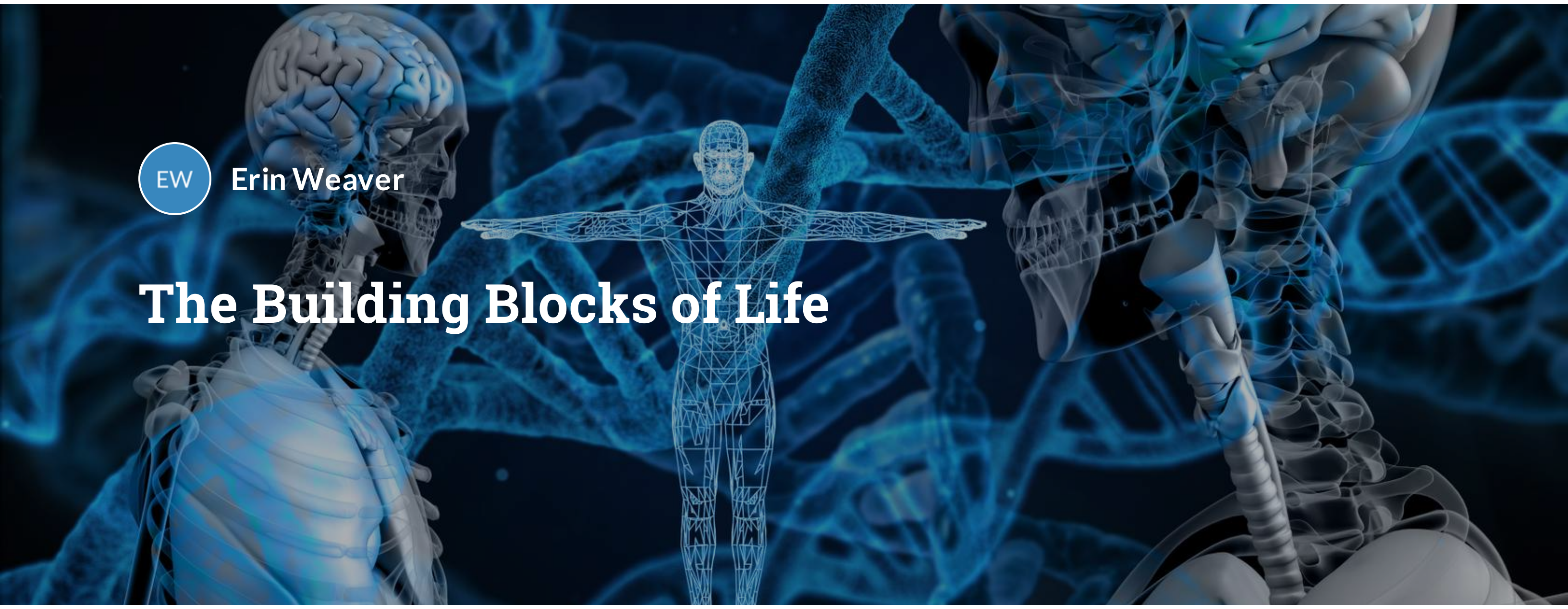


EW Erin Weaver

The Building Blocks of Life

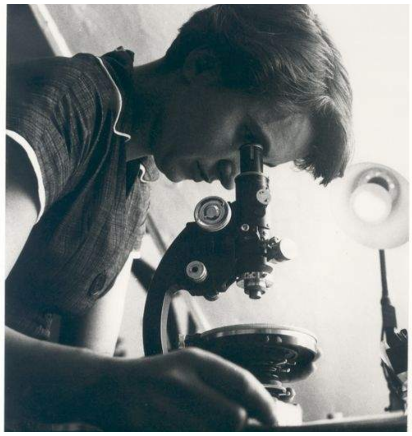
Have you ever wondered why living things look and act so differently? Why does a poodle look different than a bulldog? Why can you do math problems but a vegetable can't? Venture through this mini course to discover how one molecule makes everything alive unique!

Click the "*Start Course*" button to begin your journey.

Take the Quiz

The Molecule that Changed Everything

EW Erin Weaver



The Great Discovery

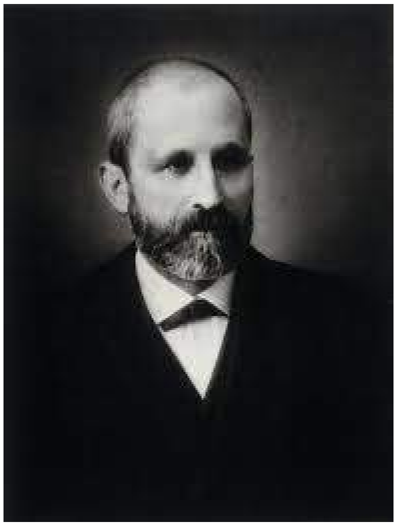
Why is life is so diverse? It's a question that has been asked for centuries by scientists across the world. The diversity of life can best be understood through the lens of genetics. **Genetics** is the study of how characteristics are passed from one generation to the next. While there are many discoveries in genetics that have led to breakthroughs in understanding the diversity of life, the discovery of a single molecule and its structure stands as the key piece to solving this puzzle. Learn more about this molecule and how it was discovered by clicking through the slides below![1,2]

A Brief History of Early Genetics

Click the "Start" button below to begin

Step 1

1869: Isolation of a Nucleic Acid



In the late 1860's, a Swiss physician named Fredrich Miescher busied himself collecting bandages from a clinic in Tübingen, Germany. Miescher used the pus he collected from these bandages to look at the nuclei of white blood cells. Miescher predicted that he would find proteins and lipids, but instead, he discovered an interesting substance he did not expect.

Miescher isolated this substance, and further characterized it's properties. He named it "nuclein" after it's location in the cell. Without knowing it, Miescher had stumbled upon the most important molecule in genetic history!

Step 2

1885-1901: Re-Naming the Molecule of Life

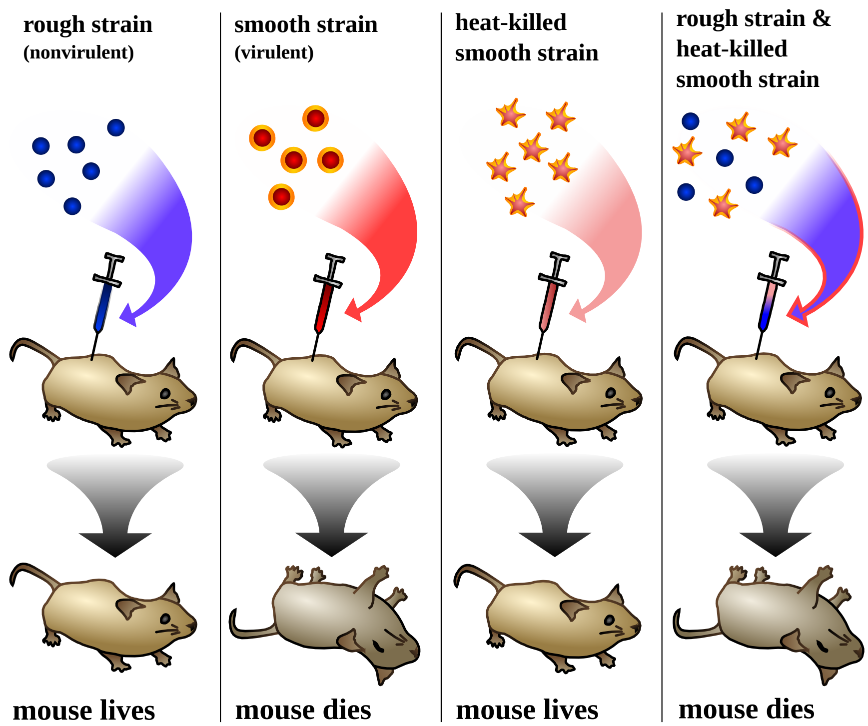
After the discovery of this unique molecule, many scientists ventured to understand it's properties. Alberecht Kossel, a German biochemist, identified this substance as a nucleic acid, a large molecule made out of small segments called **nucleotides**.

Kossel gave the molecule the name it is still called today- **Deoxyribonucleic Acid or DNA**.

He also eventually identified and described five bases that make up the **nucleotides** forming this **DNA**- adenine, thymine, cytosine, guanine, and uracil. These would prove crucial in understanding it's function in later years.

Step 3

1928: Genetic Material Can Be Transfered



In January 1928, Frederick Griffith, a British bacteriologist was performing experiments on *Streptococcus pneumoniae*, the bacteria that causes pneumonia. In his experiment, Griffith used two strains of bacteria– a type III-S strain, which was known to cause pneumonia, and a type II-R strain which did not cause pneumonia. His experiment consisted of three parts.

A. Griffith first injected mice with both strains of bacteria. The mice injected with the S strain died of pneumonia. The mice that were injected with the R strain lived.

B. Next, Griffith used heat to kill the S strain bacteria. He then injected the mice with this dead bacteria. As expected, the mice were not infected with pneumonia and lived.

C. Finally, Griffith injected the mice with both the dead (heat killed) S strain bacteria and the living R strain bacteria. When injected separately, neither strain would kill a mouse. Astonishingly, when injected with both of these strains together the mice died!

Griffith concluded that the genetic information from one strain of bacteria was somehow transferred to the other strain allowing it to kill the mouse. It was hypothesized that proteins caused this transfer of genetic material between two bacterial cells.

Step 4

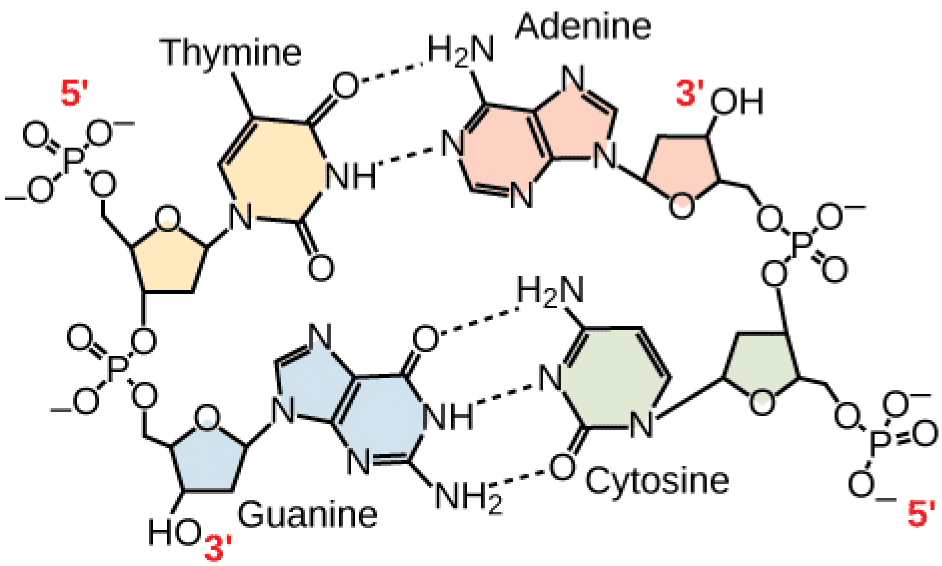
1944: DNA Transforms Cells

Motivated to find the cause behind Griffith's experimental results scientists Oswald Avery, Colin MacLeod, and Maclyn McCarty, performed their own experiment in 1944.

Through their experimentation they were able to conclude that it was not protein that was responsible for carrying genetic material from one bacterial cell to another but rather **Deoxyribonucleic Acid**. This discovery drastically changed the level of importance **DNA** held in the scientific community, proving that it was far more complex than originally thought.

Step 5

1949: Chargaff's Rule Established

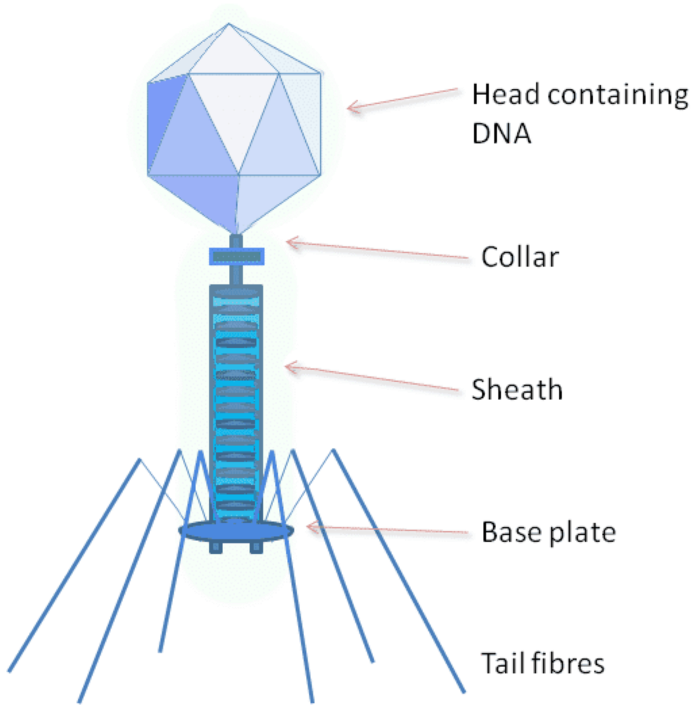


While Albrecht Kossel, identified and described the five bases that make up the **nucleotides** that form **DNA**, little was known about the relative amounts of each in a **DNA** molecule.

In 1949, Erwin Chargaff, an Austro-Hungarian born scientist working at Columbia University, discovered that the amounts of each of the five nucleotide bases (adenine, thymine, cytosine, guanine, and uracil) varied greatly among samples of DNA from different species. In addition, he found that the amounts of adenine (A) and thymine (T) were always equal and that the amounts of cytosine (C) and guanine (G) were always equal. This became known as **Chargaff's Rule**.

