes are passed on from generation to generation and instruct the cell how to make proteins.
- DNA is a long molecule formed by two strands of genes.
- DNA carries two copies—two "alleles"—of each gene. Those alleles can either be similar to each other (homozygous), or dissimilar (heterozygous).
- A genotype refers to the genetic make-up of a trait, while phenotype refers to the physical manifestation of the trait.
- Exceptions to Mendel's laws include incomplete dominance, codominance, and polygenic traits.

Human Genetics

- A genetic disorder is simply a disease or disorder that is inherited genetically. Genetic disorders can be caused by single defective gene, or by entire defective chromosomes.
- Sex-linked inheritance refers to the inheritance of traits which are due to genes located on the sex chromosomes.
- Pedigree analysis is a graphic that shows the inheritance of traits through a lineage.

Modern Genetics

- We can manipulate DNA to produce protein we want by cutting and pasting segments of DNA from different sources. These collages of DNA are called recombinant DNA.
- To cut the sections we can use special proteins called restriction enzymes. Restriction enzymes cut the DNA at specific sequences depending on the enzyme. There are over 3,000 known restriction enzymes.
- The Human Genome Project was a global effort to sequence and map human genetic information.

Textbook Reading

Lesson 1: Living Organisms

What is Science?

What do you think of when you hear the words science or scientist? When some people hear the word science, they imagine someone working with dangerous chemicals in a laboratory. Although some scientists do work with dangerous chemicals, and many do work in labs, there is much more to science than this.

There is much more to science than working with chemicals in a lab.

Science is a way of understanding the world based on repeated tests and evidence. If scientists are doing their job right, they should base their conclusions on evidence, not just on what most people think is true. **Evidence** is an observation of a thing, group of things, or a process that takes time.

Sometimes, the evidence will go against "common sense" or popular opinions. For example, many people use plastic cutting boards because they think they have fewer germs than wooden ones.

But just "thinking" something is not science. To test which kind of cutting board is really best, scientists exposed wooden and plastic cutting boards to germs, cleaned them, and then checked how many germs were still left.

They were surprised to find that although the plastic cutting board looked prettier, the evidence showed that the wooden board actually had fewer bacteria. What was shown by the evidence was not the same as what had believed by many people. When this happens, science says we should trust the evidence.

The plastic cutting board had more bacteria than the wood.

Sometimes, scientists will discover evidence that goes against what has been believed for many years. When this happens, scientists must change their way of thinking. For example, scientists thought for many years that dinosaurs were slow animals.

Recently, scientists began looking at preserved dinosaur footprints. They were most interested in the space between the footprints.

As you may know, when you move faster, there is more space between your footprints. (Try running around your room if you want to check this.) Judging by the space between dinosaur footprints, scientists discovered they were much faster than they had thought, and that some dinosaurs were possibly even faster than people.

Dinosaur footprints were helpful in determining their speed.

Even more recently, scientists attempted to create computer models of dinosaur skeletons to calculate how fast they could have run. Based on this, scientist Bill Sellers concluded that a small dinosaur called compsognathus might have been the fasted animal on two legs to ever have lived.

Every time new, more reliable evidence is discovered, scientists must look back at what they had believed, and be willing to change their minds if necessary.

The Scientific Method

Imagine you are a scientist interested in studying something that you think will help people, like the health risks of living in a smoggy city.

If you were going to share your discoveries with your fellow scientists, it would be helpful to have a procedure to follow that all scientists knew about.

For this reason, scientists sometimes use the **scientific method.** The scientific method is a series of steps that can be used to answer questions and solve problems.

Scientists don't use the scientific method all the time. It is possible to do good scientific research without it. However, this method is sometimes helpful because it allows other scientists to easily see the steps taken and reproduce the experiment themselves if they want to. The steps of the scientific method are

1. Make observations
2. Ask a question
3. Research what is already known about your question
4. Suggest an answer to the question, called a hypothesis
5. Test the hypothesis
6. Analyze the results to see if the hypothesis was correct
7. Communicate the results

Making Observations

The first step in the scientific method is to make an observation. An **observation** is anything noticed using the five senses. In the example above about the health risks of smog, you may look at the sky in a city like Los Angeles and see a great amount of smog. You might even walk around hear people coughing as they go about their business on the smoggy day. This may lead you to think that the coughing has something to do with the smog, but this is just an idea you have. We are nowhere near having actual scientific evidence, but we are on the way.

Observing the smog in Los Angeles could be the start of a scientific investigation.

Ask a Question

You have seen the smog in Los Angeles. You have heard people coughing. Now it's time to take those observations and use them to help you create a question to be answered. Coughing is associated with some medical problems, including asthma, so perhaps you would ask, "Does living in a city with a high level of smog increase the risk of developing asthma?"

Research the Topic

No matter what you are studying, it is likely someone has studied it before. In the case both of smog and asthma, many people have studied it. By doing some research, you can learn information about your topic. The Internet can be a great place to do research if you are careful. The web has some great information, and it has some terrible information. The trick is knowing the difference. As the researcher, you need to look at who the author of the website is and determine if you trust them.

Hypothesis

Now that you've asked a question and conducted some research on it, the next step is to suggest an answer to the question. A suggested answer to a scientific question is called a **hypothesis**.

Sometimes you will hear people refer to hypotheses (that's the plural of hypothesis) as educated guesses. A hypothesis is a guess, because you have not yet done any experiments to see if it is correct or incorrect, but it is educated because it is based on the research you did in the last step.

Good hypotheses do not have to be right. In fact, some of the most important scientific research is made when a hypothesis is found to be wrong. However a good hypothesis must be testable. If scientists cannot run a test to see whether or not the hypothesis is correct, it is not a useful hypothesis.

For example, many years ago, before we knew about the importance of washing your hands, people wondered why certain patients would get sick more often than others. A popular "hypothesis" at the time was that there was something "bad" about the person that made them more likely to get sick. This is not a scientific hypothesis, however, because there is no way to test if a person is good or bad.

In our smog example, a testable hypothesis could be, "people living in cities with high levels of smog will have more cases of asthma than those living in cities with low levels of smog." This is an okay hypothesis, but it could be better. Instead of saying, "cities with high (or low) levels of smog" we could do a little more research, and pick some actual cities to study.

The website www.stateoftheair.org, ranks cities in the U.S. according to their levels of air pollution. (Take a moment to go to the website. Who created it? Based on that, do you think it's trustworthy?) According to the website, the city in the U.S. with the most air pollution is Bakersfield, California, and the city with the least is Cheyenne, Wyoming.


Bakersfield (top) and Cheyenne (bottom) are America's most and least air-polluted cities.

With this new information, we can get more specific in our hypothesis and say, "The rate of asthma infections will be higher in Bakersfield than in Cheyenne." This is testable, and will lead to a yes or no answer based on our experiment.

Testing the Hypothesis

Now is (finally) the time to conduct an experiment. It is important to carefully document all the steps of your procedure, so that other scientists can evaluate and review your work. Documenting your work will also allow other scientists to reproduce your experiment if they would like to. Information you collect during your experiment is called **data**.

Data from our smog experiment, collected from the website http://www.statemaster.com/graph/hea_pre_of_ast-health-prevalence-of-asthma would tell us that both California and Wyoming have asthma rates of 7.6%.

You don't have to surf the web to find data: you might set up an experiment that gives you data as well. (We'll learn more about how to do this later in the unit.)

