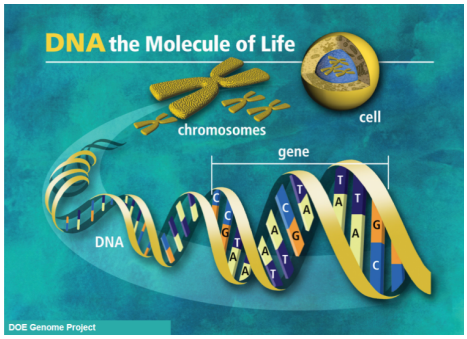
Reflect

You are probably well aware that your genetic material determines most of your physical traits. The DNA inherited from each of your two parents dictates your body structure, height, eye and hair color, and even the precise shape of your toes. Furthermore, modern science is discovering an increasing number of health characteristics influenced by genetics. Predispositions to cancer, heart disease, and even drug addiction have links to specific genetic markers. What about personality traits like calmness, anger, and anxiety? Could these traits be predetermined by our genetic makeup?

Certain phytochemicals found in fruits and vegetables are known to help prevent illnesses like cancer and heart disease.

Social and psychological scientists have long debated the question of "nature versus nurture." How much of what makes us "who we are" is predetermined by our heredity? And how much of it is influenced by our environment and actions? While scientists increasingly discover genetic links to both physical and behavioral characteristics, most agree that lifestyle choices can have a dramatic impact on many of these traits. Therefore, diet and exercise can play an important role in preventing diseases that might otherwise result from certain genetic patterns.



Inheriting our genetic material is akin to being dealt a hand of cards. It is up to each individual to make strategic decisions to optimize his or her health. But, what exactly is the genetic material that determines so much about every living organism? What does it look like, how does it work, and where is it found?

The Genetic Blueprint for Life

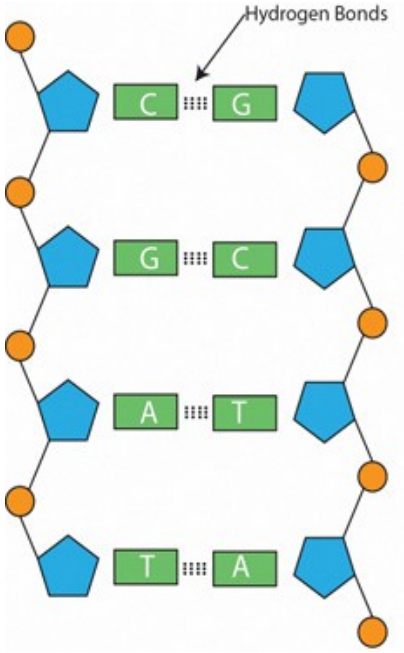
DNA, or **deoxyribonucleic acid**, stores all of the genetic information required to grow and maintain a living organism. In **eukaryotes**, DNA is housed in the nucleus of each cell. Like other major organic biomolecules, DNA is a **polymer**. It is made up of repeating molecular subunits called **nucleotides**. A single nucleotide consists of three chemical groups: a sugar, a phosphate, and a nitrogenous base. The sugar found in DNA is called deoxyribose. There are four types of nitrogenous bases: **adenine** (A), **cytosine** (C), **thymine** (T), and **guanine** (G). The particular base within a nucleotide determines the identity of that nucleotide.

Eukaryote:
an organism with a membrane-bound nucleus and organelles

Polymer:
a large molecule formed by the bonding of smaller molecular units

Reflect

Many nucleotides string together through bonds between the phosphate group of one nucleotide and the sugar of the next. These bonds are called strong covalent bonds. This nucleic acid structure, including the four nitrogenous bases, sugar, and phosphate, is identical in the DNA of all living organisms.



Two individual nucleotide strands are joined by hydrogen bonds between their respective nucleotide bases. In this way, the DNA molecule may be pictured like a ladder. Together, the sugars and phosphate groups make up the vertical beams of the ladder, and the nucleotides make up the horizontal rungs. To complete the picture, imagine the ladder twisted into a helical configuration. This yields the double helical structure of DNA.