Step 6

1952: DNA is the Carrier of Genetic Material

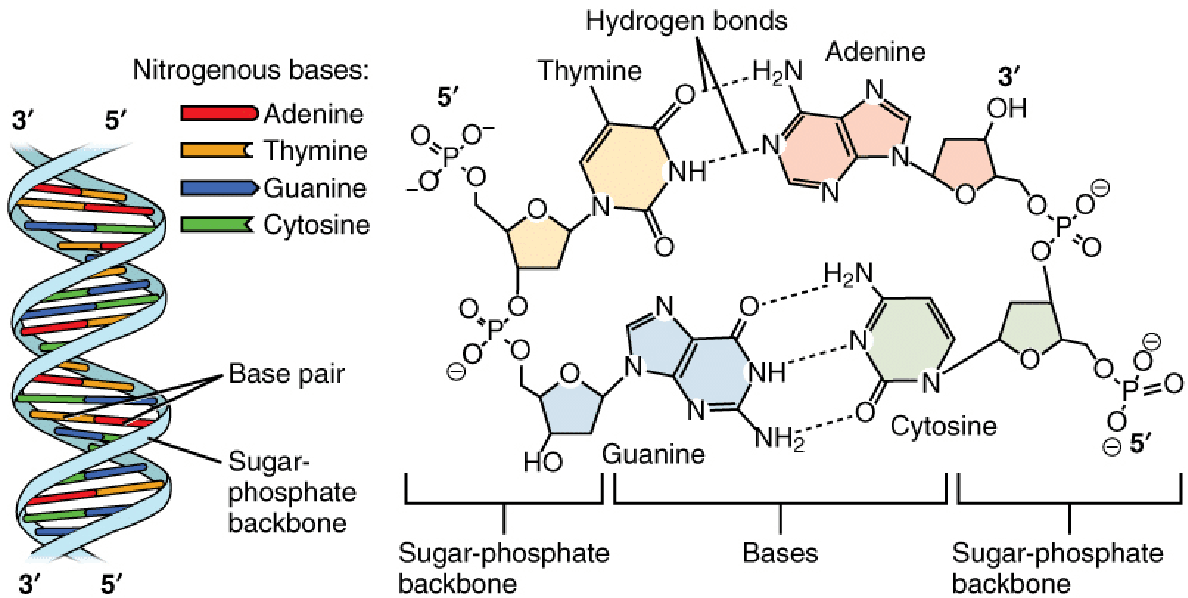


Despite the 1944 experiments of Avery, MacLeod, and McCarty, the idea that protein was responsible for carrying genetic information continued to persist.

In 1952, scientists Alfred Hershey and Martha Chase set out to test this theory once more. They experimented with **bacteriophages**, a virus that attacks bacteria and is made primarily of DNA and protein. Their experiment revealed that, while transfer of genetic information is occuring, most of the protein from the bacteriophage does not even enter the bacteria they attack. **DNA**, however, did enter the host. This confirmed, definitively, that **Deoxyribonucleic Acid** is the carrier of genetic material.

Step 7

1953: A 3D Model is Formed



Now that DNA had been identified as the molecule that was responsible for carrying genetic information the race to determine more about it's structure was on.

Rosalind Franklin, a British scientist, experimented with x-ray crystallography to seek answers. She captured images of crystallized **DNA** (shown below) that gave insight into the structure of the molecule.

These images were shown to scientists James Watson and Francis Crick, another pair of British scientists by Franklin's colleague, Maurice Wilkins. Watson and Crick used Franklin's images, as well as previous research in the field, to perfect their own theory on the structure of **DNA**. In 1953, they published their model of **DNA.** This model portrays two strands twisted like a ladder to form a "double helix" and is still used today!.

Summary

Over the course of 85 years of scientific research and experiments, Deoxyribonucleic Acid (DNA) was identified as the molecule that carries genetic information, and it's structure was accurately outlined [1,2].

Knowledge Check

Identify each statement below as true or false by dragging and dropping it in the appropriate location.

True

Frederick Miescher discovered DNA and called it nuclein.

Rosalind Franklin contributed to the formation of a 3D model of DNA

It has been confirmed that DNA is the carrier of genetic information

Experiments show that DNA facilitates exchange of genetic info between bacteria

False

The model of DNA that we have today was formed by a single scientist.

Griffith's rule says that the nucleotide base A =T and the nucleotide base C=G

Erwin Chargaff named DNA deoxyribonucleic acid because of it's composition.

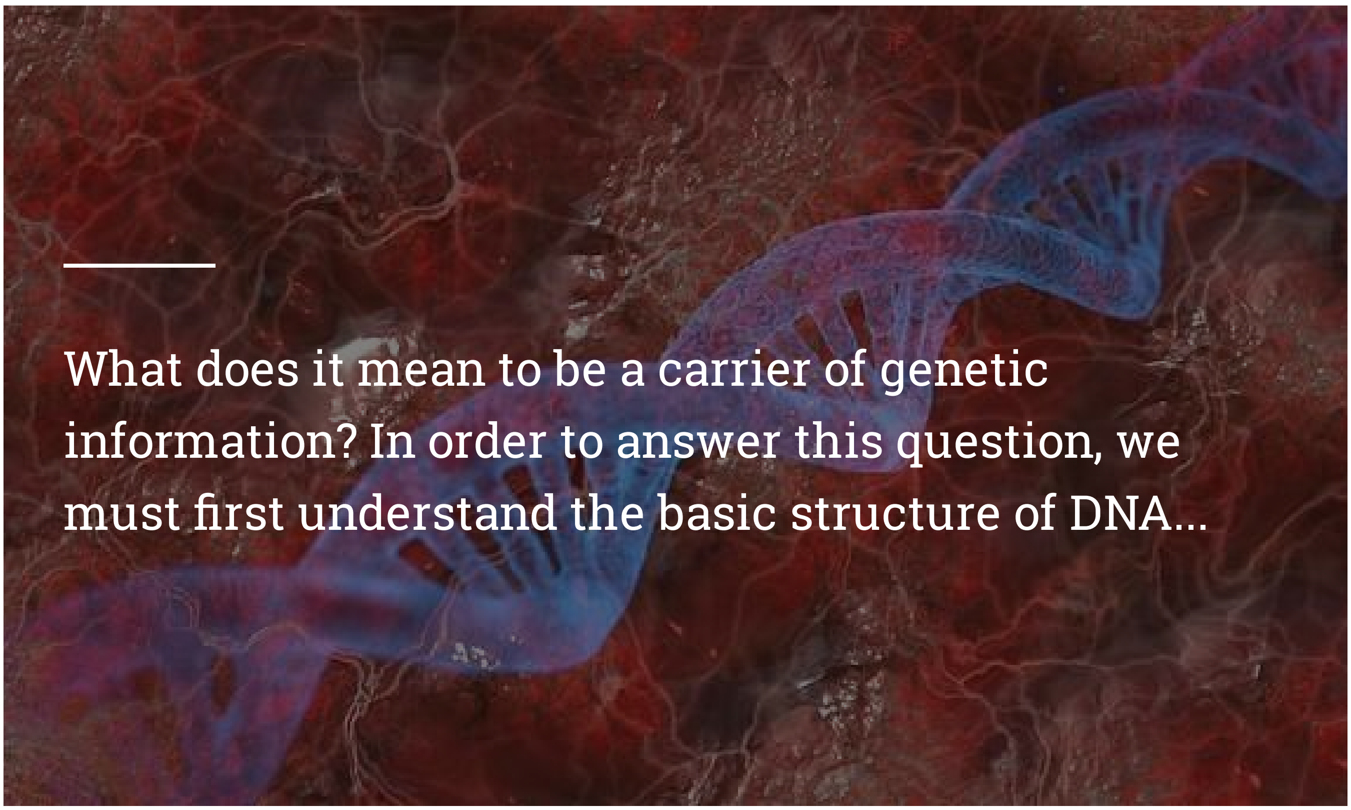
So far, we've learned the history of early DNA research, and that DNA is the carrier of genetic information. But what does that mean? Click "continue" below to find out.

CONTINUE

Sources: 1) “A Brief History of Genetics: Defining Experiments in Genetics.” Nature News, Nature Publishing Group, www.nature.com/scitable/ebooks/a-brief-history-of-genetics-defining-experiments-16570302/contents/. 2) “Genetic Timeline.” National Human Genome Research Institute. https://www.genome.gov/Pages/Education/GeneticTimeline.pdf.

The Double Helix

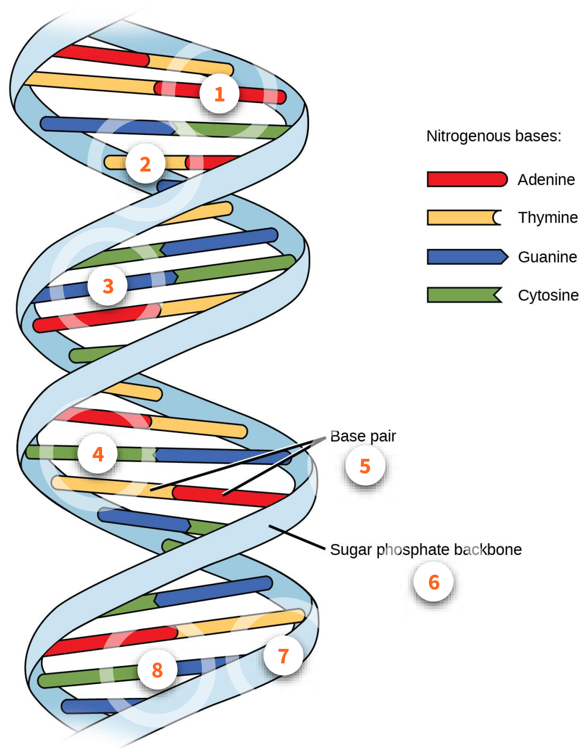
EW Erin Weaver



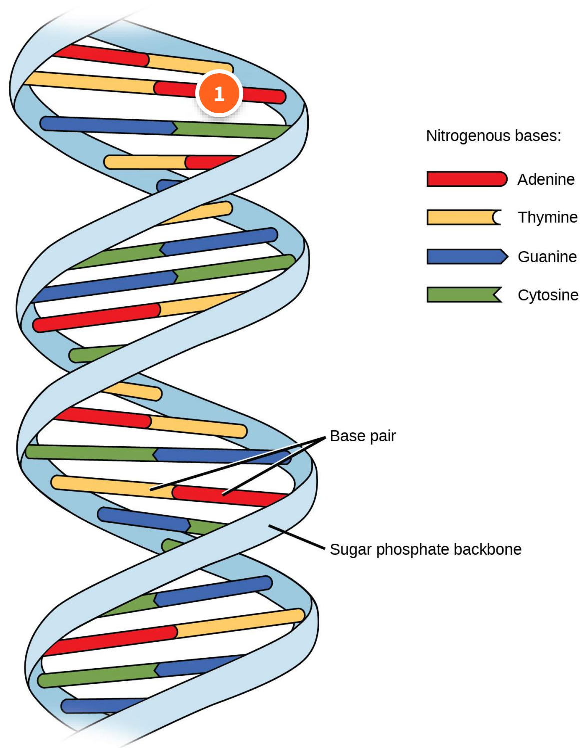
What does it mean to be a carrier of genetic information? In order to answer this question, we must first understand the basic structure of DNA...

The Structure of DNA

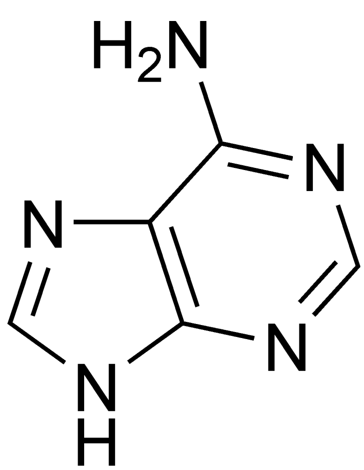
Click each button below to learn more!



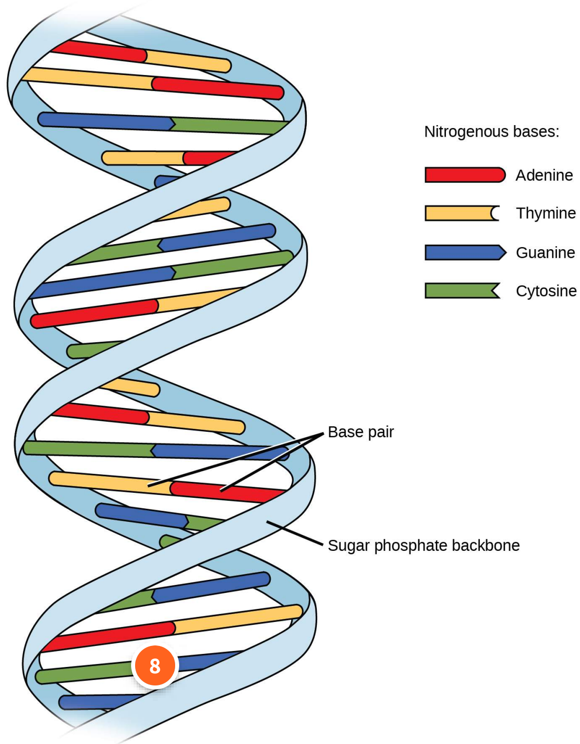
Nitrogenous bases:
Adenine
Thymine
Guanine
Cytosine
Base pair
Sugar phosphate backbone
1
2
3
4
5
6
7
8



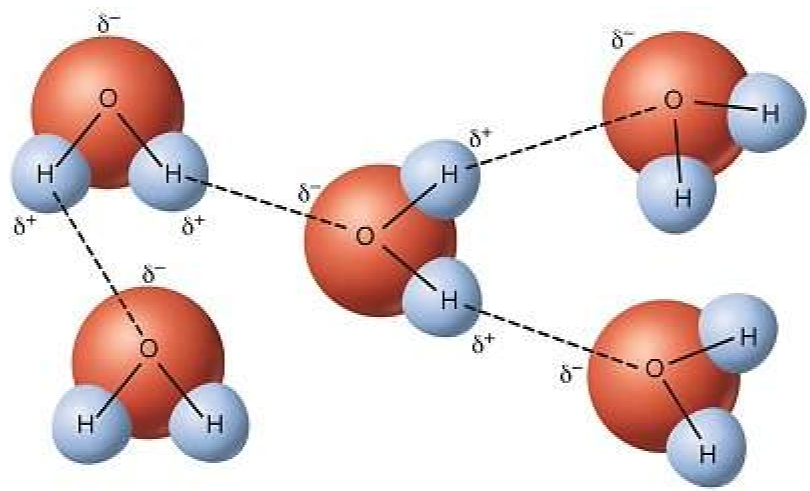
Adenine



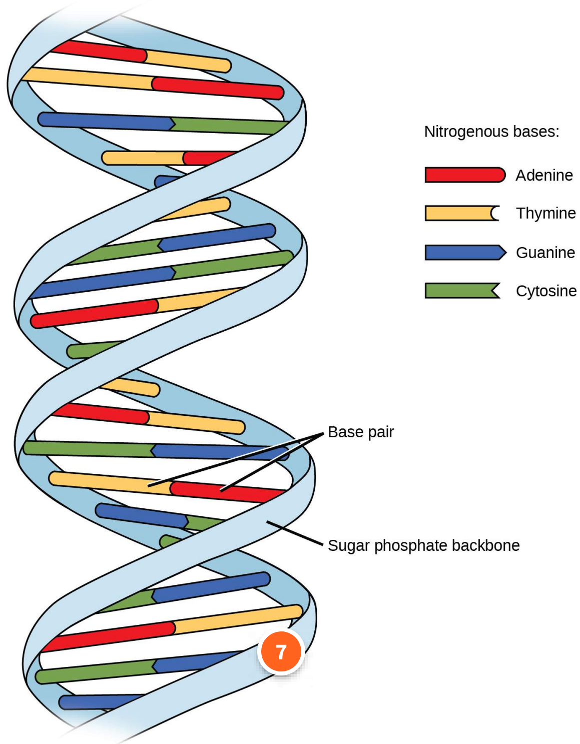
Nitrogenous base that always pairs with Thymine in DNA. Often abbreviated "A."