Analyzing Data and Making Conclusions

Now is the time to look at our data, look back at our hypothesis, and see if we were right or wrong. We hypothesized that Bakersfield would have more cases of asthma than Cheyenne.

Although we didn't find city data, the states in which the cities are in have the same rates. (Do a little research and see if you can find city rates, if you'd like.) It appears that our hypothesis was wrong. At this point, we might want to say all kinds of things about our results.

We might want to say that it must be genetics that causes asthma, or that smog doesn't make you have asthma, but could make it worse if you already have it.

These are all interesting ideas, and could lead to a new experiment, but it's important to realize that we have not *proven* any of these things.

All we have proven is that the rates of people with asthma are not higher in smoggier states.

Communicating Results

The last step of the scientific method is to communicate your results. Whether your hypothesis was right or wrong, it is important to let other scientists know what you have discovered.

This will allow them to conduct their own experiments based on yours. This is how science moves forward. To communicate results, scientists sometimes create web sites, give lectures, or write articles for scientific magazines.

Wow! That was a lot of work just to answer a question. It's true that the scientific method is a lot of work, and that's one reason why it's not used in all cases. Even so, understanding this process is important because so many important discoveries have been made in this way.

Controlled Experiments

In an experiment, it is important to make sure that you are really testing the thing you mean to test. For example, imagine a scientist developed a new medication that she thought could treat bronchitis.

If she tested the medication by giving it to 100 people with bronchitis, and 90 of them got getter in three days, does that mean the medication works?

Maybe. Or maybe the people would have gotten better even without the medication. The problem is that we have no way of knowing. For that reason, this experiment is not good. But it can be improved.

What if the scientist took 200 people, gave 100 of them the medication, and gave the other 100 nothing. If 90 of the people who got the medication were better after three days, but only 50 of the 100 people who didn't get the medication got better, would that be proof that the medication works.

Well, we're getting closer, but there is still a problem. Sometimes, people who are getting medication think they are going to get better, so they start to feel better, *even if the medication is doing nothing!* If you don't believe this, watch little kids playing on a playground and wait for one of them to fall down. (Don't push them.)

In many cases, the child will ask for a Band-Aid, even if they have no cut! If their parents give them one, they often start to magically "feel better" and go on playing. Now, if you were watching this, you would know the Band-Aid is not helping. But the young child has convinced himself that he will be getting better, so he feels better.

This idea of feeling better because you expect to feel better is known as the **placebo effect**, and can be a big problem for scientists testing new medications. The people in the experiments might tell scientists they are feeling better, and they aren't really lying. It's just that what is making them feel better has nothing to do with what the scientist is trying to test.

So let's go back to our scientist with the bronchitis medication. We know she needs to give both groups of people *something*, but we also know she can't give everyone the medication.

So what's the solution? The scientist must give one group the real medication and the other group something that looks like the medication, but isn't actual medication. This fake medication is called a **placebo**. In this type of experiment, the group of people receiving the actual medication is called the **experimental group** and the group getting the placebo is called the **control group**.

At the conclusion of the experiment, one of three things will happen:

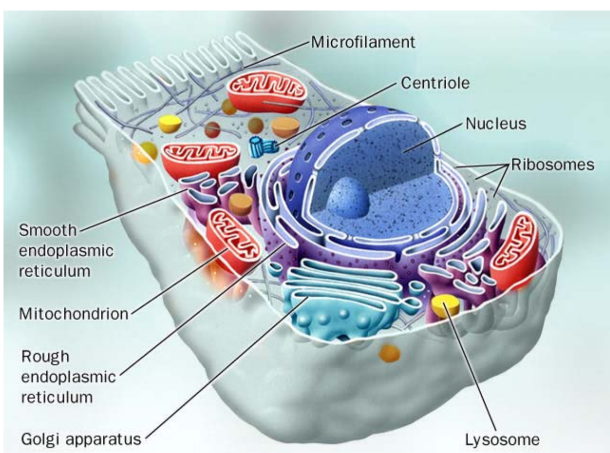
1. Neither the experimental group nor the control group will get better. This means the medication does not work.
2. The experimental and control group will get better at the same rate. This means that it is the placebo effect, not the medication, that is making people better. There is no proof that the medication works.
3. The experimental group gets better at a higher rate than the control group. This would be evidence that the medication works.

Control groups and experimental groups are not just for experiments about medications. Scientists looking to study animal behavior, what makes plants grow, or how bacteria multiply will likely have these types of groups in their experiments.

Using Models in Science

One of the most important tools scientists have are models. **Models** are representations of other things. Even the best model will never be as good as the real thing, so scientists only use models when the real thing cannot be easily studied, usually because it is too big or too small.

For example, highly powerful microscopes have allowed scientists to see pretty good images of cells, the tiny structures that make up all living things, but even with these tools, understanding cells is made easier when scientists create larger models of them.



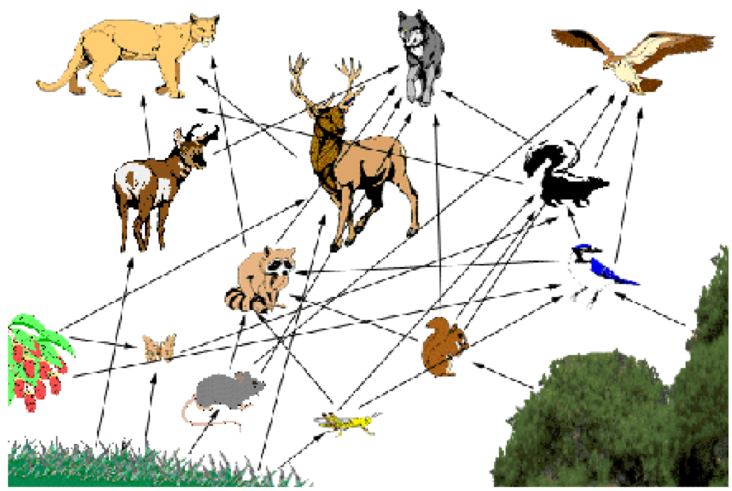
A model of a cell allows scientists to show the parts of these tiny objects.

On the other extreme, a scientist studying the solar system might want to create a smaller model.

Not every model represents physical objects. Some represent ideas.

For example, a scientist studying the life science field of **ecology**, the study the interaction of living things with other living things and non-living things, might wish to discuss what animals eat what in a certain area.

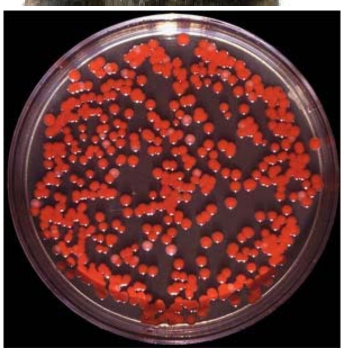
A model called a **food web** can be created to show this idea. These models allow scientists to show what eats what in a visual way, rather than relying on words alone.



Food webs graphically show what eats what.

What Makes Something Alive?

Life science is the study of living things, which are also called **organisms**. But how do we know if something is alive? We can't tell just by looking at it. A dog and a dish of bacteria are both alive, but they look very different.



A dog and a dish of bacteria do not look similar, but both are alive.

Luckily, there are some things that tell us something is alive.

All Living Things Keep a Stable Internal Environment

The first thing all living things have in common is that they keep things inside their bodies stable, or just about the same.