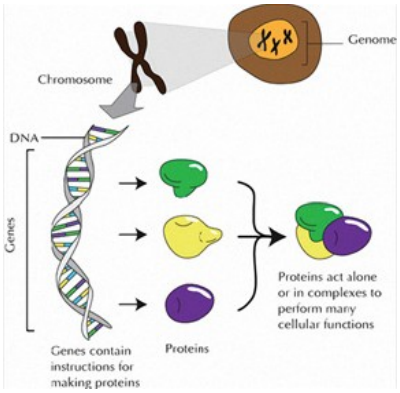
Because of their unique structures, the nitrogenous bases that join two strands of a DNA molecule bind according to the following rules: adenine binds with thymine, and cytosine binds with guanine. Due to these binding rules, the two strands of DNA are said to be “complementary.” Therefore, if the sequence of one strand is known, the other can be deduced. The bonds between the sugar and phosphate groups of a DNA molecule are strong **covalent** bonds. In contrast, nitrogenous bases are connected by weaker **hydrogen** bonds. Covalent bonds are formed through the sharing of electrons. In contrast, a weak association between a hydrogen atom and with the negatively-charged area of another atom forms hydrogen bonds. This relatively weak bond becomes important when a DNA molecule must be separated in order for each strand to be replicated. DNA replication occurs each time a cell divides.

What Do You Think?

Examine the following nucleotide sequence in a strand of DNA: CAGTTGATAGCC. What sequence of nucleotides would be found in the complementary strand?

Reflect

Genes and the Production of Proteins

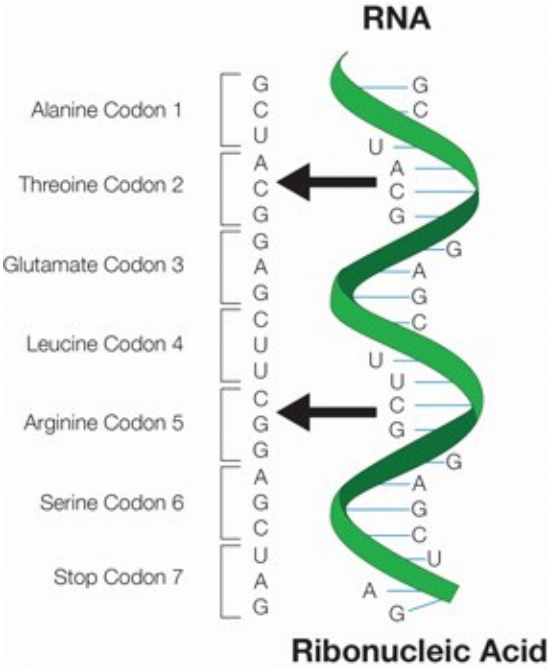


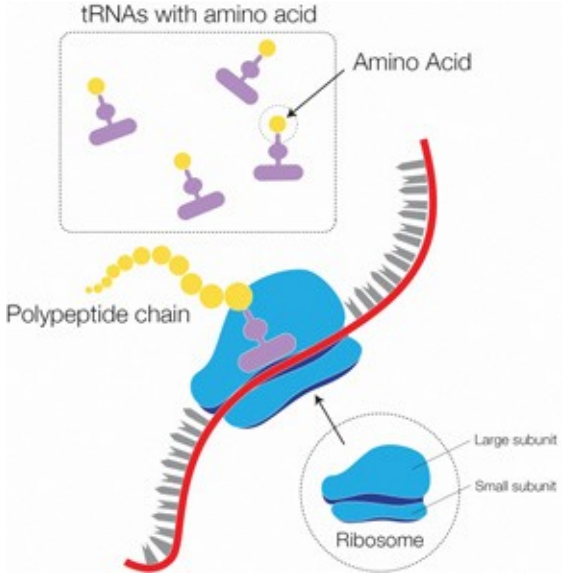
Each cell in an organism contains the entire genome for that organism (the full complement of its DNA). If all of the DNA within a human cell were laid out in a straight line, it would span approximately two meters in length! In order to fit inside the tiny cellular nucleus, DNA is folded up tightly. Individual strands are wrapped around special proteins called histones. Histone complexes are then repeatedly coiled to form chromatin. During the prophase of mitosis and meiosis, each strand of chromatin is supercoiled into tightly compact structures called chromosomes.