Hydrogen Bond

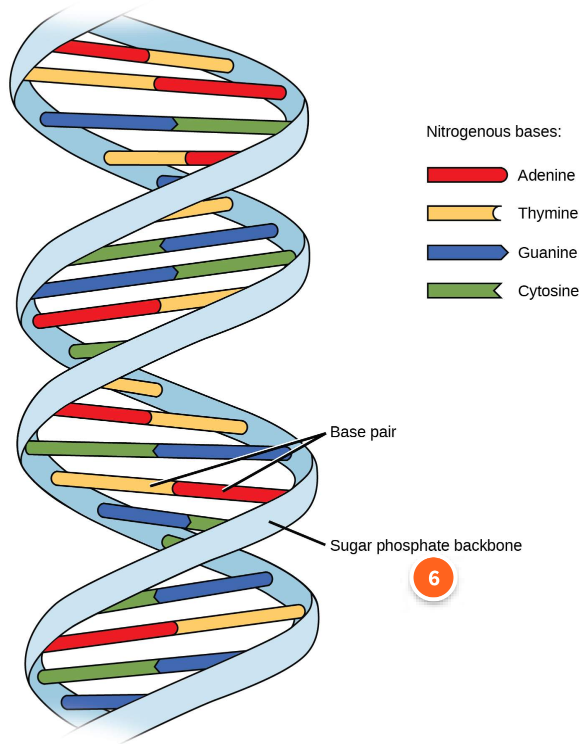


Each base pair is joined together by a **hydrogen bond**. This is a weak bond that forms when the electrons in different elements causes a partial charge to exist. This charge can then be attracted to other partially charged particles and form a bond.

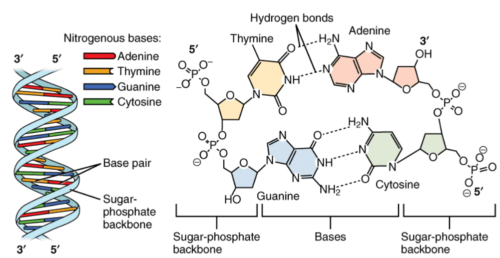


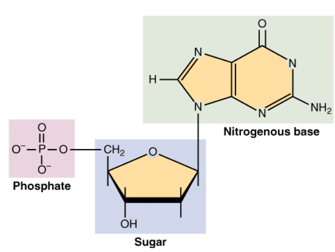
Double Helix

The term given for the "twisted ladder" structure of DNA as a whole.

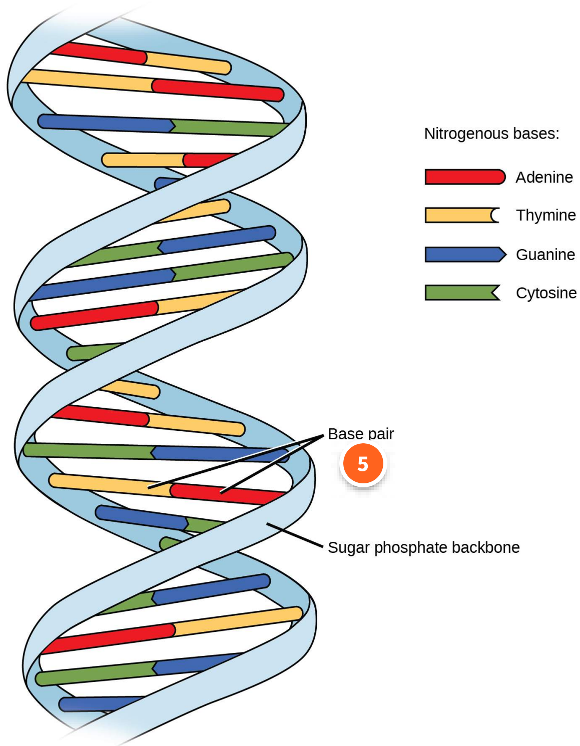


Backbone



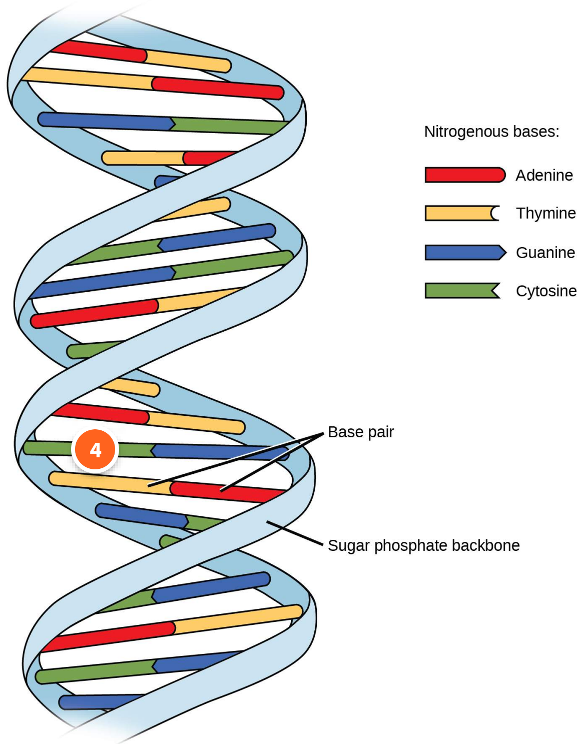


DNA's backbone is made up of a sugar, called deoxyribose, and a phosphate group.

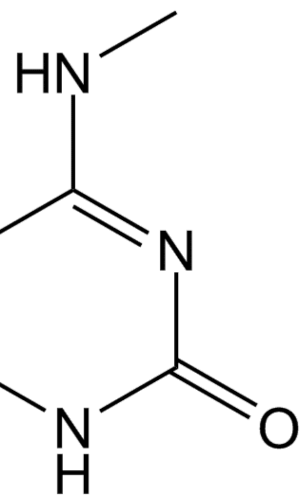


Base Pair

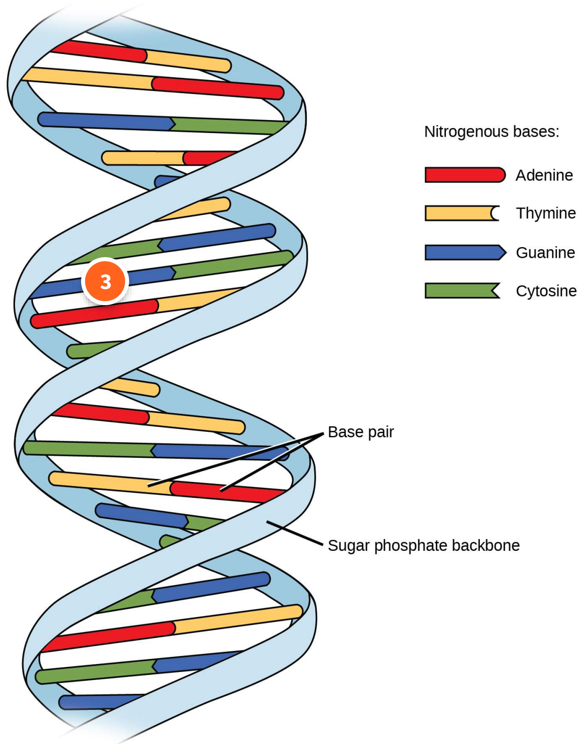
Term used to describe a pair of nitrogenous bases, i.e. adenine and thymine.



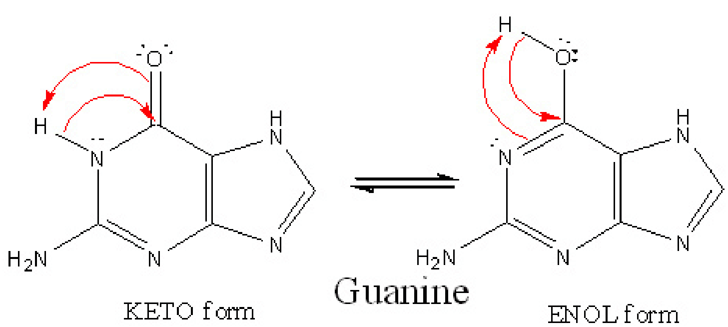
Cytosine



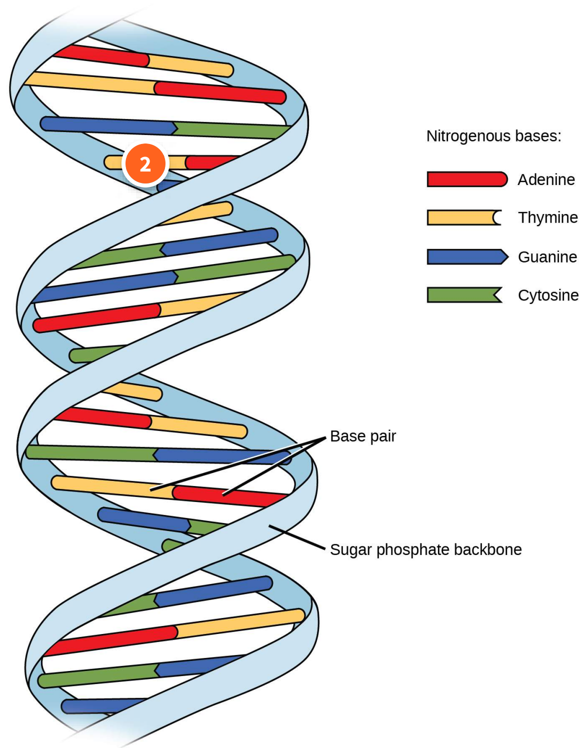
Nitrogenous base that always pairs with Guanine in DNA. Often abbreviated "C."



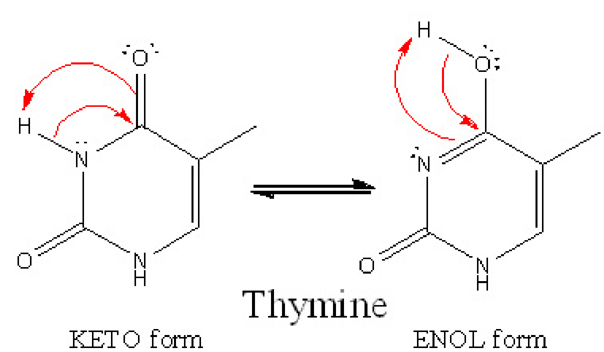
Guanine



Nitrogenous base that always pairs with Cytosine in DNA. Often abbreviated "G."



Thymine



Nitrogenous base that always pairs with Adenine in DNA. Often abbreviated "T."

DNA: By the Numbers

Exactly how much DNA does it take to make up a human? How tiny is it? How does it all fit? Watch the video below to explore mind blowing facts about DNA and learn more key terms for describing it's structure.

Key Points

1. DNA has a double helix structure with a sugar (deoxyribose) and phosphate backbone found in the nucleus of every cell
2. DNA is composed of nitrogenous bases called adenine, thymine, guanine, and cytosine that are paired through hydrogen bonding
3. In DNA, adenine always pairs with thymine, and guanine always pairs with cytosine
4. Chromosomes are a very condensed form of DNA
5. A gene is a portion of chromosome that gives instructions to produce a specific trait

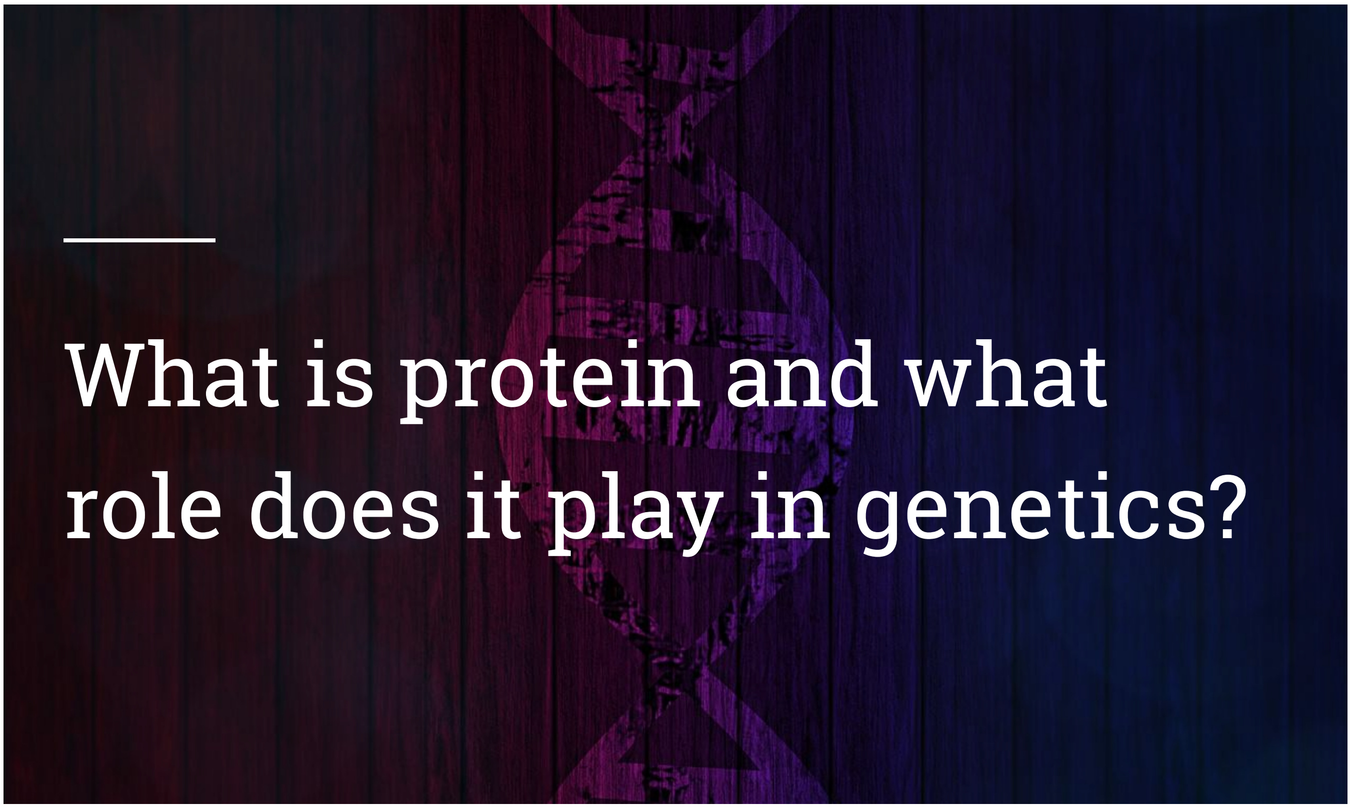
In the next section, we'll learn about another essential concept in understanding genetics- protein.