For example, think about our body temperature. You probably know that if everything is going well, your body temperature stays at about 98.6 degrees F (37 degrees C.) This is true whether it's hot or cold outside. Our bodies do certain things to keep this temperature.

Some things, like sitting under a shady tree on a hot day, are conscious.

But in humans, and in many living things, most are unconscious. When it's cold, you start to shiver and the amount of blood going to your body parts goes down. When it's hot, you begin to sweat. Doing this allows our body to make sure that no matter what it's like outside, our body is about the same temperature inside. This is not only true about body temperature.

There are many things about our bodies that stay the same no matter what. Keeping a stable internal environment is something all things do, and it is called **homeostasis**.

All Living Things Reproduce

Reproduction is the process of creating new organisms, and is another thing all living things do.

During reproduction, one or more living things (the parents) pass on information, called traits, about themselves to a new organism (the offspring.) Traits control many of the things about us, including our eye color, body size, whether we have a beak or a mouth, and whether we have feathers, fur, gills, or something else. This process of passing on traits is called **heredity**.

The baby birds will have many of the same traits as their mother.

Some living things require a male and female to reproduce. Others only need one parent passes on information to the offspring, like bacteria. Some lizards also do this: lizards (which are all female) just lay an egg, and a baby is born that has all the same traits as the parent.

Living Things are Made of Cells

As different as living things look from each other, it may be hard to believe that we are all made of the same thing, but living things are all made of **cells.** Cells are the smallest parts of organisms that are still considered to be alive.

Human beings have trillions of cells, and many of them have special jobs, like the ones shown below. For this reason, cells are sometimes called the building blocks of life.

A human has about 40 billion blood cells, like the ones shown here.

Living Things Need Energy

All living things need energy. Some living things are able to produce their own energy. These organisms are called **autotrophs**.

For example, plants use energy from the sun to produce the energy they need to grow and reproduce. Other living things, like humans, can't make their own food from the sun. These organisms get energy by eating plants, or by eating animals that eat plants. Organisms like this are called **heterotrophs**.

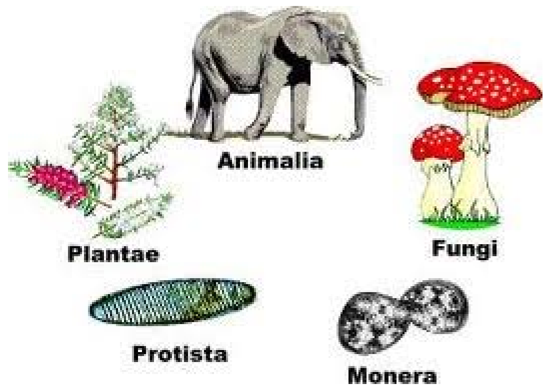
Classifying Living Things

If you like music, you might have some CDs, or songs loaded onto an mp3 player, and they may not be in any particular order. This fine if you don't have that many CDs or songs, but if you get a lot of them, you'll probably need to start organizing them, by doing things like putting all the CDs by the same artist in the same spot, or organizing the songs alphabetically.

Organizing things into groups is called **classification.** If classification is needed for a collection of songs, imagine how badly it is needed with organisms.

There so many kinds of living things – many more than there are songs on even the biggest music-lover's mp3 player. So how can they be organized? Scientists have been working on this problem for several hundred years. This has led to a detailed system to classify organisms.

First, living things are classified into kingdoms. Kingdoms are things like animals, plants, or funguses. All in all, there are five named kingdoms, although current science indicates that there may need to add more kingdoms as are more organisms are discovered and described. Kingdoms include many organisms, but all the organisms in the same kingdom have things in common. For example, all plants are autotrophs.



The five kingdoms of life

Animals in a kingdom are broken down into groups based on similarities. Each of these groups is called a phylum. From here, things get more and more specific, as you can see below:

kingdom → phylum → class → order → family → genus → species

Each organism has a scientific name, which is created by putting together the name of the genus and species.

In a scientific name, the genus is capitalized and the species is written in lower case.

Scientific names are always underlined or written in italics. These names can be very useful when communicating around the world about a particular organism.

For example, a dog is called perro in Spanish and chien in French. But whether you are in the U.S, Spain, or France, the scientific name for dog is *Canis familiaris*.

Since scientists often work with scientists from other countries, having a common language when describing organisms is important.

Conclusion

Life science is a type of science studying organisms and how they interact with their environment. Science is a way of thinking and answering questions, sometimes in a process called the scientific method. Living things all have certain things in common, and can be classified and names based on their characteristics.

Lesson 2: Cells

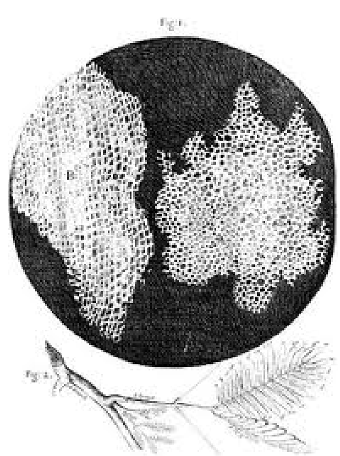
Take a look the world around you. As you look around, you will see many things that are alive. You probably know that people and animals are alive, and you might also know that plants are alive. What makes these things, and many other things, alive? There are actually many hints that tell us something is alive. One thing that is true about all living things is that they all have tiny structures called cells.

This tree, like all living things, is made of cells.

Cells are the smallest objects that can do all the things needed for life. Some people call cells the "building blocks" of life. If you've ever played with blocks, you can understand why people say this. When you play with blocks, each block gets put together to make giant towers, castles, or whatever else you can imagine. Cells get put together to make apple trees, elephants, or whatever other living thing you can imagine!

How Were Cells Discovered?

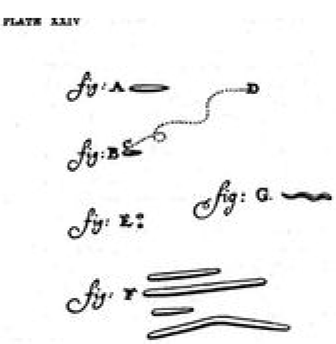
Imagine if you took a rocket to another planet that nobody had ever been to, and saw things there that nobody else had ever seen. Can you imagine the feeling of excitement when you described what you discovered to everyone? About 450 years ago, a scientist named Robert Hooke got to do something kind of like that. Hooke took some cork (which comes from plants) and sliced it so it was very thin. Then he put the thin slice of cork under a microscope. Microscopes help people see things that are too small to see with just your eyes. When Hooke looked at the cork, he saw some things that looked like little boxes, or rooms. He called these things cells.



When Hooke looked at the cork, he saw little boxes.

He couldn't see the cells very well, because his microscope wasn't as good as the microscopes we have today. But his discovery is still very important, because it helped us to understand that living things are made of cells.

Another scientist who looked at cells was Anton van Leeuwenhoek. Leeuwenhoek's microscope was almost as good as the microscopes we use to look at cells today, and he saw lots of things nobody had seen before. He saw animals that had never been seen. No one had seen them because they were too small to see with just your eyes. He also saw the cells that make up human blood. Leeuwenhoek even did an experiment where he scraped the plaque off his teeth and looked at it under his microscope. When he looked at the plaque, Leeuwenhoek saw tiny living things.



