Reading DNA

Abstract

Students use edible models of the DNA molecule to transcribe an mRNA sequence, then translate it into a protein.

Learning Objectives

- Students will understand that information within the DNA molecule is divided into segments called genes.
- Students will learn that each gene contains the instructions for assembling a unique protein that performs a specialized function in the cell.
- Students will be able to summarize the two-step process of transcription and translation by which the information in a gene is used to construct a protein.

Estimated time

- Class time 45 minutes
- Prep time 60 minutes

Materials

- tape
- scissors

Per student or group

- 1 black licorice stick (Twizzlers)
- colored marshmallows, 9 each of pink (labeled “U” with marker), orange, yellow, and green
- 6 toothpicks, cut in half
- colored circle cut-outs, 2 each of red, pink, dark yellow, light yellow, green, blue, and purple

    TIP: laminate them for continued use and put each group’s cut-outs in an envelope

- edible models of DNA previously built for the activity Have Your DNA and Eat It Too

Background Information

The DNA molecule has the same basic structure and function in all living things. It carries the instructions for building and operating an organism in the form of a sequence of chemical bases each represented by the first letter of its name: adenine (A), cytosine (C), guanine (G), and thymine (T). Human cells contain forty-six DNA molecules that when tightly packaged during cell division can be visualized as forty-six chromosomes.

The sequence information in each DNA molecule is divided into segments called genes. Each gene contains a blueprint for constructing a unique protein that has a specialized function in the cell. Upon completion of the Human Genome Project in the year 2003, it was determined that humans have approximately 20,000 genes. Scientists now have the enormous task of deciphering how these genes direct the development and maintenance of an organism as complex as the human body.

The human body with its different tissues and organs requires a large variety of cell types to function, yet every human cell contains the exact same set of DNA instructions. How, then, can the diversity among cells be explained? Different cell types arise because each cell uses different combinations of genes, building only the proteins it will need to perform its special job. To assemble a protein using the information in a gene, a cell employs the two-step process of transcription and translation.

After a cell has chosen a gene from which it will build a protein, it makes a copy of the information in the form of messenger ribonucleic acid (mRNA) to send to the protein-building machinery. The synthesis of an mRNA molecule from a DNA template is referred to as transcription. The structure of mRNA is very similar to DNA in that it has a sugar-phosphate backbone to which the chemical bases are attached. However, there are some important differences: (1) mRNA is single-stranded and therefore does not form a double helix, (2) the sugar used to form the backbone is slightly different, and (3) the chemical base thymine (T) is replaced by uracil (U).

The sequence of the mRNA molecule is determined by using one strand of the DNA molecule as a template and applying the rules of base pairing. Except, the base adenine (A) will now cause uracil (U) instead of thymine (T) to be added to the mRNA sequence. Note that the mRNA sequence is a complement of its DNA template.

Once the DNA information has been copied or transcribed, the mRNA leaves the nucleus and enters the cytoplasm where the instructions it contains are used by the cell's protein-building machinery to assemble a protein. The process of assembling a protein from an mRNA transcript is referred to as translation.

The protein-building machinery (an enzyme called the ribosome) reads the mRNA sequence three letters at a time. Each combination of three letters codes for a particular protein building block called an amino acid. There are twenty amino acids for the machinery to choose from. The order in which the amino acids are assembled is different for all proteins. The amino acid sequence determines the shape of the protein, and provides the characteristics that enable it to perform a specialized function in the cell. The three-letter codes used by the protein-building machinery to assemble a protein are collectively referred to as the Universal Genetic Code. It is universal because all living organisms use the same three-letter codes to specify the same amino acids.

Instructions

1. Begin class with a discussion about genes. Explain that the information in DNA is divided into segments called genes. Each gene contains the instructions for building a particular protein. Proteins do the majority of the work in our cells and make it possible for cells to perform special jobs.

2. Discuss general protein functions, e.g. enzymes catalyze (speed up) chemical reactions, transport proteins carry small molecules or ions across the cell membrane, signaling proteins carry signals from cell to cell, structural proteins give cells their different shapes, etc.

3. Provide specific examples for each general protein function you discuss. You might use the following examples: DNA polymerase is an enzyme that makes new DNA, hemoglobin in red blood cells carries oxygen to tissues and organs, insulin hormone acts as a signaling protein to control glucose levels in the blood, α-keratin forms fibers that reinforce the structure of epithelial cells and is the major protein in hair.

4. Explain that students will be using the edible DNA models they built previously to simulate the two-step process a cell follows to build a protein, namely transcription and translation.

   - In the first step, a cell reads the information in a gene and makes a copy (called mRNA) to send to the protein-building machinery (an enzyme called the ribosome) in the cytoplasm of the cell. The process of making an mRNA molecule from a DNA template is referred to as transcription.