Source: 1) “What Is DNA?: MedlinePlus Genetics.” MedlinePlus, U.S. National Library of Medicine, 19 Jan. 2021, medlineplus.gov/genetics/understanding/basics/dna/.

CONTINUE

Protein Matters

EW Erin Weaver



Protein Structure and Function

How do we get from DNA's structure as a double helix to it's function as a carrier of genetic information? In order to understand how DNA's structure allows it to produce specific traits like what color flower a plant has or whether or not you have freckles, we need to first understand the role of **protein** in living organisms.

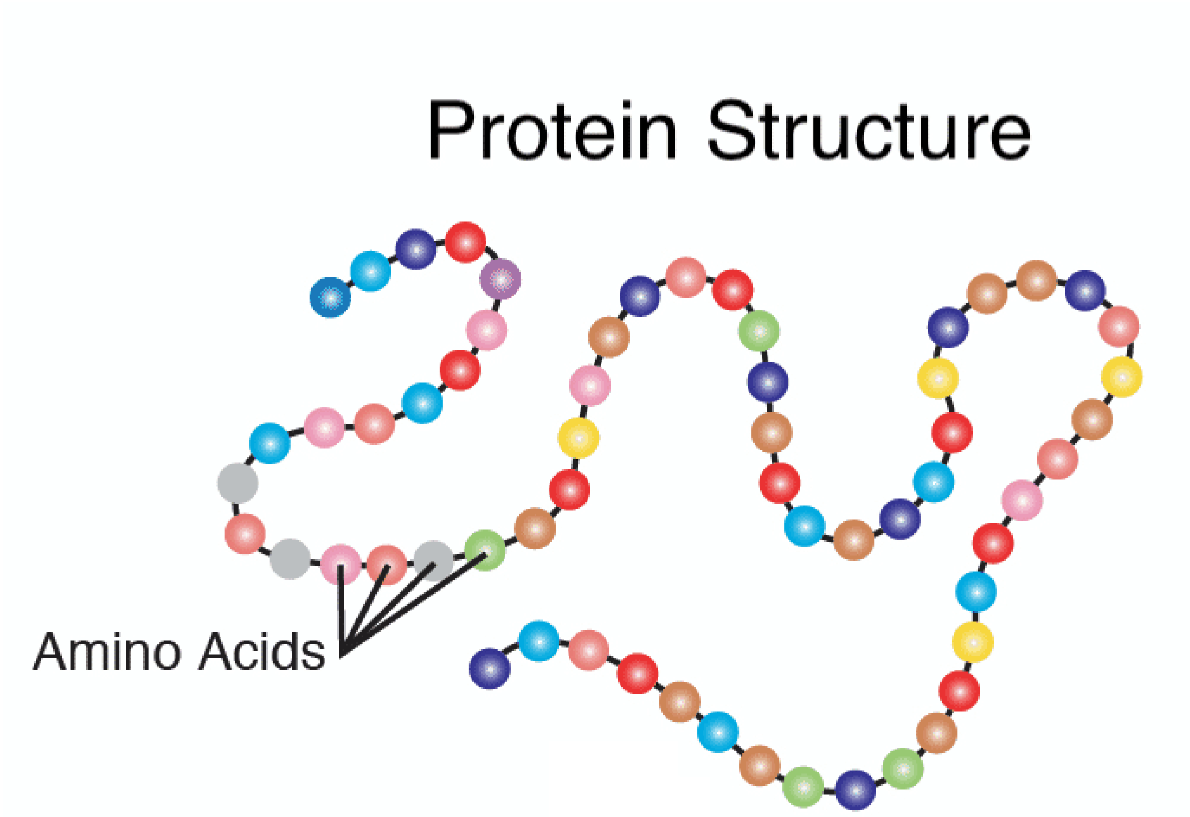
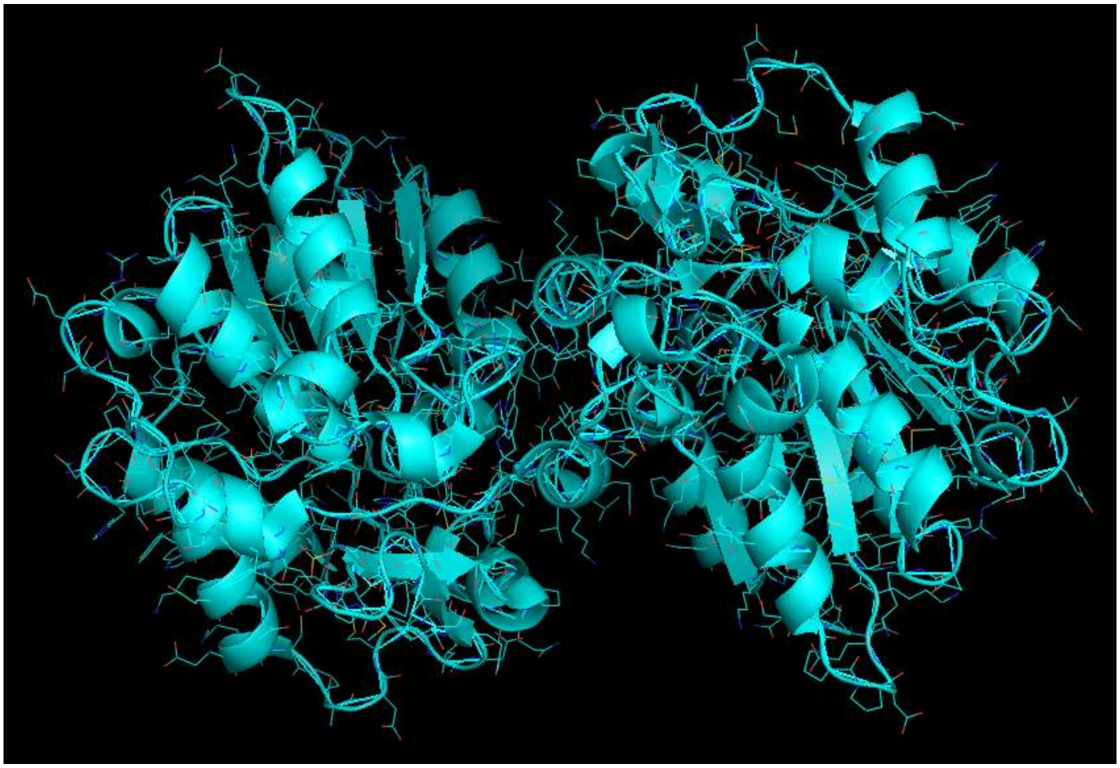


Image Modified From: “Levels of Protein Organization.” Protein, National Human Genome Research Institute, www.genome.gov/genetics-glossary/Protein.

A **protein** is a large molecule made up of smaller connected segments called **amino acids** (Figure 1). You may have heard of protein in relation to the food that we eat, but it is so much more than that! Protein plays an incredibly important role in the development and proper functioning of living things. The specific proteins that an organism has determines what characteristics it will display. Expand each section below to discover the variety of ways protein is essential for life. [1,2]

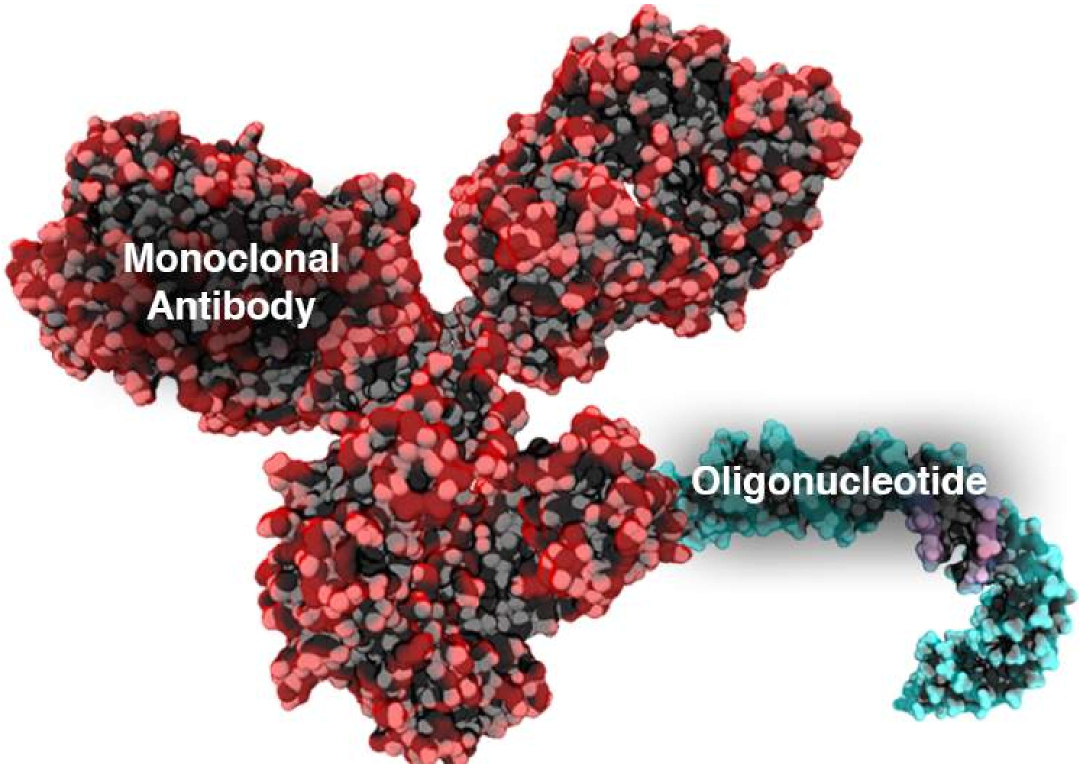
Enzymes

Chemical reactions are essential to the cellular function of living things. They allow life sustaining processes like photosynthesis, cellular respiration, and muscle contraction to occur. **Enzymes** are a category of protein that speed up these chemical reactions. Without enzymes most of the cellular processes happening inside your body would not be possible!



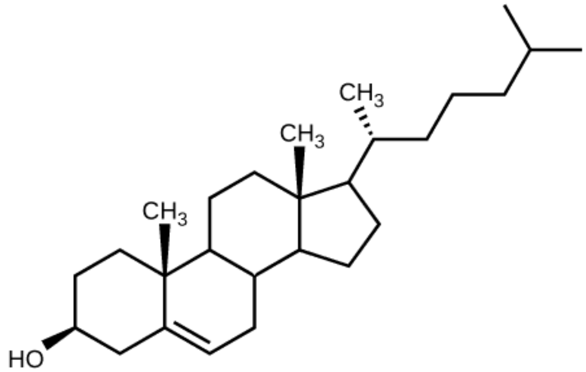
Antibodies

An **antibody** is a type of protein that helps to protect the body from things that don't belong- like viruses or bacteria. Antibodies identify foreign substances and neutralize them in a variety of ways. This role is critical to the proper functioning of the immune system.

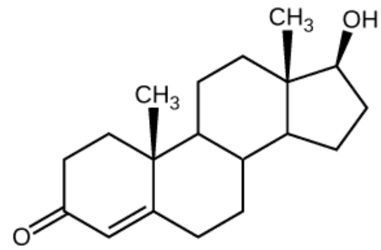


Messenger Proteins

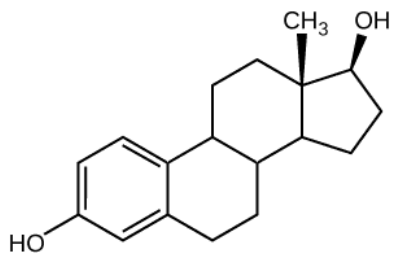
Proteins also serve as messengers that help send information between cells, tissues, and organs. This includes **hormones** such as insulin, testosterone, estrogen, and serotonin, each of which play a vital role in maintaining chemical communication throughout the body.