Van Leeuwenhoek drew these sketches of what he saw from the plaque in his mouth

Today we know that those things are bacteria. Think about that the next time you are brushing your teeth! (There are cool experiments that relate to this in the activities section!)

By the middle of the 1800's, several other scientists had studied cells, and this work led to a theory. In science, a **theory** is a group of ideas that explains why or how something happens. The **cell theory** says three things. These three things are:

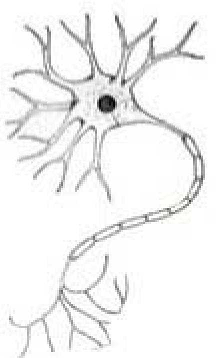
1. All living things are made of one or more cells
2. All of the activities needed for life happen in cells
3. All cells come from other cells

The cell theory is a very important part of biology, which is the study of life.

Cell Shape and Size

In order for your city or town to survive, people need to do different jobs. Police officers, construction workers, teachers, doctors, and fire fighters all do certain things to make sure everything runs smoothly. The different cells of your body also do different jobs that make things run smoothly in your body. In fact, you have trillions of cells, and each one plays an important role in getting and using energy, responding to the world around you, and reproducing.

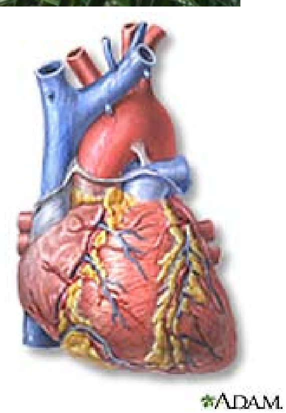
Many cells have special shapes that help them do their job well. For example, one group of cells, called nerve cells, have the job of getting messages to other cells. Nerve cells have long extensions coming out of them so they can easily reach the cells they need to give the message to.



The extensions on this nerve cell help it give messages to other cells

Although cells may have different shapes, they are all very small. In fact, you could fit about 500 average-sized cells in the period at the end of this sentence. Being small is good for cells, because it allows materials to get in and out of the cells very quickly. Cells take in **nutrients**, which are substances that are helpful to people or other living things, and get rid of waste. If it took a long time for the good stuff to get in or the bad stuff to get out, the cell could not survive.

A group of cells working together to do the same job is called a **tissue**, and a group of tissues working together to do the same job is called an **organ**. An example of a tissue is the stem of a plant. In this tissue, many cells work together to get water and nutrients to the various parts of the plant. You've probably heard of some organs, like your brain, heart, and lungs. All of these organs are made of tissues, and all those tissues are made of cells. Cells really are the building blocks of everything!



The stems of plants are tissues; the human heart is an organ.

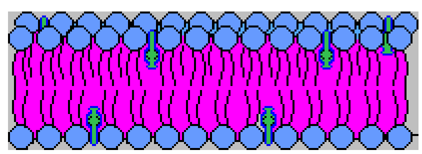
What's Inside of a Every Cell?

Take a look at your friends, and the other kids in your neighborhood. You probably notice that even though you are all kids, and maybe even all about the same age, you look pretty different. Even though we look different on the outside though, we know are made of a lot the same things, like bones, muscles, and organs, on the inside. It's the same with cells. Look back at the picture of the nerve cell in the last section. Now look at the three pictures below.

Red blood cells (left), a single-celled paramecium (center), and an amoeba (right) don't look the same. But they are all cells.

Although these pictures look very different, they are all pictures of cells. Even though cells look very different on the outside, these cells, just like people, do have some things in common. In fact, there are three things that every cell in the world has.

First, every cell has a **cell membrane**. The cell membrane is made of **lipids**, which are fat molecules. The cell membrane is located along the edge of the cell, and has a job like a security guard. It allows things the cell needs to get into the cell and keeps out things that could hurt the cell.



The cell membrane acts like a guard, only letting certain things into the cell.

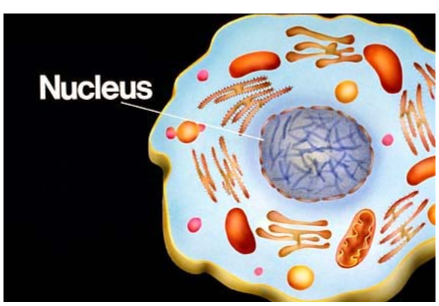
The second thing all cells have is **cytoplasm**. Cytoplasm is all the material inside the cell membrane. Cytoplasm is made of a watery material called cytosol. Many structures are found inside cytoplasm. These tiny structures are called **organelles**. We will study some of the organelles later.

The third and final things that all cells have are **ribosomes.** Ribosomes are organelles where proteins are made. Proteins control everything that happens in a cell, from growth, to reproduction, to death. As you can see, proteins are very important for cells, so ribosomes have a very important job! Some ribosomes are found all alone, but others are found in groups, or attached to other organelles, as we will learn later.

Ribosomes have the important job of making proteins.

The Nucleus

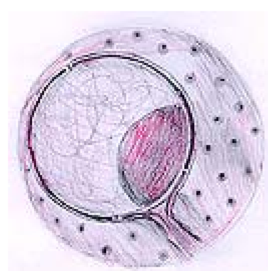
Some cells have an organelle called the **nucleus.** The nucleus is the largest organelle, and can be thought of as the "brain" of the cell.



The nucleus is thought of as the "brain" of the cell.

Just like your brain controls almost everything your body does, the nucleus controls everything the cell does. How does it do that? Well, you might remember that ribosomes make proteins, and proteins control everything that happens in a cell. The nucleus controls which proteins the ribosomes make. That's how it controls everything that happens in the cell.

The nucleus is so important that it has its own membrane around it, called the **nuclear membrane**. Just like the cell membrane controls what does or doesn't go into a cell, the nuclear membrane protects the nucleus by controlling what does or doesn't go into it.



The nuclear membrane controls what does or doesn't go into the nucleus.

Not all cells have a nucleus. In fact, there are two big groups of cells, and the big difference between them is that one group has nuclei (that's the plural of nucleus) and the other one doesn't.

The cells with nuclei are called **eukaryotes** and the cells without nuclei are called **prokaryotes**. Most animal and plant cells are eukaryotes, and most bacteria cells are prokaryotes.

Other Organelles

So far, you have learned about two organelles. First, you learned about ribosomes, the organelles all cells have for making proteins. Next, you learned about nuclei, the organelle some cells have for deciding what proteins should be made. Now let's talk about other organelles found in some cells.

Endoplasmic Reticulum

Endoplasmic Reticulum (or ER for short) is kind of like the freeway of the cell. Like a freeway taking cars from one place in the city to another, ER carries lipids and proteins from one place in the cell to the other.

The endoplasmic reticulum transports lipids and proteins around the cell.

There are two kinds of ER. Rough ER (which is the kind shown in the figure above) has ribosomes attached to it. Smooth ER does not have ribosomes.

Golgi Apparatus

The Golgi Apparatus is an organelle that is sometimes called the "post office" of the cell. To understand why it's called this, let's think for a minute about what a post office does. Imagine that you live in California, and you mail a birthday card to your friend who lives in New York. The post office gets your letter, separates it from all the mail going to other places, and then puts it in the pile with all the other mail going to New York (or somewhere near there.) Then it's shipped off and delivered exactly where it was supposed to go. The Golgi Apparatus doesn't get birthday cards from California. It gets proteins from the ER. Like a post office sending mail to the exact right place, it sends the proteins exactly where they need to go. Sometimes that means the proteins go to other places in the cell. Other times, the proteins are sent to the cell membrane so they can be sent out of the cell to other parts of the body.