One major question remains: How is it that DNA controls the traits of living organisms? The answer involves a very important cellular component: proteins. Proteins effectively determine virtually everything about a living cell and, thus, an organism. The proteins within a cell determine the cell's structure and function. Proteins regulate which materials will be transported into and out of cells. They determine the products a cell makes such as hormones, pigments, or mucus. They also determine whether a cell will be motile (like sperm and certain immune cells) or contain large amounts of contractile muscle fibers (like muscle cells). Simply put, DNA controls cellular fate by providing the instructions for making each protein within a cell. The specific sequence of nucleotide bases within a section of DNA serves as a code that translates into the sequence of amino acids required to build a specific protein. This special section of DNA that includes the sequence necessary to build a protein is called a *gene*. The number and specific nucleotide sequence of all of the genes within an organism's DNA determines the inherited traits of that organism.

The process of reading out the information within a cell's DNA to produce a protein takes place in two stages. First, a specific gene within the DNA is copied to produce a nearly identical molecule of RNA (**ribonucleic acid**). RNA differs from DNA in that it consists of only one strand. RNA also uses sugar ribose instead of deoxyribose. Additionally, RNA lacks the nucleotide thymine. In place of thymine, RNA uses a nucleotide called **uracil** (U). Once a strand of RNA is synthesized complementary to a gene on the DNA, it leaves the nucleus. In the cytoplasm of the cell, the nucleotide code of the RNA strand is decoded, or "translated," into an amino acid code. Amino acids are brought together one by one with the help of other molecules. These amino acids are assembled in the appropriate sequence to form the final protein.

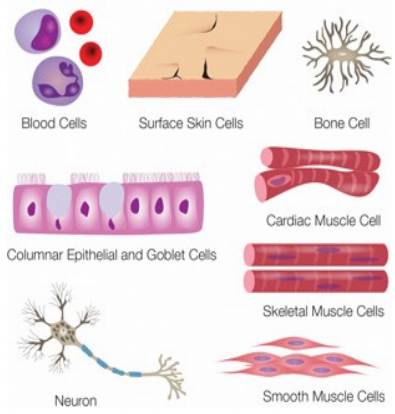
Reflect





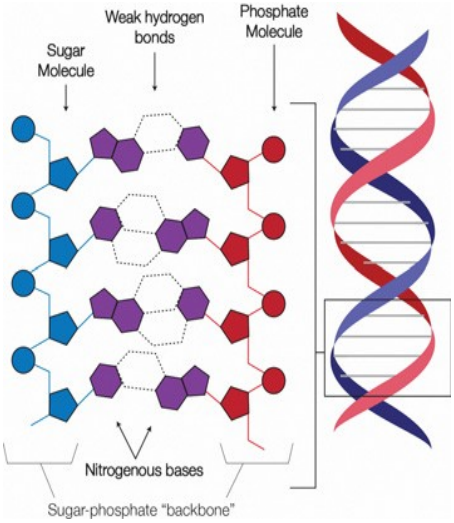
Look Out!

Complex multicellular organisms contain a huge variety of cell types. Consider the differences between muscle, brain, blood, skin, and bone cells. Each of these cells has a different structure and performs unique jobs. These differences arise from the different proteins expressed in each of them. However, it was mentioned earlier that all cells contain a copy of the same genome (all of an organism's DNA.) How is it that different cell types contain different types of proteins if all cells contain exactly the same DNA? The answer lies in the control that each cell exerts over which genes are expressed (actively copied to make RNA) and which remain silent. Imagine
a group of actors rehearsing a play with each actor holding a copy of the same script. Each actor only reads his own lines, skipping everyone elses. Similarly, each cell within an organism only expresses the specific genes that it needs to perform its functions, skipping other genes. This discretion is made possible with the help of special proteins called "transcription factors." Transcription factors bind to genes within the DNA and either promote or hinder the copying of those genes into RNA.



Reflect

Discover Science: The Discovery of the Structure of DNA



The discovery of DNA structure in the 1950s answered many important biological questions. For years, the hunt was on to determine what this molecule was made of and what it looked like. By the 1940s, scientists knew that nucleic acids specifically containing the four bases, A, C, T, and G, comprised the molecule of heredity. However, the arrangement and structure of this molecule remained a mystery until the following decade. Two scientists at Cambridge University, James Watson and Francis Crick, worked hard to uncover DNA's structure. They used various models and arranged atoms in a variety of ways. They made structural predictions based on what they knew about the atomic makeup of DNA.

At the same time, another scientist, Rosalind Franklin, was also working hard to determine the structure of DNA. Franklin used a sophisticated research technique called X-ray crystallography, in which X-rays are shot at crystalized samples of a molecule. When the X-rays diffract off of the molecule's atoms, a vague, shadowy image is revealed. Using this technique, Franklin generated an image of the DNA molecule, which her research partner, Maurice Wilkins, showed to Watson and Crick.