(a) Cholesterol



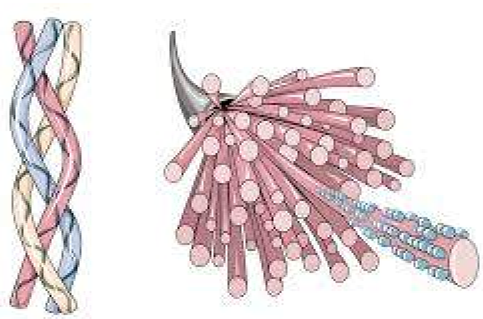
(b) Testosterone



(c) Estradiol

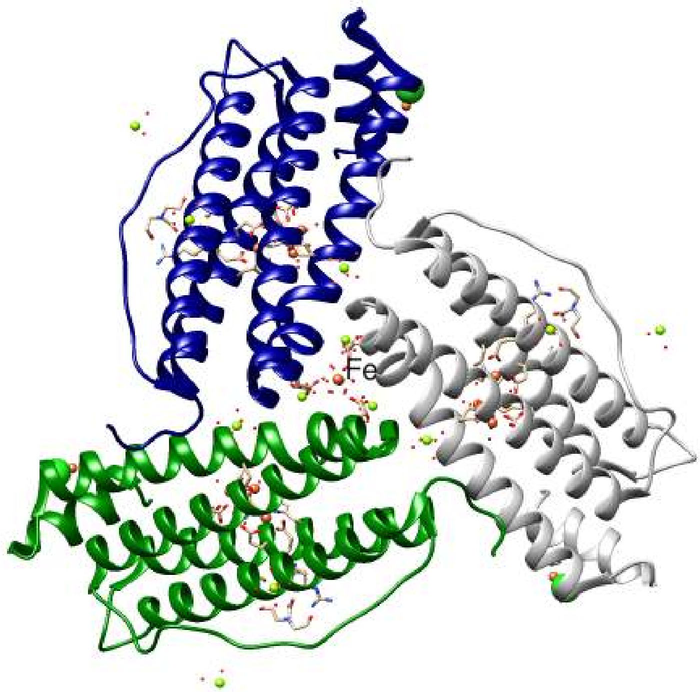
Structural Proteins

Some proteins provide essential structure for cells and tissues. Collagen is the most common structural protein in the human body and helps support your skin, bones, tendons, and ligaments. Other examples include elastin, which aids lung function among other key roles, and actin which works to maintain cell shape and aids cell movement, and cell division.



Transportation and Storage Proteins

Many proteins function as transporters for other molecules through the bloodstream. One example is hemoglobin. Without this protein, oxygen would not be transported throughout your body! Proteins can also help to store amino acids and metal ions for later use. Ferritin is a storgage protein found in the human body that stores and releases iron.



Protein & Traits

There are thousands of different proteins in the human body that each have a distinct role to play in keeping you alive and in producing your genetic traits. Despite the great variety of protein types, proteins are made of different sized chains of just 20 different amino acids (Figure 2).

In order to form a protein, amino acids are pieced together to form long chains connected by peptide bonds. In humans, their size can range anywhere from 44 amino acids to over 30,000 amino acids in a single protein [4,5]. Different numbers and combinations of amino acids result in a different proteins formed. Each unique protein serves a different function in the body of an organism- this results in billions of possible traits!

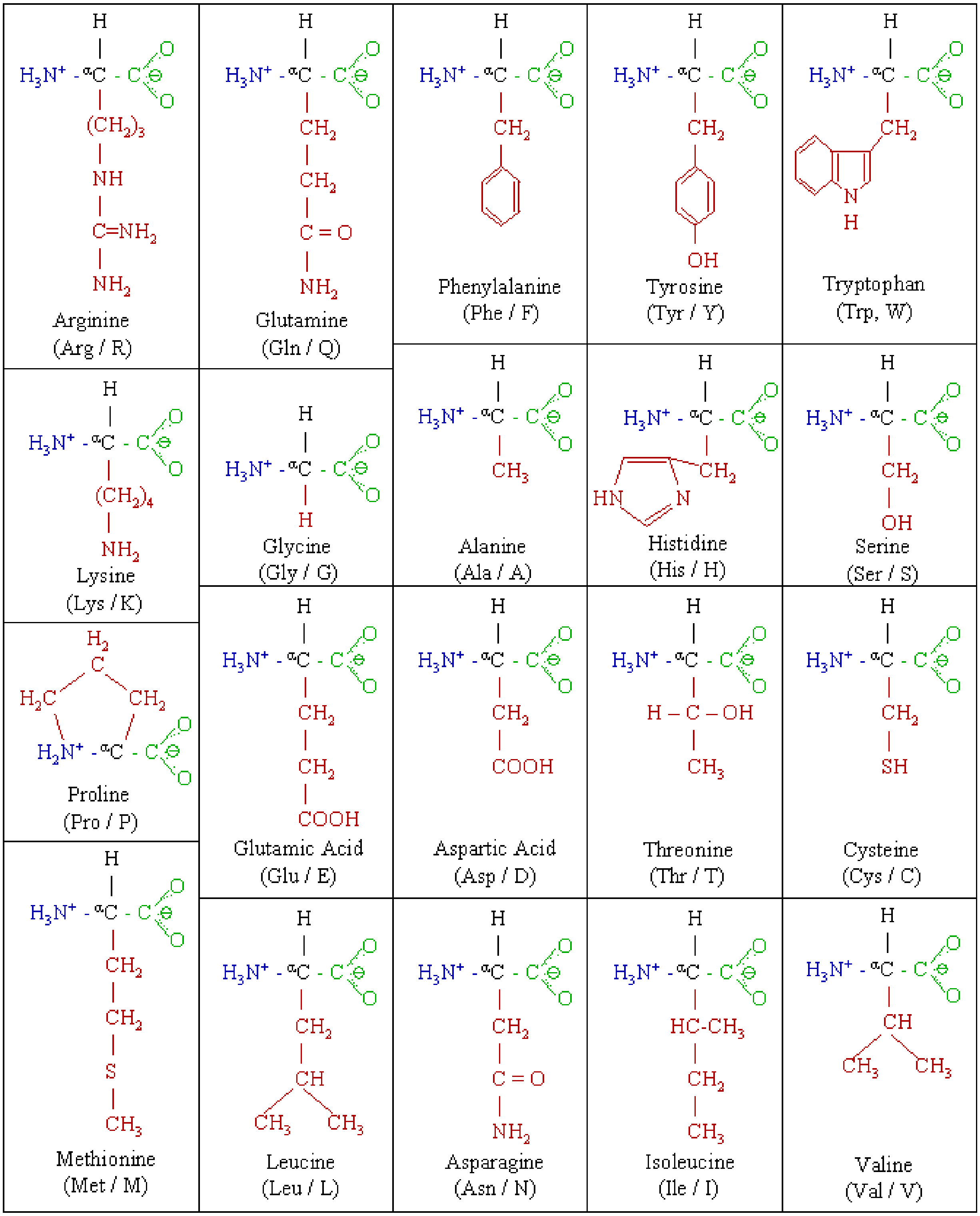


Figure 2: Note- In prokaryotes there are 21 protein creating amino acids. 20 in the standard genetic code, plus one more, selenocysteine. Read more about it here. [3]

In the next lesson, we'll discover how DNA is related to protein. Click "continue" below to proceed.

CONTINUE

Knowledge Check

Proteins are composed of...

- Nucleotides
- Nitrogen Bases
- DNA
- Amino Acids

SUBMIT

__________ are proteins that speed up chemical reactions.

- Enzymes
- Antibodies
- Structural Proteins
- Transport Proteins

SUBMIT

_________ are a type of messenger protein

- Enzymes
- Hormones
- DNA

Amino Acids

SUBMIT

Sources: (1) Alberts B, Johnson A, Lewis J, et al. Molecular Biology of the Cell. 4th edition. New York: Garland Science; 2002. Protein Function. Available from: https://www.ncbi.nlm.nih.gov/books/NBK26911/?_ga=2.140140339.1297965577.1611688470-725446071.1611688470, (2) Van de Walle, Gavin. 9 Important Functions of Protein in Your Body. Healthline, 20 June 2018, www.healthline.com/nutrition/functions-of-protein#TOC_TITLE_HDR_9, (3) "Rare, but Essential – the Amino Acid Selenocysteine." Research Features, 3 Sept. 2020, researchfeatures.com/amino-acid-selenocysteine/. (4) UniProt ConsortiumEuropean Bioinformatics InstituteProtein Information ResourceSIB Swiss Institute of Bioinformatics. "Titin." UniProt ConsortiumEuropean Bioinformatics InstituteProtein Information ResourceSIB Swiss Institute of Bioinformatics, 2 Dec. 2020, www.uniprot.org/uniprot/Q8WZ42. (5) Su, Mingming et al. "Small proteins: untapped area of potential biological importance." Frontiers in genetics vol. 4 286. 16 Dec. 2013, doi:10.3389/fgene.2013.00286

Lesson 4 of 8

From DNA to mRNA

EW Erin Weaver

Protein is vital in living organisms, but what does protein have to do with DNA?

DNA & Protein

Recall that DNA is a double helix with four nitrogenous bases forming the connection between it's two sides. These nitrogenous bases are adenine (A), thymine (T), cytosine (C), and guanine (G) and they pair together in specific ways- A to T, and C to G. Looking at a DNA molecule, billions of bases long, these bases could be arranged in any possible way producing infinite variety in DNA strands. So where does protein come in to play?

DNA strands form a code that guide your cells to produce proteins. Proteins, in turn, produce traits that make you unique. Without DNA to provide the instructions for making protein, living organisms would not be able to function! In this section, we will begin learning how living organisms use DNA as a code for making protein.

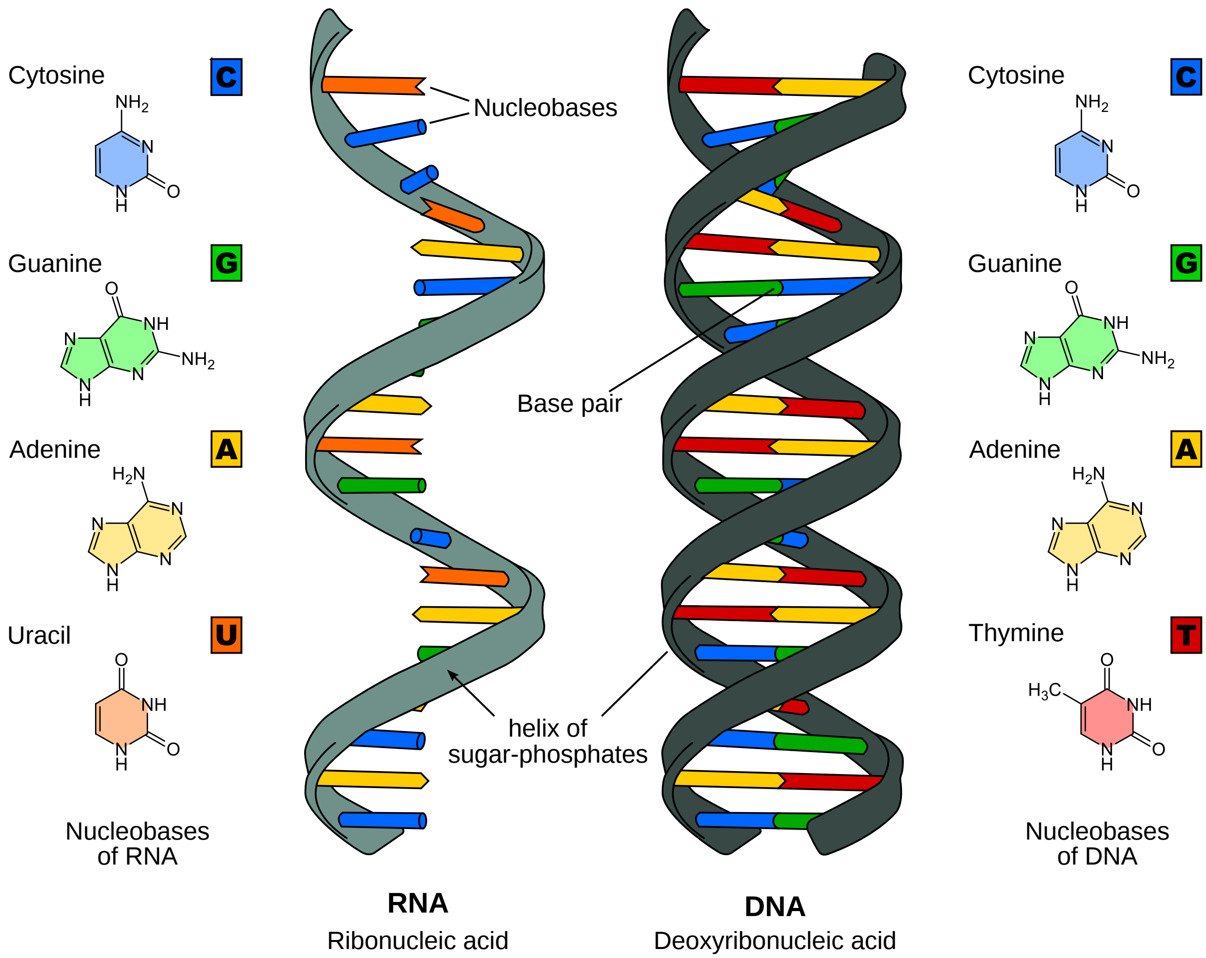


Figure 1: Comparison of DNA and RNA

What is RNA?

The first step to making a protein from DNA is called **transcription**. During this step the instructions from DNA, found in the specific combination of nitrogenous bases it contains (A, T, G, or C), are used to make a molecule called **RNA**. RNA, or ribonucleic acid, is very similar to DNA except that it is a single strand, and instead of the nitrogenous base, thymine, it substitutes a base called **uracil** (Figure 1). There are several different types of RNA, but the type that transcription produces is known as messenger RNA or mRNA. It is responsible for carrying the genetic message that dictates how cells form proteins.