The Golgi Apparatus receives proteins and sends them where they need to go.

The Golgi Apparatus actually does more than a post office does, because it also labels the proteins to determine where they should go. If post offices were like the Golgi Apparatus, you could deliver a blank envelope to the post office, and someone at the post office would know where your mail was supposed to go and write the address on the envelope for you. It would be like a psychic post office!

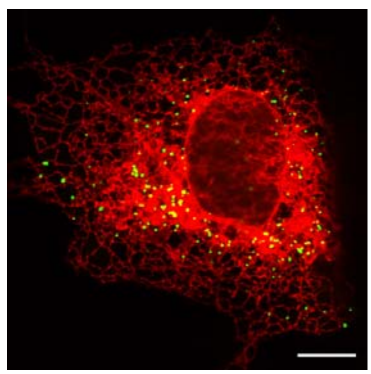
Mitochondrion

The **mitochondrion** is the organelle that makes energy available for the cell to use for growing, reproducing, and anything else it needs to do. Mitochondria (that's the plural of mitochondrion) use compounds like glucose, which is a common type of sugar, to make ATP. ATP is an abbreviation for adenosine triphosphate, and is the most common source of energy for cells.

The mitochondrion provides the energy cells need.

Vesicles and Vacuoles

Vesicles are small sac-like organelles. They store materials in the cell, and help move proteins wherever they need to go. For example, vesicles move proteins from the ER to the Golgi Apparatus for sorting. Special vesicles also break down dead cells, material that doesn't belong in a cell, or poisons.



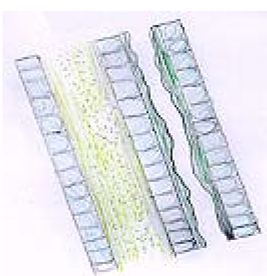
This vesicle has the important job of breaking down poisons in the cell.

Vacuoles are similar to vesicles, but are larger in size. In plant cells, a large vacuole is located in the center of the cell. This central vacuole stores such things as water and salt. It also helps some of the tissues in plants, like stems and leaves, keep their shape, and helps give flowers their colors.

The central vacuole of a plant cell has many jobs.

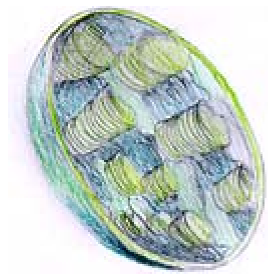
Cell Wall and Chloroplast

There are two organelles that are very important in plant cells, but not found in animal cells. The first one of these is the **cell wall**. This organelle supports and protects the cell. Cell walls have small holes, called pores, in them. This lets water, nutrients, and other substances into the cell.



The cell wall surrounds plant cells, giving the cells protection and support.

The other organelle that only plants have is the **chloroplast**. These organelles have a pigment called chlorophyll, which allows the plant to take sunlight and make its own food. Imagine if we could make our own food from the sun. Anytime you were hungry, you could just stand outside and soak in some rays. You could try this some time, but since your cells don't have chloroplasts, standing out there will only make you hungrier!



Chloroplasts allow plants to make their own food from sunlight.

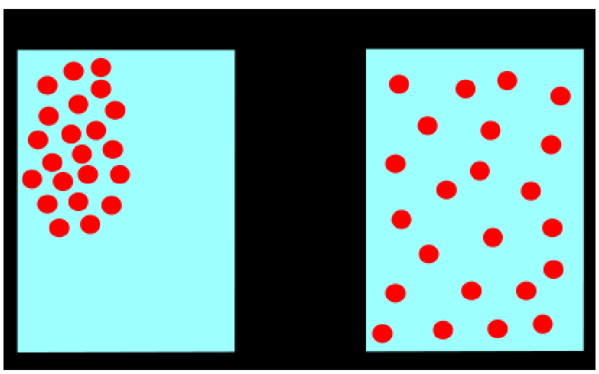
Getting Into the Cell

In the last section, we talked about the cell membrane. We talked about how this structure let in the things the needed and didn't let in the things it didn't need, like a security guard deciding who should or shouldn't get into a building. There are two ways substances can get into a cell.

The first way substances can get into a cell is called **passive transport**. This process does not require any energy, because of the **concentration** of the substance inside and outside the cell. Concentration is how much of a substance there is in a certain area. In passive transport, the substance is going from an area of high concentration to low concentration.

To understand how this works, imagine blowing up a balloon and then letting the air out. When you do this, the air flows out quickly and without any extra energy because it is going from a place where there are a lot of air molecules (inside the balloon) to a place where there are fewer air molecules (outside the balloon.) In other words, it is going from an area of high concentration to low concentration.

Look at the figure below if you're having trouble with this idea.



The red dots are all in the top left corner. This is where the concentration is the biggest. The dots will move down and to the right, until they are spread out evenly.

Sometimes substances undergo passive transport all by themselves. They just slide right through the cell membrane. Other times they need a protein to help them make it across the membrane. But they *never* need energy, because they are going from high to low concentration. One special kind of passive transport is **osmosis,** when water crosses into the cell.

You probably can figure out the second way substances can get into a cell. Since the first way was getting in *without energy*, the second way is getting in *with energy*. Since "active" is the opposite of "passive," this method is called **active transport**. As you might expect, active transport happens when the substance wants to go from an area of low concentration to high concentration. Think back to the balloon with air shooting out of it. If you want to get air to go into the balloon, where the concentration is high, that's going to require some energy. ATP, the molecule created by the mitochondria in the cell, provides the energy for active transport. Just like with passive transport, proteins are sometimes needed to help out with active transport.

Photosynthesis

In the last section, we talked about active transport needing energy. When you hear the word energy, you might think about playing sports or running in a race.

Although both of these things do require energy, they don't tell us what energy is. In science, **energy** is the ability to cause a change. Some of the changes energy can cause are changes in temperature (something getting hotter or colder), changes in state (going from a solid to a liquid, liquid to a gas, etc.) or a change in location (moving from one place to another.)

The heat energy from the stove makes the water in this pot hotter, and then changes it from liquid water to steam.

Several common kinds of energy are light, heat, sound, electricity, kinetic energy (the energy of motion) and chemical energy (energy stored up in things like batteries or cells.) Energy cannot be created or destroyed, but you can change energy from one type to another.

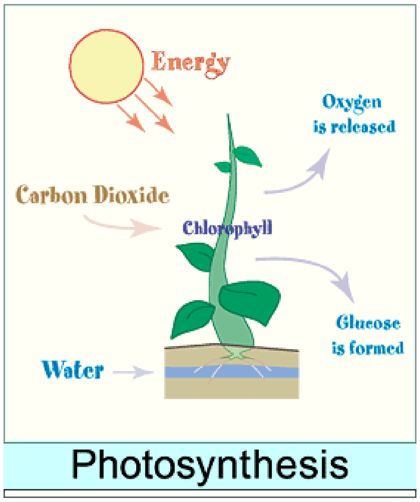
When a match is struck, the chemical energy in the match is changed to light and heat.