     Describe the structural differences between the DNA and mRNA molecules, and how the rules of base pairing ensure that an exact copy of the DNA instructions is made. Include in your discussion that the adenine (A) in DNA now directs the base pair uracil (U) to be inserted into the mRNA sequence.

   - In the second step, the sequence information contained in the mRNA molecule is used by the ribosome to string together amino acids, or protein building blocks. This process is called translation. The order in which the amino acids are assembled dictates the shape and function of the protein.

5. Have students work with a partner(s) to complete the activity. Follow the instructions in the student handout to transcribe and translate the short gene sequence in students' edible DNA models.

6. When students have completed the activity discuss the Universal Genetic Code. Emphasize that it is universal because all living cells use the same code when reading mRNA and building proteins. Show students how to use the code to find the names of the amino acids in their assembled protein.

7. Assess student understanding by checking the mRNA and amino acid sequences to ensure students have followed the rules of base pairing and correctly assembled the protein.

Adaptations

- Before students begin the activity, lead them through the steps of transcription and translation using the interactive animations What Makes a Firefly Glow and/or Transcribe and Translate a Gene.
- View a step and then have students carry it out with their model and materials.

Misconceptions

- Because the DNA (or genetic information) is the same in every cell of an organism, students may have the misconception that all cells use every gene and build every protein. Be sure to explain that cells only build the proteins they need to perform their specialized functions.

- The sequence of chemical bases for all twenty-three pairs of human chromosomes has been determined as part of the Human Genome Project (completed in April 2003). Students may not appreciate that knowing the sequence of a gene is only the beginning. Scientists now have the huge task of determining the function of our ~20,000 genes, and the special job each gene's protein product performs in the cell.

Answer Key

Step 1: The mRNA sequence should read as follows.

mRNA-1 = AUGCAUACUUUG

mRNA-2 = ACCAAAUCTTAA

Step 2: The protein sequence should read as follows.

Methionine, histidine, threonine, leucine, threonine, lysine, serine, stop

Green, purple, pink, blue, pink, dark yellow, light yellow, red

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Cut-outs

Reading DNA

The four chemical bases in DNA (A, C, G, and T) create a code. Cells "read" this DNA code to make proteins, the building blocks of all organisms. This is done in two steps:

- Transciption - Copying the directions – Transcription
- Translation - Reading the copy to string together the small molecules (amino acids) that make up a protein

Making a Copy of DNA – Transcription

Cells read DNA in small portions (genes) to create a protein. To do this, the cell must first make a copy of the gene's code to send to the protein-building machinery. This process is called transcription. Using the following materials, follow the steps below to see how this is done.

You will need:

- Your licorice and marshmallow model of DNA
- 9 green marshmallows
- 9 yellow marshmallows
- 9 orange marshmallows
- 9 pink marshmallows labeled "U"
- 6 toothpicks broken or cut in half (12 half-toothpicks total)
- 1 piece black licorice

1. Unzip your DNA. Cells copy only one side of the DNA ladder. In order to make this copy, the chemical bases forming the rungs of the DNA ladder must be separated.

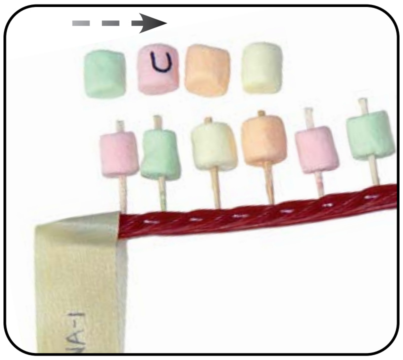
a. Cut or break in the middle the toothpicks in your model to separate the chemical bases and unzip the DNA ladder.

b. Set the unlabeled backbone (with chemical bases attached) aside.

2. Begin to form your mRNA strand. The exposed chemical bases of the unzipped DNA are used to make the copy. This copy is called messenger RNA (mRNA). The mRNA molecule is also made of a backbone and the same chemical bases as DNA. There is one exception however – instead of Thymine (T), mRNA uses Uracil (U). The chemical bases in mRNA form pairs in the same way as DNA:

Adenine (A) binds with Uracil (U)

Guanine (G) binds with Cytosine (C).



a. Place your backbone labeled "DNA-1" or "DNA-2" (depending on which you used to make your model) in front of you.

b. Follow the rules of base pairing to make your mRNA copy of the DNA code by lining up colored marshmallows with their appropriate match.