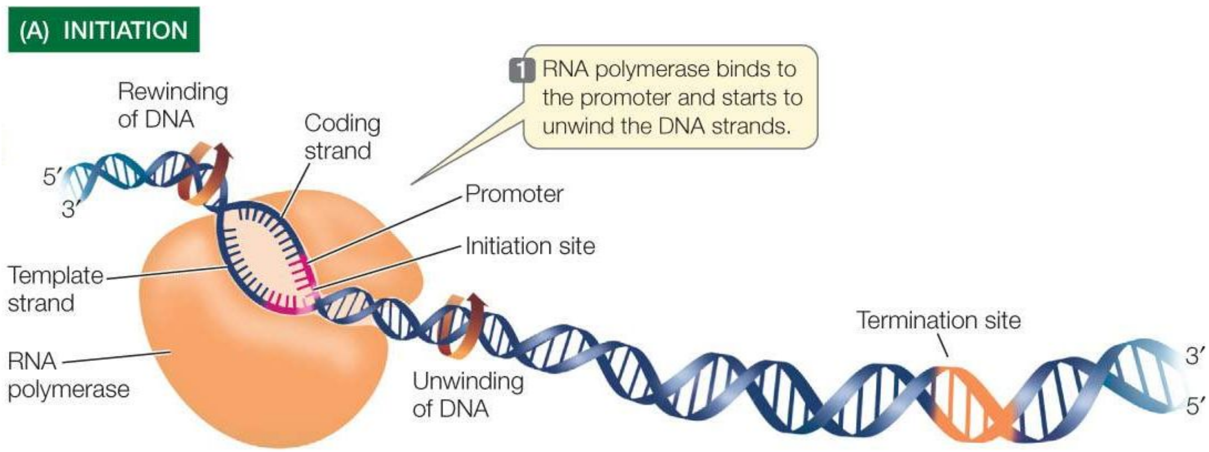
Note: There are two of other types of RNA that we will discuss in more detail in the next section. **Transfer RNA** or tRNA, which functions to bring amino acids from the cytoplasm of the cells to the ribosomes to be used for making protein. **Ribosomal RNA** or rRNA, is a key component of ribosomes, the organelle in charge of protein formation.

Transcription

Transcription is the process by which DNA is used to make messenger RNA. There are three main stages to this process. Click through the slides below to learn more[1,2].

Step 1

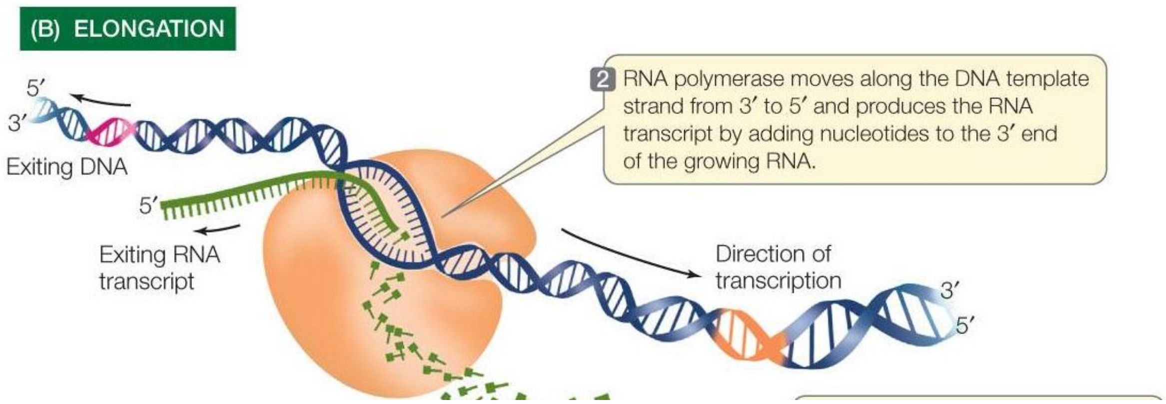
Stage One: Initiation



DNA is unwound to form a single strand with the help of the enzyme RNA polymerase. This leaves the nitrogenous bases exposed.

Step 2

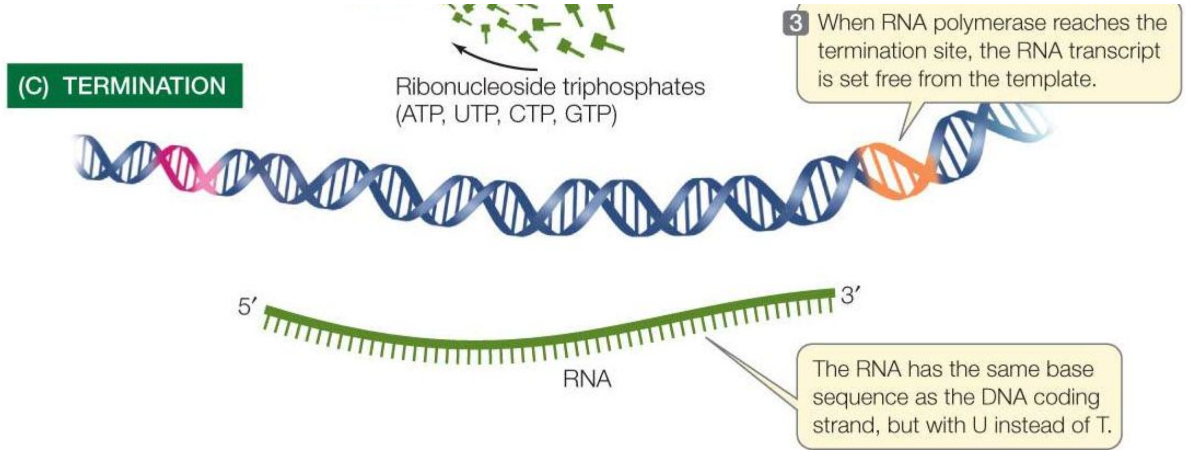
Stage Two: Elongation



RNA polymerase pairs new nucelotides (sugar + phosphate + nitrogen base) with each of the exposed bases of the DNA strand by pairing complimentary bases together. For example, if the original DNA strand had the bases TGCGAAG then new nucelotides with the bases ACGCUUG would pair with them. (Remember that, in RNA, thymine is replaced with uracil)

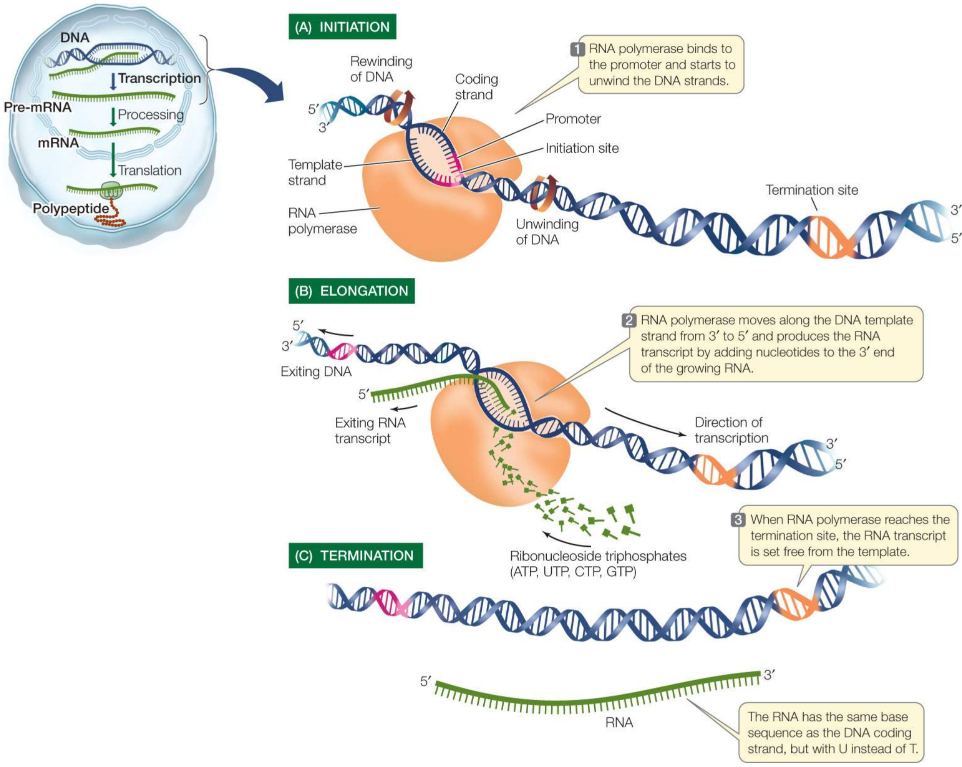
Step 3

Stage Three: Termination



Lastly, when complete, the newly formed strand of mRNA is separated from the original DNA strand. The DNA is then wound again to remake a double helix. The end result? The DNA is unchanged and a strand of mRNA if formed.

Sources:



All Images Adapted From: Aryal, Sagar. "Three Stages of Transcription." Microbe Notes, microbenotes.com/prokaryotic-transcription-enzymes-steps-significance/.

Check Your Knowledge

The process of _____________ takes a strand of DNA and forms a strand of mRNA

Type your answer here

SUBMIT

Type out the mRNA sequence that would be created given the following DNA strand: TTGACCCA

Type your answer here

SUBMIT

Click "continue" below to learn about the second phase of making protein from DNA.

CONTINUE

Sources: 1) “Transcription of DNA - Stages - Processing.” TeachMePhysiology, 20 Oct. 2020, teachmephysiology.com/biochemistry/protein-synthesis/dna-transcription/. 2) “Gene Expression and Regulation.” University of Leicester, 17 Aug. 2017, www2.le.ac.uk/projects/vgec/highereducation/topics/geneexpression-regulation. 3) Aryal, Sagar. “Prokaryotic Transcription- Enzymes, Steps, Significance: Molecular Biology.” Microbe Notes, 7 Jan. 2020, microbenotes.com/prokaryotic-transcription-enzymes-steps-significance/.

From mRNA to Protein

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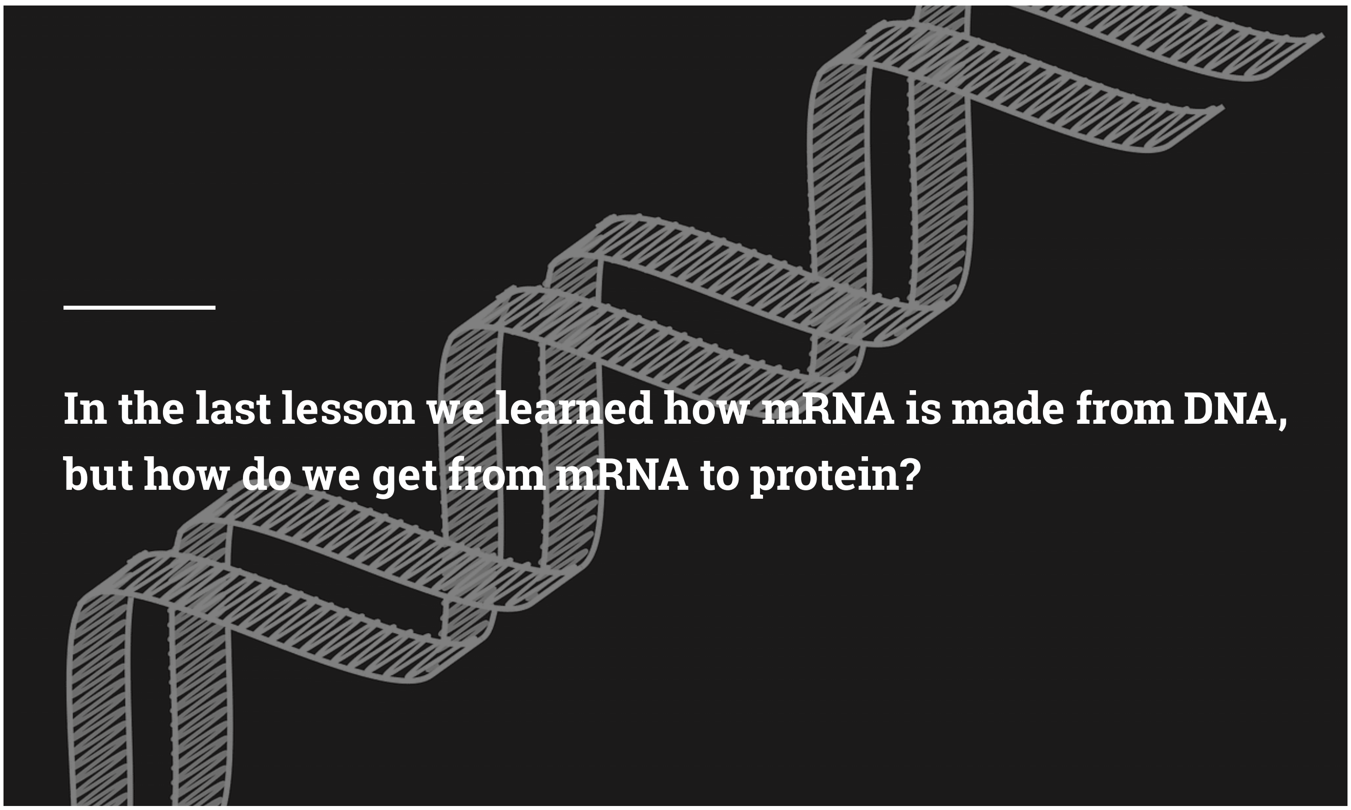


In the last lesson we learned how mRNA is made from DNA, but how do we get from mRNA to protein?

mRNA & Codons

At the end of transcription we have a new strand of mRNA made by using a strand of DNA as a template. A strand of mRNA organizes it's instructions for making protein in chunks of three nucelotides called **codons** (Figure 1). These three letter codons serve as the basic genetic "words" used to build a protein. Each codon calls for a specific amino acid. For instance, the codon made of the bases UGG codes for a amino acid called tryptophan. Tryptophan is the amino acid that produces the hormone melatonin which regulates the sleep-wake cycle in humans.