Photosynthesis is a process where light energy is changed into chemical energy. As we said in the last section, this process happens in the chloroplast of plant cells. Photosynthesis is one of the most important things that happen in cells. In fact, photosynthesis is considered one of the most important processes for all life on Earth. It makes sense that photosynthesis is really important to plants, since it gives them energy, but why is it so important to animals? Let's learn a little more about photosynthesis and see if we can answer that question.

There are many steps to photosynthesis, but if we wanted to sum it up in one equation, it would be carbon dioxide (CO_2) + water (H_2O) makes glucose ($C_6H_{12}O_6$) and oxygen (O_2). These words can be written like this:

$6CO_2 + 6H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2$

It can also be shown in a picture like this:



Carbon dioxide, water, and energy combine to form glucose and oxygen.

We learned in the last section that glucose is a kind of sugar. This sugar is important for energy, so the plant stores all the glucose it creates. However, the plant releases the oxygen it creates.

Now we can see two reasons why photosynthesis is so important not just to plants, but to animals too. First, all animals need oxygen to live. Photosynthesis produces oxygen, so without this process, animals could not survive. Also, don't forget that since animals can't make their own food, they have to eat plants, or eat other animals that have eaten plants. So without plants, animals would quickly run out of food.

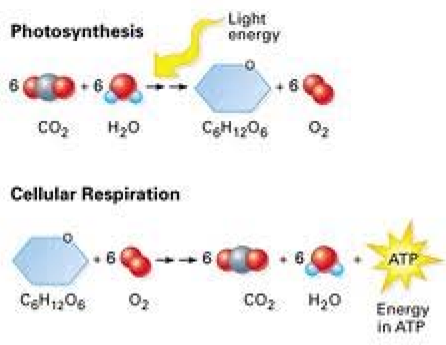
Cellular Respiration

Plants get glucose from photosynthesis, and animals get it from eating. Glucose is a great type of energy for storage, and energy is stored as glucose in both plants and animals. However glucose is not good for actually providing the power for the processes in a cell. It is too powerful. ATP, which we learned about earlier, has exactly the right amount of power to do everything the cell needs to do. So, cells need some way to change the chemical energy in glucose to chemical energy in ATP. This process is called **cellular respiration**. Cellular respiration happens in both animal and plant cells, and happens in the mitochondrion.

In cellular respiration, glucose and oxygen combine to make carbon dioxide, water, and ATP. An equation showing this would be:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O +$ ATP

You should notice that this is almost exactly the opposite of photosynthesis. Even so, plants need to go through both steps, so that they have glucose to store energy.



Photosynthesis and cellular respiration combine to change light energy to energy in the form of ATP.

Cell Division

Every living thing, from tiny bacteria to giant oak trees, began life as a single cell. That's right, just one cell. So how do living things go from one cell to the trillions of cells some living things are made of? The answer is cell division! **Cell division** is a process in which one cell becomes two cells. The cell that starts cell division is called the **parent cell** and the cells that the parent cell makes are called **daughter cells** (even though cells are not male or female.)

This parent cell is in the process of cell division.

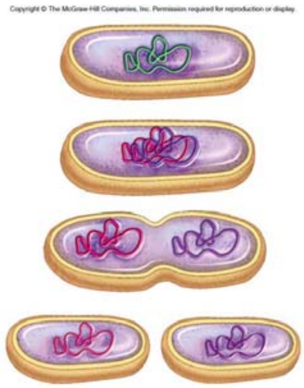
There are several different kinds of cell division that we will talk about.

One thing that all cell division has in common is that all the **DNA** in the parent cell must be passed on to each of the daughter cells. DNA is the genetic material that provides all the information about the cell.

If the cell has a nucleus, the DNA is located in the nucleus. If not, it is found in the cytoplasm. In order to make a daughter cell that is an exact copy of the parent cell, all of this information must be passed on.

Binary Fission

One simple form of cell division is binary fission. This process has three steps. In the first step, the DNA doubles, so that the daughter cells will each have all of the DNA fount in the parent cell. Next, the two sets of DNA move to the sides of the cell. Finally, a new cell membrane begins to grow in the middle of the parent cell. Eventually the cell breaks apart, and, just like that, daughter cells have formed.



Binary fission is a simple three-step process.

Binary fission is common in bacteria.

Budding

Another method of cell division is called budding. In this method, a small “bud” forms on the parent cell. The bud looks kind of like a bubble sticking out of part of the cell. Eventually, the bud develops all the material it needs and breaks off, forming a daughter cell.

In this yeast cell, the bud is visible at the top of the cell.

Mitosis

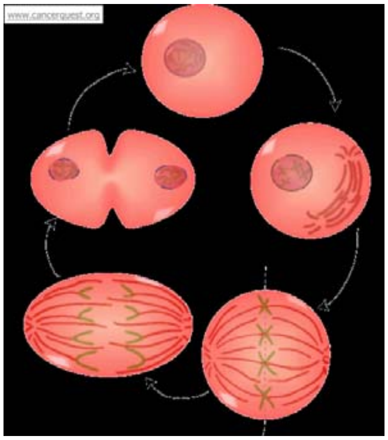
You may have noticed that when we talked about binary fission and budding, we didn’t say anything about the nucleus. That’s because these types of cell division happen in prokaryotes. Remember that prokaryotes don’t have nuclei. This makes cell division a lot easier, because it’s easier to get a complete set of DNA into each daughter cell. In eukaryotes, there is a nucleus, so a more complex process is needed. This process is called mitosis, and is divided into four parts, or phases.

Phase 1 – Prophase: In this phase the nuclear membrane begins to break down and the DNA forms structures called chromosomes.

Phase 2 – Metaphase: In this phase the chromosomes line up along the center of the parent cell

Phase 3 – Anaphase: In this phase, the chromosomes break apart, with a complete set of DNA going to each side of the cell

Phase 4 – Telophase: In this phase, a new nuclear membrane forms around each of the sets of DNA



The four stages of mitosis (the cell at the top has not started mitosis) lead to two daughter cells.

A little after telophase, the cytoplasm splits and a new cell membrane forms. Once again, two daughter cells have formed. Take a look at this animation for a good overview of mitosis and see if you can identify all the phases.

Cells continue to divide until a protein tells them to stop. As they divide, they become different and specialized, eventually making the tissues and organs found in the many different living things we see every day. There are many living things all around us, and it all starts with cells!

Lesson 3: Genetics

The Beginning of Genetics—Mendel

Gregor Mendel, the father of genetics, playing with his peas.

Gregor Mendel (1822-1884), was an Austrian (now part of Czechoslovakia) is best known for his experiments with peas. His experiments and careful record-keeping allowed him to be the first to develop the **laws of heredity**.