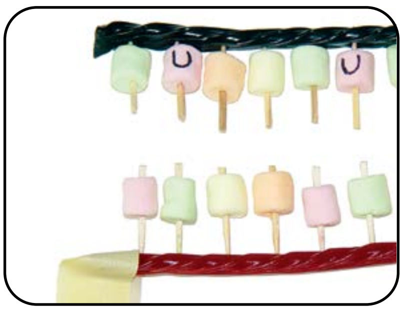
Adenine (A) = Green

Uracil (U) = Pink

Cytosine (C) = Yellow

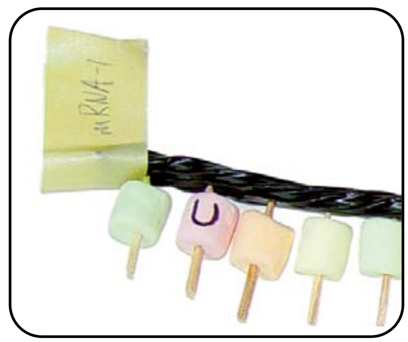
Guanine (G) = Orange

3. The chemical bases of mRNA are also attached to a backbone as in DNA.



a. Attach the new chemical bases to a piece of black licorice backbone using toothpicks cut or broken in half. This forms a new mRNA copy of your DNA strand.

b. Label this new strand mRNA-1 or mRNA-2 (the same number as your DNA strand) on the left end of the backbone.



Reading a Copy of the DNA Instructions to Assemble a Protein – Translation

The mRNA copy of DNA is essentially a recipe for assembling a protein. Proteins are built from small molecules called amino acids. When the mRNA copy is sent to the protein-building machinery it is read and the appropriate amino acids are assembled. This process is called translation. Using the following list of materials, follow the steps below to see how this is done.

You will need:

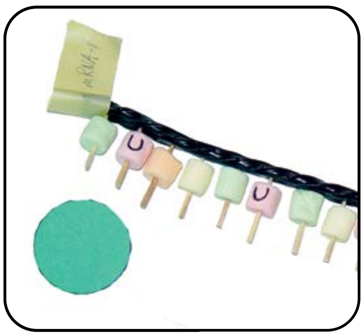
- Your new mRNA strand
- Two of each colored circle cut-out
- Tape

1. Begin to create your protein. mRNA is read in groups of three chemical bases. Each group of three tells the cell which amino acid to assemble. In other words, each group of three is a "code" for a particular amino acid.

a. Find a partner who has a different mRNA sequence (mRNA-1 or mRNA-2) than you do.

b. Place both strands of mRNA end-to-end on the table in front of you, with the mRNA-1 strand on the left.

AMINO ACID KEY								
Code	**AAA**	**ACC**	**ACU**	**AUG**	**CAU**	**UAA**	**UCU**	**UUG**
Amino Acid	dark yellow	pink	pink	green (start)	purple	red (stop)	light yellow	blue



c. Look at the first 3 chemical bases on the left end of your mRNA strand.

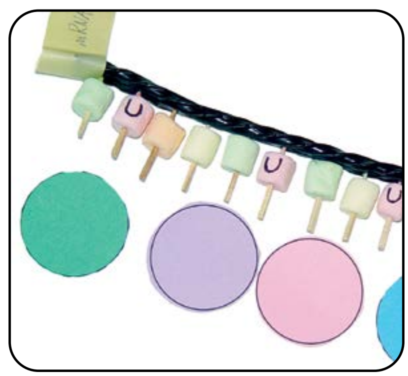
d. Use the Amino Acid Key above to determine which amino acid these 3 chemical bases code for.

e. Place the colored circle cut-out representing that amino acid on the table directly below the three chemical bases.

2. Continue to create the protein.

a. Repeat Step 1 for each group (or code) of three chemical bases on the mRNA strand.

b. When you have all of the appropriate amino acids lined up, tape them together. Now you have a protein!



Extension: Find the name of each amino acid coded for above. An amino acid table is available on the next page.

For example:

AAA codes for the amino acid called __________________.

THE GENETIC CODE:

First base in mRNA triplet	A								G					C					U							
Second base in triplet	A		G		C	U			A		G	C	U	A		G	C	U	A		G			C	U	
Third base in triplet	A G	C U	A G	C U	A C G U	A	G	C U	A G	C U	A C G U	A C G U	A C G U	A G	C U	A C G U	A C G U	A C G U	A G	C U	A	G	C U	A C G U	A G	C U
Amino Acid Encoded	Lysine	Asparagine	Arginine	Serine	Threonine	Isoleucine	Methionine	Isoleucine	Glutamic acid	Aspartic acid	Glycine	Alanine	Valine	Glutamine	Histidine	Arginine	Proline	Leucine	Stop	Tyrosine	Stop	Tryptophan	Cysteine	Serine	Leucine	Phenylalanine