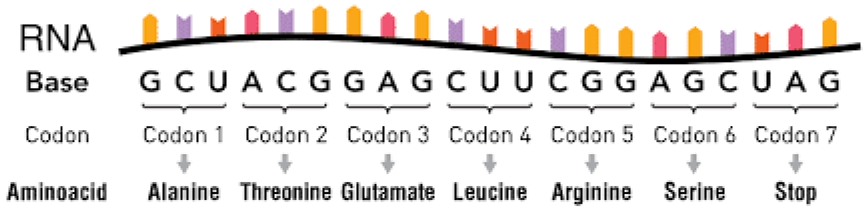
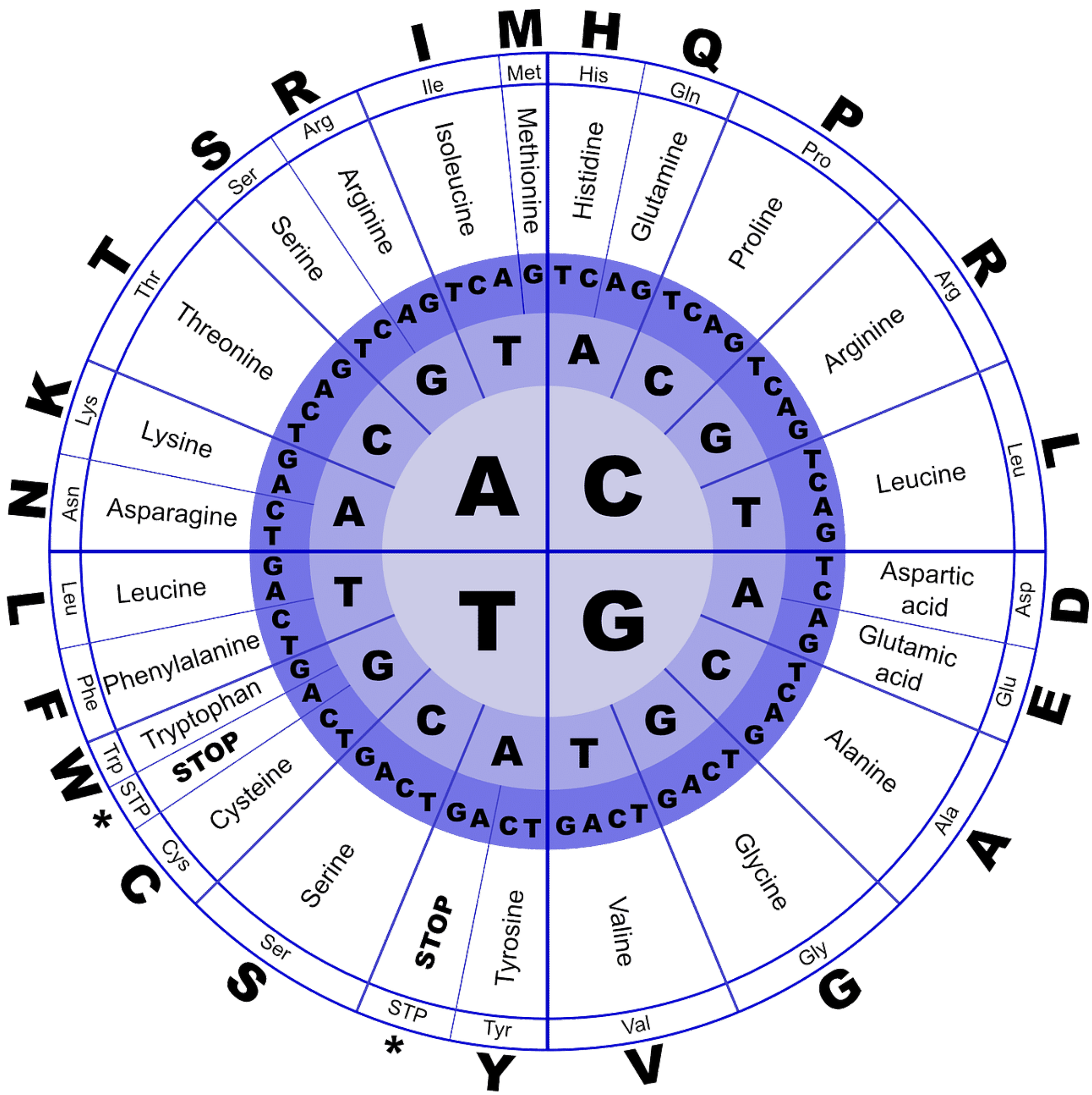


Figure 1: Codons labeled on a strand of RNA

The chart below shows which codons correspond to which amino acids. To use the chart simply start with finding the first letter of the codon in the light purple middle of the circle. This narrows your options to only a quarter of the circle. Using the next circle outward (medium purple) find the second letter of the codon. This narrows your options even further. Finally, using the outer circle (dark purple) find the third letter of your codon sequence. This should narrow your options down to one amino acid. (Note: some amino acids have multiple codons that code for them)[1,2]



You may notice that some codons on the above chart return an amino acid that reads STOP. This indicates that this is the final codon of the amino acid sequence building a protein. Now find the amino acid Methionine (Met). It's corresponding codon is ATG. This is known as the START codon. It indicates the beginning of a chain of amino acids building a protein.

Translation

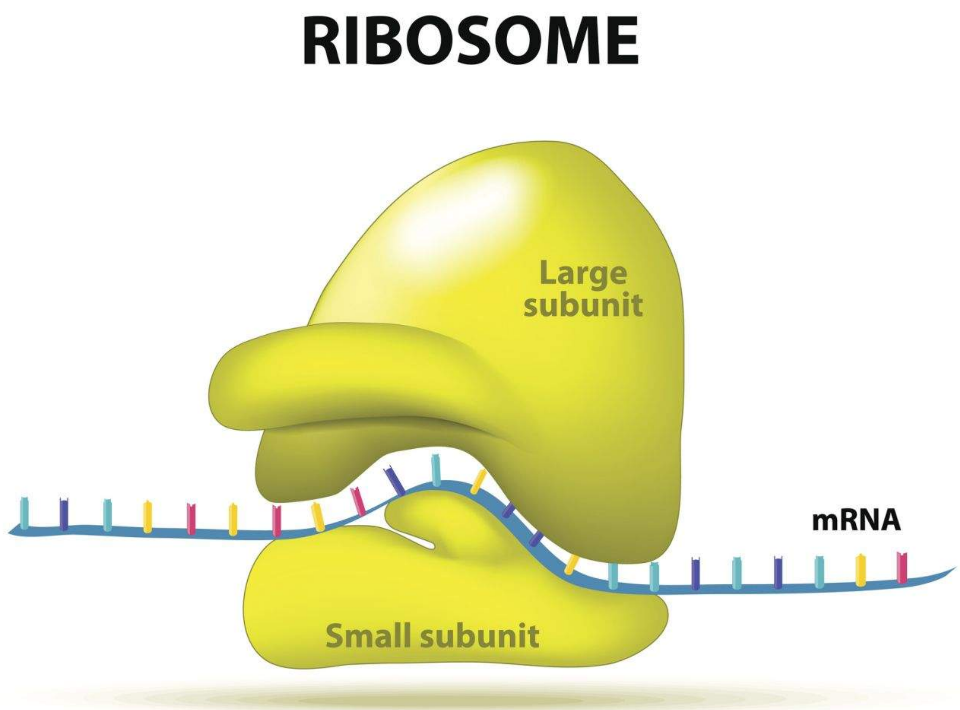
The process of taking mRNA (and the information stored in it's codons) and turning it into a protein is called **translation**. Translation, sometimes called protein synthesis, is a multi-step process that takes up where transcription leaves off. Learn more below! [1,2]

Translation: From mRNA to Protein

Just like the process of transcription, translation can be broken down into the same three basic phases [2,3] 1) initiation, 2) elongation, and 3) termination. Click through these slides to find out more!

Step 1

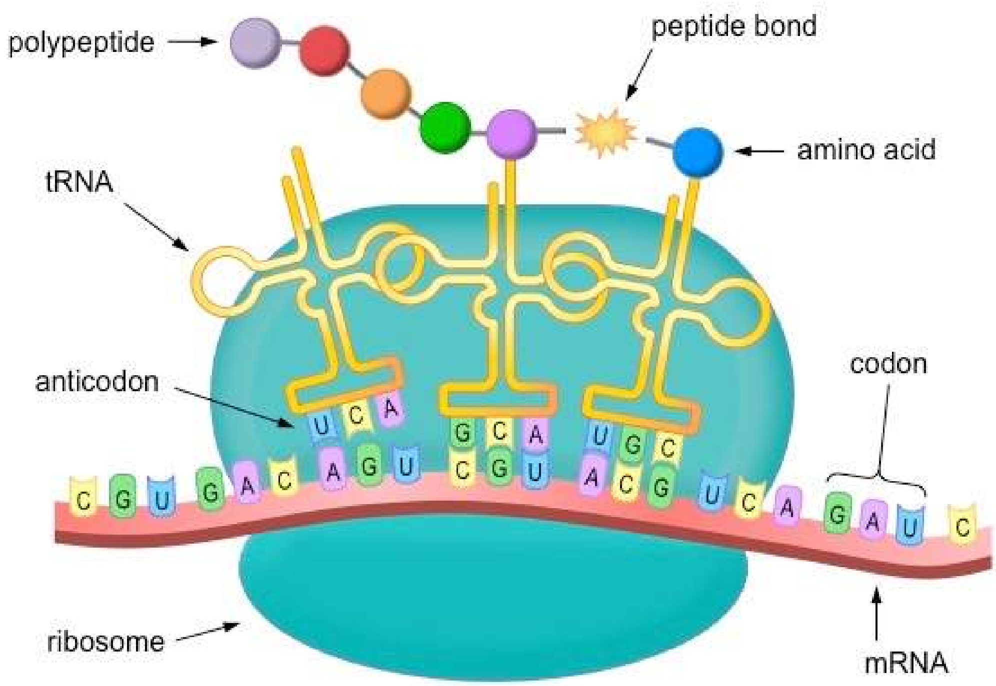
Initiation



The first step of translation starts with the mRNA strand attaching to a ribosome. **Ribosomes** are the organelles that are responsible for protein synthesis. The attachment between mRNA and the ribosome occurs only when the codon AUG, or methionine, is recognized on the mRNA strand.

Step 2

Elongation



In the last section we mentioned that there is another type of RNA, called transfer RNA, that is responsible for carrying the amino acids that form proteins out of the cytoplasm of the cell where they are stored to the ribosomes to be make a protein. The elongation phase of translation is where this happens.

Transfer RNA has a unique shape. At the bottom of each transfer RNA strand is a three letter code called an **anticodon**. Each anticodon corresponds to one of the codon sequences on the mRNA strand produced in transcription. For instance the codon sequence UAG on an mRNA strand would match with a tRNA anticodon reading TUC.

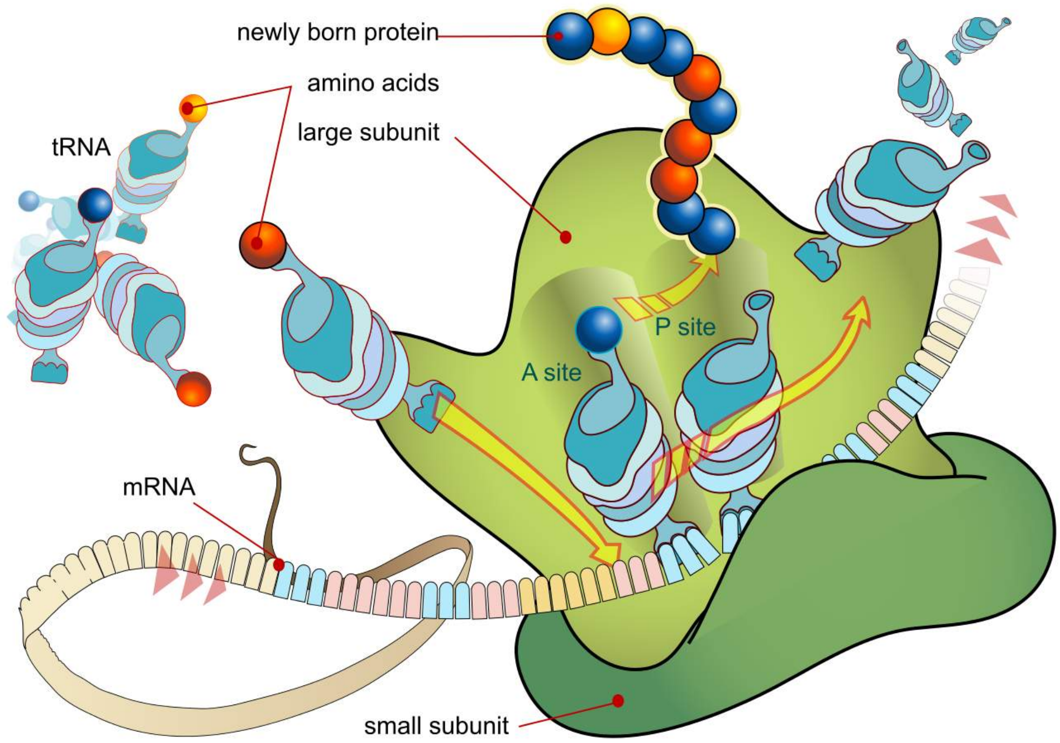
Transfer RNA is in charge of bringing the correct amino acid from the cytoplasm to the mRNA strand. When an anticodon and codon match up via base pairing, tRNA deposits it's amino acid, and goes back to the cytoplasm to retrieve another amino acid.

The amino acids left behind are linked together forming a chain that continues to grow. This chain will become our protein!

Image Credit: Cornell, Brent. “Translation Overview.” BioNinja, ib.bioninja.com.au/standard-level/topic-2-molecular-biology/27-dna-replication-transcri/translation.html

Step 3

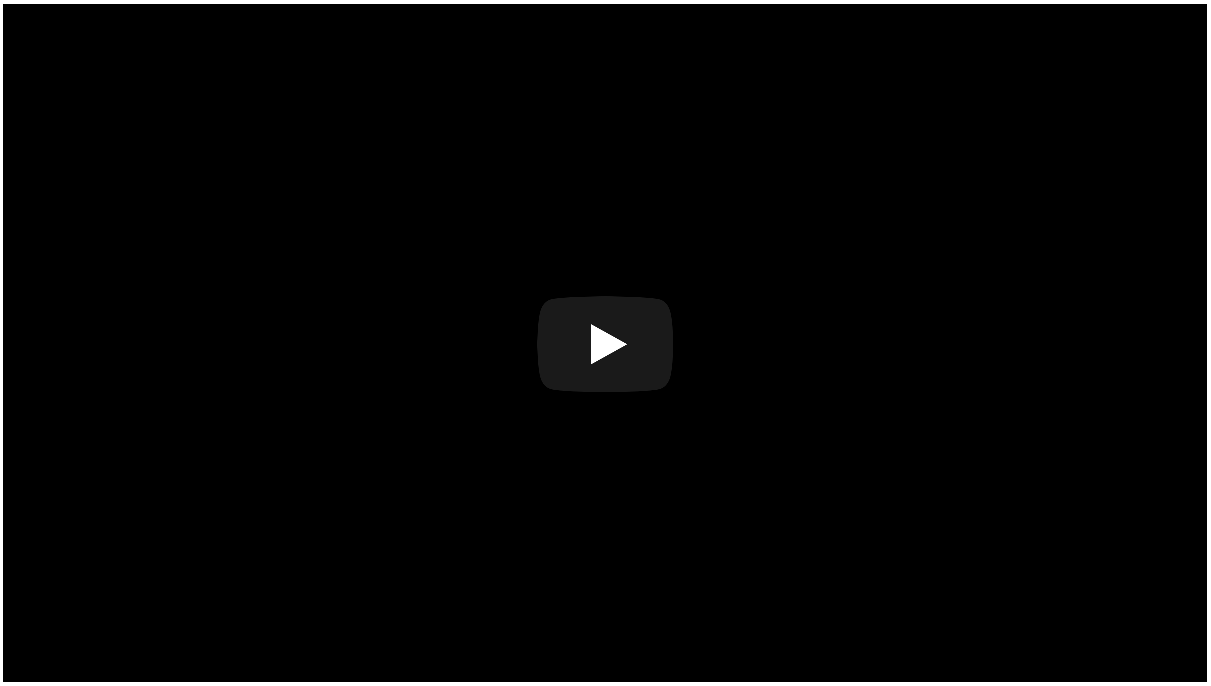
Termination



Termination begins when a STOP codon is recognized on the mRNA chain. When this happens, the tRNA and the newly formed protein are released. The ribosome disconnects from the strand of mRNA and is reused by the cell.