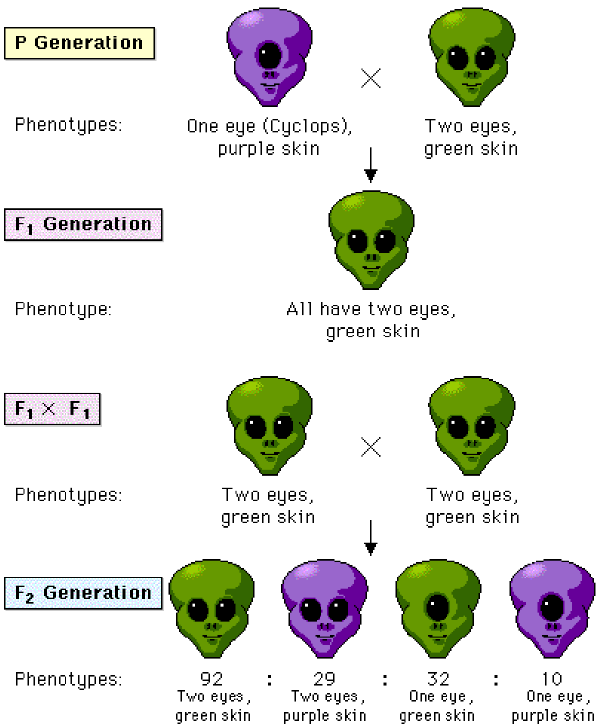
Mendel experimented with peas that did not carry all the same features. Some were tall, some were short, some had white flowers, some had purple flowers, some had wrinkled seeds while others had round ones... the peas carried many different features (which we will call **traits**[4] from now on).

Mendel followed the traits over generations. Peas were well suited to the experiment because peas have such short lives. Can you imagine trying to study generations of dogs? It would take years to see traits passed from one generation to the next! Mendel kept good records, and always noted when a trait was passed to the next generation, if it skipped a generation, or if it never appeared again. Another advantage was the way the pea flowers were pollinated; they could either self pollinate, or be cross-pollinated by Mendel. This way, Mendel meticulously constructed and observed the passage of traits over many generations of many varieties of plants.

P, F1, and F2

Mendel used a short-hand to discuss his results. Mendel called the parental generation of his peas the **P** generation. He called the offspring of the P generation the **F1** generation (short for *Filius*, meaning sons and daughters in latin). The offspring of the F1 generation he then called the **F2** generation.

[4] Trait is just another word for “feature”. However it’s the word used by biologists, so it’s the one we’ll use. The official definition of a trait is “a distinguishing characteristic or quality” (dictionary.com)



Mendelian nomenclature. Mendel used P to refer to the parent generation, F1 to refer to the offspring of P, and F2 to refer to the offspring of F1. In this case we're looking at alien inheritance of Mend-alien traits. An experiment Mendel never managed to get around to…

Mendel's strange results

At the time, people expected that traits were mixed and averaged each generation. If a tall woman and a short man had a child, that child was expected to be of average height. Likewise, when Mendel crossed a tall plant and a short plant the expected result in the F1 generations was a short plant. But it wasn't!

All of the F1 plants were tall—a completely unexpected result. But, even more unexpectedly, in the F2 generation 75% of the plants were tall, and 25% were short.

The law of segregation

This lead Mendel to develop **the law of segregation**—a law that still serves as a fundamental law of modern genetics. The law states that each organism gets two copies of the same gene[5], which separate (the "segregation" in the name of the law) when gametes[6] are produced.

Mendel used this law to resolve the curious results found in the short pea plant/tall pea plant experiment. He guessed that each plant has two copies of the same trait, but could only pass on one copy through reproduction. He then guessed that some traits were more dominant—more likely to show itself in the offspring—than others. For example, the *tall* trait was more dominant than the *short* trait. He called these traits that were more likely to be chosen (like the tall trait) **dominant**, and the

[5] At the time Mendel did not know that genes existed, so he simply referred to them as "hereditary factors".
[6] Remember: gametes are the reproductive cells produced via meiosis. Gametes only have one copy of DNA—half the amount found in the organism.

traits less likely to be chosen (like the short trait) **recessive**.

His experiments showed that if a plant with a dominant trait and a plant with a recessive trait reproduced the F1 generation would be 100% dominant trait. For example, all of the offspring of the tall and short plant were tall. But, the F2 would always be 75% dominant and 25% recessive—and F2 generation that was 75% tall and 25% short, in our example.

The dominant traits are designated by a capital letter, and the recessive traits are designated by a lowercase letter. For example, the dominant trait “tall” is designated the letter *T*, while short is given the lowercase letter *t*. Since the plants have two copies of each trait the combinations can be either TT, Tt, tT, or tt.

If both copies are dominant, than the dominant trait is seen (TT= tall plant). If there’s a mix, than the dominant trait is seen (Tt/tT = tall plant). If both traits are recessive, than the recessive trait is seen (tt = short plant). Since three of the four options result in tall plants, and one of the four results in short plants, it makes sense that Mendel observed the results he did.

That’s because after the first generation of TT X tt all of the plants were Tt and tT. But, when the tT/Tt generation was crossed, the plants could have all four combinations. Three out of the four combinations (TT, tT, and Tt) yield dominant traits, while the fourth combination (tt) yields short plants. Thus ¾ = 75%, and ¼ = 25%.

A good way of visualizing these results is with **Punnett Squares**. Punnett squares are simply tables we can use to show the possible combinations of traits. In our Tall/short example we can draw this Punnett Square:

Parental (P) Generation: TT crossed with tt

	The Recessive Plant		
The Dominant Plant		**t**	**t**
	T	Tt	Tt
	T	Tt	Tt

Result: 100% Tt. 100% tall.

F1 Generation: Tt crossed with TT

	T	**t**
T	TT	Tt
t	tT	tt

Result: 25% TT, 50% Tt, 25% tt. 75% tall, 25% short.

Modern Genetics: Additions, Further Explanations, and Exceptions to Mendel's Laws

It's really rare to get everything completely right the first time. It's only natural that Mendel's laws—while essential to the science of genetics—didn't fully explain the mechanisms of inheritance and overlooked some exceptions to the rules. After Mendel's contributions to genetics, there were still some questions to be answered.

First and foremost: What *are* these "inheritance factors"? What is the "tall" trait? What does it look like? What are these mysterious things? Could finding out cause a revolution in the field of biology[7]?

Second: What about the exceptions? Sometimes offspring are neither fully dominant, nor fully recessive. Sometimes a white flower crosses with a red flower and produce a *pink-flowered* F1 generation! How can we explain exceptions like this and others?

[7] Yes.

DNA—the "inheritance factors"

DNA (short for deoxyribonucleic acid), the double-helix shaped molecule found in all cells, answered the question of what these "inheritance factors" were. DNA is often thought of as the cell's "recipe book." DNA holds the instructions for building proteins the same way recipe books hold the instructions for making dishes. The individual codes for making proteins are called **genes**, and are like the recipes of the cookbook. <u>These genes are the inheritance traits</u>.

The genes are passed on from generation to generation and instruct the cell how to make proteins. Here's the tricky part: the proteins made by the cell—according to the recipe from the gene—is the trait exhibited by the organism.

For example: In Mendel's peas there were some peas that had a "wrinkled" appearance, and others that hand a smoother "round" appearance. As it turns out, "wrinkled" and "round" are just two versions of the same recipe. Some plants used the "wrinkled" recipe; others used the "round" recipe. Although we're calling it a recipe right now, we can just as easily call it by its scientific name—a gene.

These genes are what is inherited. These genes are the "inheritance factors" Mendel discussed.

DNA is simply two strands of genes. That is to say, the way traits are inherited as genes. To be exact, two copies of each gene in inherited. Which version of the gene is expressed (shows in the offspring) depends on dominance as well as other factors.

So, to answer the question "what are the 'inheritance factors' discussed by Mendel?": genes.

Different versions of the same gene: Alleles

In every cell there is DNA which is composed of two copies of every gene. That means, each gene has a corresponding copy. For example, if there's a tall pea plant that means there's a *T* gene as well as either another *T* or a *t*. These corresponding copies are called **alleles**. The alleles can either be the same or different[8].