When Watson and Crick saw the image, they quickly deduced that it pointed to a double-helical structure. Watson and Crick soon published their findings that DNA was a double helix, with a sugar-phosphate backbone on the outside and nucleotide bases on the inside. Watson, Crick, and Wilkins shared the Nobel Prize for this discovery in 1962. Unfortunately, Rosalind Franklin was not included in the honor because she had died before it was awarded. In her lifetime, Franklin did not receive the credit she deserved, but the scientific community today is well aware of her contribution to this momentous discovery.

Reflect

Looking to the Future: Looking Into *Your* Future by Knowing Your Own DNA Sequence

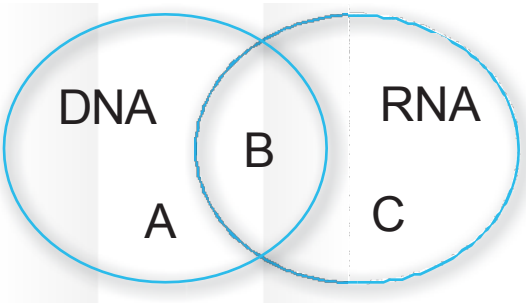
If you could see into your own future using a magic crystal ball, would you do it? At one time, people thought this was science fiction, but determining one's future based on genetics is quickly becoming a reality. The term "predictive medicine" refers to the concept of determining a person's risks for disease and illness based on his or her specific genetic sequence. The groundbreaking "human genome project," spanning about 13 years and costing billions of dollars, successfully determined the full sequence of human DNA in 2003. Since then, many companies have been racing to develop commercial technology that can do the same thing—sequencing a person's full genome—for the average individual. The company *Life Technologies* announced such a service in January 2012. For $1,000, any individual can know his or her DNA sequence in one day.

Full, individual genome sequencing would reveal genetic markers that indicate risks for cancer, neurological disease, cardiovascular disease, and much more. The implications of such technology are vast, and some are controversial. Of course, the ability to be proactive about making lifestyle choices to prevent one's own health risks would be hugely advantageous. However, should medical insurance companies have access to your DNA sequence? Would they use that information against you? How might you live your life differently if you knew your DNA?

What Do You Know?

Using the following list of phrases and the Venn diagram below, decide whether each phrase belongs in category A, B, or C. Write the correct letter next to each phrase.

1. Directly translated into protein
2. Double helix
3. A nucleic acid
4. Contains the sugar **ribose**
5. Wrapped around histones
6. Single stranded
7. Contains nitrogenous bases
8. Double stranded
9. Sugar-phosphate association through covalent bonds
10. Contains adenine, cytosine, guanine, and uracil



Connecting With Your Child

Building a DNA model

To help your child better understand DNA structure, build a DNA molecule together.

Using construction paper or cardboard, draw the different molecular group components of DNA and cut them out: phosphate, deoxyribose, and nitrogenous base. You can find templates for these at the bottom of the page. Decide how long your molecule will be based on the amount of time, space, and paper you have available. Try to use each base pair at least once. Since DNA is double stranded, you will need twice the number of components to build one strand and its complementary strand.

Label the nitrogenous bases A, C, T, or G. You may want to staple the sugar-phosphate groups together and use tape to connect the nitrogenous bases. When constructing the complementary strand and connecting nitrogenous bases, be sure to pair the bases in the appropriate configuration (A pairs with T, and C pairs with G.) Once your molecule is complete, take hold of each end and twist gently until a double helix is formed. You may want to construct a double helix that reaches from the floor to the ceiling. If there is a base on which to attach both ends of the molecule, the model can be twisted and maintained in a helix.

Here are some questions to discuss with your child:

- When DNA is copied to make an RNA strand, the double helix must be separated into two individual strands. Given this, why do you think it is important that the sugar- phosphate bonds be strong covalent bonds (as opposed to the weaker hydrogen bonds between bases)?
- Remember that during meiosis, our DNA is tightly condensed into structures called chromosomes. If a fertilized egg inherits a full complement of chromosomes (23) from both the sperm and the egg, how many chromosomes are contained in the fertilized egg?
- Looking at your DNA model, in what ways would this model differ if it were a model of RNA?