Summary

DNA translation I Protein Synthesis



Check out this video for a more detailed view of translation!

Knowledge Check

The process whereby messenger RNA is used to make protein is called

____

Type your answer here

SUBMIT

Which organelle is used in making protein?

- Nucleus
- Cytoplasm
- Golgi Apparatus
- Ribosome

SUBMIT

A strand of mRNA has the codon GCA what amino acid would this call for?

Type your answer here

SUBMIT

What tRNA anticodon would match up with an mRNA codon reading UAC?

Type your answer here

SUBMIT

In the next lesson, we will look at taking all of the information you've learned and applying it to a real life scenario. Click "continue" to move forward.

CONTINUE

Sources: 1) "Stages of Translation (Article)." Khan Academy, Khan Academy, www.khanacademy.org/science/biology/gene-expression-central-dogma/translation-polypeptides/a/the-stages-of-translation. 2) "DNA Translation - Initiation - Elongation - Termination." TeachMePhysiology, 7 June 2020, teachmephysiology.com/biochemistry/protein-synthesis/dna-translation/. 3) Cornell, Brent. "Translation." BioNinja, ib.bioninja.com.au/standard-level/topic-2-molecular-biology/27-dna-replication-transcri/translation.html.

Tying it all Together

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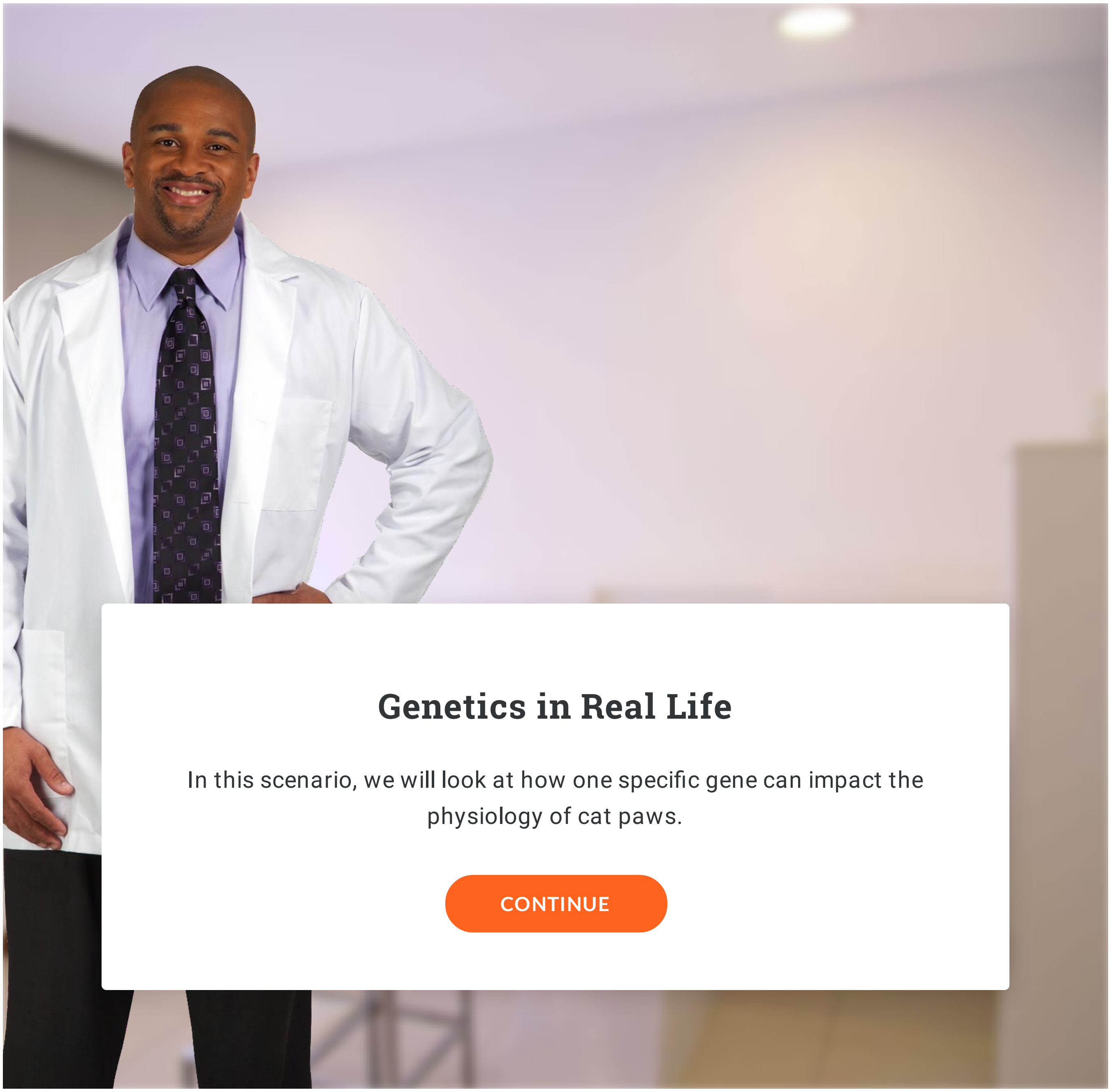
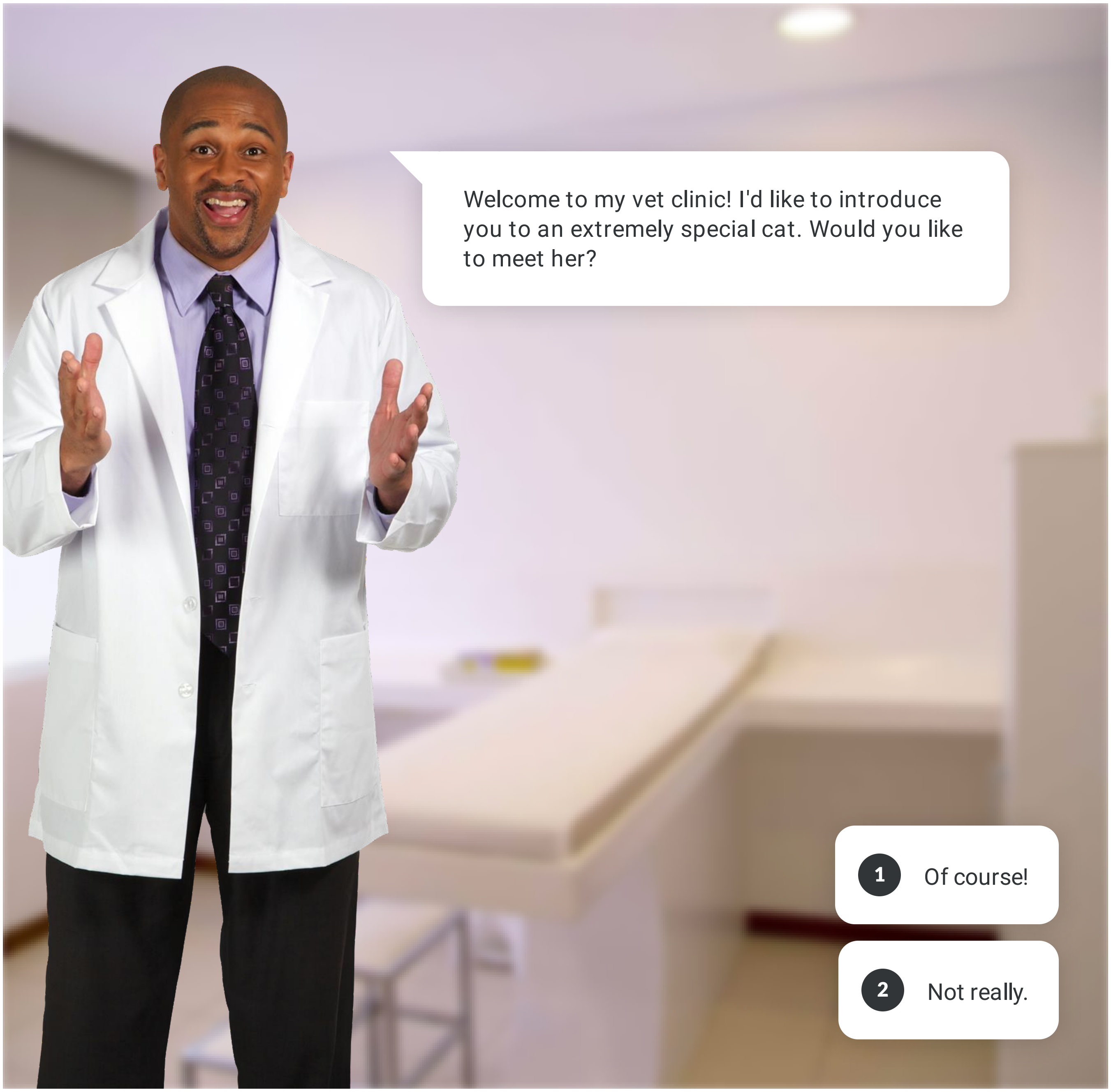
Examples and Application

So far in this course, you've learned that living things are different because they each have unique strands of DNA that code for particular proteins which produce diverse traits. But what does this look like in real life? Explore the scenario below to apply what you've learned.



Scene 1 Slide 1

Continue → Next Slide



Scene 1 Slide 2

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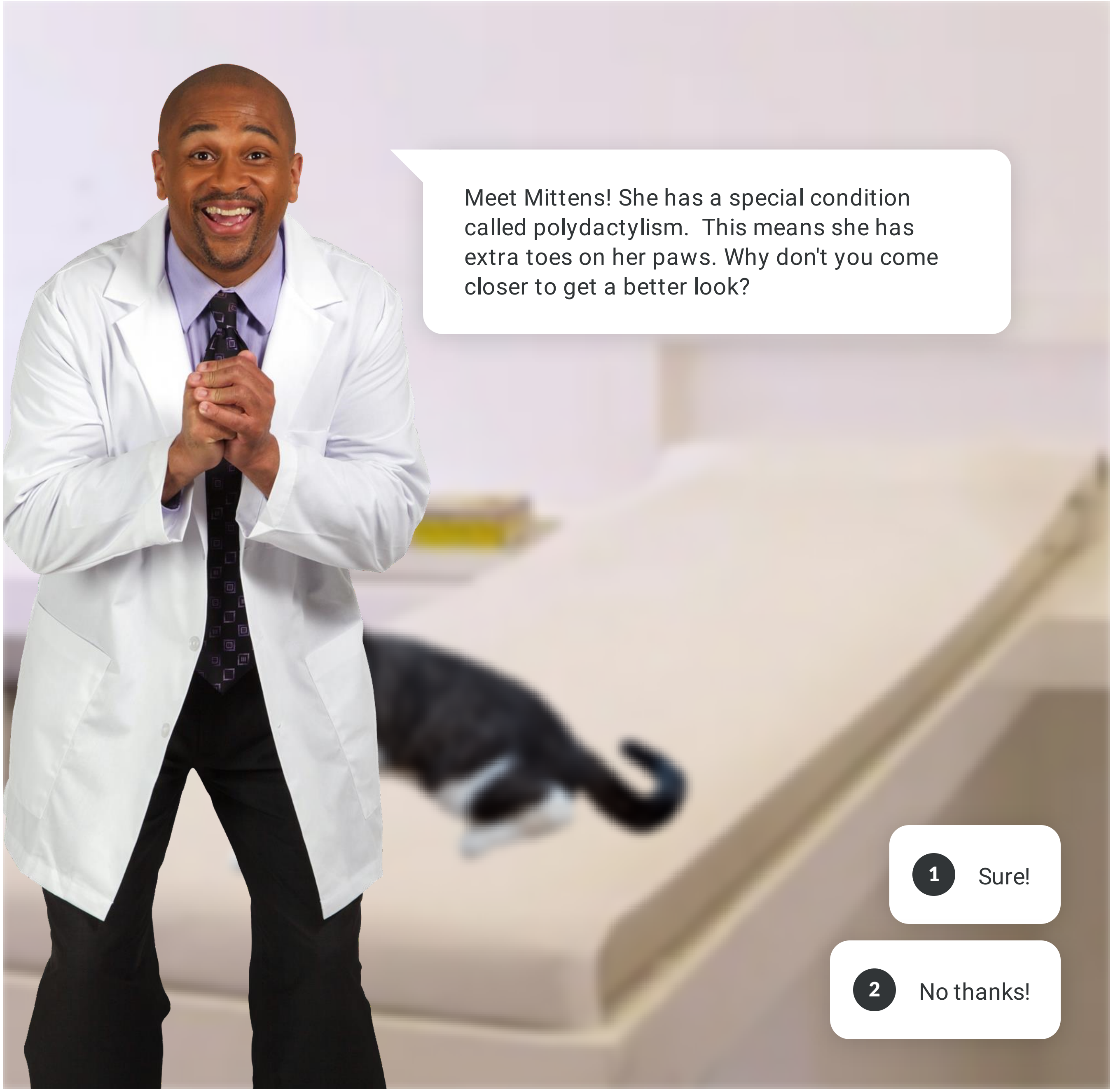

Scene 2 Slide 1

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Scene 3 Slide 1