Genotype and Phenotype

Genotype and **phenotype** are the words we use to describe what genes an organism has, and which traits are expressed, respectively.

[8] If they are the same they are called "homozygous" and if they are different they are called "heterozygous".

They are extremely useful because organisms do not express all of their genes—mostly the dominant ones. We use the word "genotype" to describe the genetic composition of a cell. Is the cell a TT? Is it a Tt? Is it a tt? To talk about which genes an organism has we use the word "genotype".

Phenotype, on the other hand, is just used to describe the appearance of the organism. Is it round? Wrinkled? Tall? Short? The phenotype is the physical trait expressed.

Exceptions to Mendel's Laws

Incomplete dominance and codominance

Mendel's laws do not explain when traits are averaged. When both a dominant and a recessive trait are present in the DNA (a heterozygous genotype), but an average of the two traits is expressed. For example, when a red Snapdragon Flower is crossed with a white Snapdragon Flower, and the F1 offspring are… Pink! There is no explanation for that in Mendel's laws. According to his laws, the dominant must be expressed.

This exception is called **incomplete dominance**. The dominant trait is expressed, but not fully.

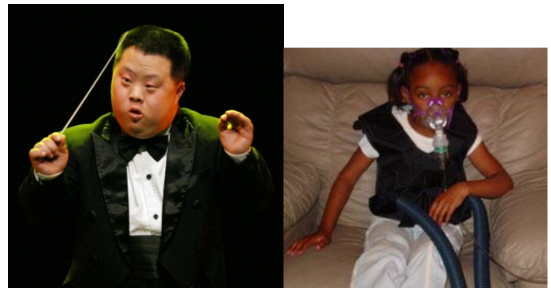
Pink Snapdragon Flower. Incomplete dominance in action!

Another exception is when there are two different types of dominant alleles which are both expressed. This is called **codominance**. For example the AB bloodtype carries traits of both the A and B blood type despite both of them being different dominant alleles.

Polygenic traits

Polygenic traits are traits controlled by multiple genes. For example, human height and skin color traits are controlled by multiple genes.

Human Genetics



Genetic disorders. *Left to right: a man with Down Syndrome, and a girl with cystic fibrosis.*

Peas are great, but what does genetics have to do with me? What does genetics have to say about human beings? A lot, actually.

Mendel's laws help us study the various **genetic disorders** (such as Down Syndrome, and Cystic Fibrosis) that affect humans. A genetic disorder is simply a disease or disorder that is inherited genetically. Genetic disorders can be caused by single defective gene, or by entire defective chromosomes. These disorders caused by defective chromosomes are called **chromosomal disorders**. Downs Syndrome is an example of a chromosomal disorder.

Using simple Punnett Squares, and Mendel's laws, we can figure out how genetic disorders are inherited.

Sex-linked Inheritance

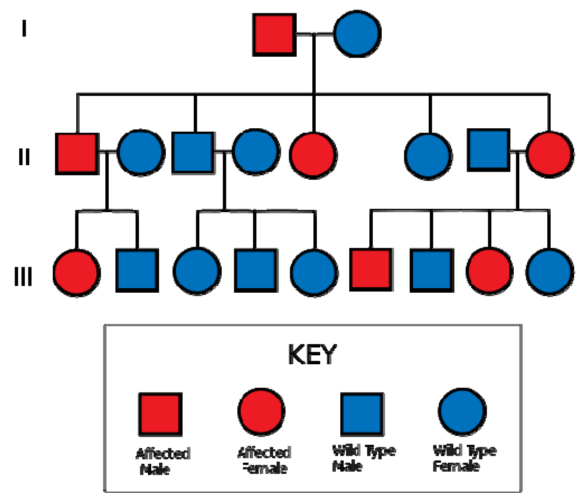
What determines if a baby is a boy or a girl? Recall that you have 23 pairs of chromosomes, one pair of which are the sex chromosomes. Everyone has two sex chromosomes, X or Y, that determine if we're male or female.

Females have two X chromosomes, while males have one Y chromosome and one X chromosome. So if a baby inherits an X from the father and an X from the mother, it will be a girl. If the baby inherits the Y chromosome, it will be a boy.

Notice that a mother can only pass on an X chromosome, so the sex of the baby is determined by the father. The father has a 50 percent chance of passing on the Y or X chromosome; hence it is a 50 percent chance whether a child will be a boy or a girl.

One special pattern of inheritance that doesn't fit Mendel's rules is **sex-linked inheritance,** referring to the inheritance of traits which are due to genes located on the sex chromosomes. The X chromosome and Y chromosome carry many genes and some of them code for traits that have nothing to do with determining sex. Since males and females do not have the same sex chromosomes, there will be differences between the sexes in how these sex-linked traits are expressed.

Pedigree Analysis



What is this chart? It's a **pedigree analysis**. These charts, usually used for families, allow us to visualize the inheritance of genotypes and phenotypes (traits). In this chart, the P, F1, and F2 generation are represented by the numerals I, II, and III respectively. Notice that those carrying the trait are colored red, and those not carrying the trait (the normal-looking ones) are in blue. The normal, non-trait carrying organisms on the chart are called the **wild-type**.

The term wild-type is used in genetics often to refer to organisms not carrying the trait being studied. For example, if we were studying a gene that turns house-flies orange, we would call the normal-looking ones the wild-type.

Modern Genetics

Genes are the stuff of life. Naturally, current genetic research is extremely relevant and exciting. Advances in genetics include better treatments of diseases, more productive agriculture, and improved crime-fighting. However, as we learn to control the basic units of life we begin to walk into ethical grey-zones. Should humans be able to clone themselves? Should we be able to choose what traits we want our children to have? These are questions that still need to be answered. As we reap the benefits of our control, we must still ask ourselves—at each step—whether what we are doing is ethically correct.

How to cut and paste genes

We can manipulate DNA to get proteins we want, and even entire organisms we want.

This is done by creating **recombinant DNA**. Recombinant DNA is DNA from multiple sources. For example, we can take genes (that is, a piece of DNA) from one bacterium and put them into the DNA of another. Because we have to separate the genes we want from the first bacterium and then *re-combine* them into the second, we call the DNA we create recombinant.

To cut genes out of a strand of DNA, geneticists use an extremely useful tool called **restriction enzymes**. Restriction enzymes cut DNA at specific points (specific sequences of DNA). There are more than 3,000 known restriction enzymes. Because we know where theses restriction enzymes cut the DNA, we can use them to cut the specific section of DNA we want to re-combine. Restriction enzymes' ability to cut DNA at specific sequences makes them an important part of the process of creating recombinant DNA.

The Human Genome Project

A genome is all the genetic information of an organism. The human genome is all of the genetic information that humans have—all that makes us human.

The **Human Genome Project**, completed in 2003, was an international effort to identify and locate[9] the over 20,000 human genes. Although the project was completed, the results (the identified and mapped genes) are still being analyzed. The results will make help us understand how we work, and who we are. That knowledge will help us fight diseases and genetic disorders. It can lead to advances in **gene therapy,** the manipulation of human genetic information to cure disorders. Additionally, since it contains the information of our ancestors, it will also help us understand where we come from. The Human Genome Project sequenced and mapped all human genetic information.

[9] On the chromosome.

