

How Genes Make Proteins

Ability level Grade 7 life science –
Grade 12 AP biology
Class periods required 1–3

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Introduction

This lesson examines how the sequence of nucleotide bases in DNA are translated into a sequence of amino acids in proteins. Students will act out the steps of protein synthesis to learn about this process. The lesson can be used as a follow-up to a lesson on DNA structure.

Objectives

At the end of this activity, students should be able to:

1. Name five types of proteins and describe their functional roles.
2. Define and describe the two major processes of protein synthesis, including:
 - where these processes occur and the major cellular structures involved.
 - the roles of DNA, mRNA, tRNA and amino acids.
3. Use any two sequences of DNA and mRNA, or mRNA and tRNA to demonstrate the concept of complementary base-pairing.
4. Recognize and understand these words:
protein synthesis, template, complementary base pairing, amino acids, nucleotides, genetic code, transcription, translation, DNA, mRNA, tRNA, codon, anticodon.

Materials

For entire class

- ▼ photocopy masters from the *Sourcebook* (4 DNA, 4 mRNA, 4 tRNA and 2 amino acid)
- ▼ colored paper (card stock if possible), four colors, two pages of each color
- ▼ scissors
- ▼ letter-sized envelope

Adapted from Luken, J. (1987). Does biotechnology have a place in introductory biology. *The American Biology Teacher*, 49(6).

Teacher Preparation

1. Use the photocopy masters and colored paper to make the sheets from which the cards can be cut. The master sheets need to be photocopied as two-sided pages. The first two master sheets make one page, sheets 3–4 make the second page, etc. You should have two pages of DNA, mRNA and tRNA, and one page of amino acids when you finish.
2. Cut out the code cards from the sheets (or have your students cut them out in class). Arrange the cutouts into four stacks: DNA, mRNA, tRNA and amino acids. Keep the “start” sequence (TAC) on top of the DNA stack, and the stop sequence (ATC) on the bottom.
3. Store the cards in an envelope.

Teaching Tips

1. Laminate the four stacks of cards for use with your other classes.
2. Multiple copies of the cards can be used for quizzes, remedial flash cards or make-up challenges.

Procedure

1. Students do Background Reading. You may wish to discuss this as a class.
2. Students follow the procedure of the Activity Sheet. They set up the classroom, then act out Transcription and Translation.
3. Students complete Question Sheet (can be a homework assignment or done as a class).

Answers to Student Questions

1. Collagen, keratin – structural
Hemoglobin, serum albumin – transport
Hormones (auxins, gibberellins, insulin) – chemical messengers
Enzymes (RNA polymerase, amylase) – catalyze biochemical reactions

Actin, myosin – contractile, found in muscles
Antibodies – fight foreign substances in the body

2. ▼ mutations, selective breeding and genetic engineering:

Compare: All are mechanisms of genetically modifying organisms.

Contrast: Mutations occur naturally (or can be induced), can occur as a change in a single base pair, gene or whole chromosome; selective breeding is man-made and occurs at the organism level; does not change genetic make-up of organisms involved in breeding event, but alters the genetic makeup of the population or gene pool; genetic engineering is man-made and occurs at the base pair or gene level.

▼ DNA replication and protein synthesis:

Compare: Both require an unzipping of the DNA molecule.

Contrast: The function of DNA replication is to make more DNA, occurs in the nucleus; the function of protein synthesis is to make proteins, occurs partly in the nucleus and partly in the cytoplasm.

▼ transcription and translation:

Compare: Both are major processes of protein synthesis.

Contrast: Transcription occurs in the nucleus, involves DNA and mRNA; translation occurs in the cytoplasm, involves mRNA, tRNA and amino acids.

- 3a. Uracil in RNA substitutes for thymine in DNA

- b. The order of nucleotides in DNA dictates the order of nucleotides in mRNA. The linear sequence of codons in the mRNA dictates the order of tRNAs. Since specific amino acids are attached to specific tRNAs, DNA also dictates the order of amino acids. Amino acids are the building blocks of proteins.

4. Translation. Because transcription involves DNA and mRNA, and can occur without the presence of a particular amino acid. Translation depends on the presence of amino acids to build proteins.

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- 5a. They are exact opposites of each other.
 b. Yes. Because the opposite message would be transcribed and translated, and the desired protein not produced.

6a.
 Use the following tRNA/amino acid relationships:

			GGC pro	UUA asn	CAG val	CUC glu	GAU leu	AGG ser	CCG gly			
DNA:	TAC	AGG	GGC	CTC	TTA	CAG	CTC	GAT	AGG	CCG	GAT	ATC
mRNA	AUG	UCC	CCG	GAG	AAU	GUC	GAG	CUA	UCC	GGC	CUA	UAG
tRNA	UAC	AGG	GGC	CUC	UUA	CAG	CUC	GAU	AGG	CCG	GAU	AUC
Amino Acid	met start	ser	pro	glu	asn	val	glu	leu	ser	gly	leu	stop

6b. They are the same except for "T" and "U."

7.
 Use the following tRNA/amino acid relationships:

			GGC pro	UUA asn	CAG val	CUC glu	GAU leu	AGG ser	CCG gly			
DNA	TAC	GAT	CAG	GGC	CCG	TTA	AGG	CTC	CTC	GGC	CAG	ATC
mRNA	AUG	CUA	GUC	CCG	GGC	AAU	UCC	GAG	GAG	CCG	GUC	UAG
tRNA	UAC	GAU	CAG	GGC	CCG	UUA	AGG	CUC	CUC	GGC	CAG	AUC
Amino Acid	met start	leu	val	pro	gly	asn	ser	glu	glu	pro	val	stop

Resources

Kits

Demonstration kit: *DNA Made Easy*.
 Catalog #17-1040. Carolina Biological Supply Company (2700 York Rd., Burlington, NC 27215).

Audio/Visuals

6-part videotape: *Protein Synthesis*.
 Catalog #84-2489. TV Ontario (TV Ontario, 143 W. Franklin St., Suite 206, Chapel Hill, NC 27514).

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STUDENT PAGE 1



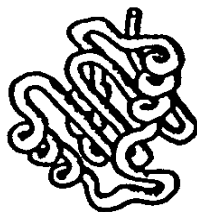
Background Reading

Naturally occurring **mutations** have created new genetic combinations since the origin of life. For centuries, humans have developed and used **selective crossbreeding** to improve organisms used for food, clothing, transportation, etc. Since the early 1970s, **genetic engineers** have developed molecular techniques to alter the genetic make-up of organisms. All three of these mechanisms involve changing the genetic make-up of organisms. How do these changes in an organism's genetic make-up (genotype) affect the trait that is expressed (phenotype)?

Proteins provide the structural and functional basis of life. They play a part in every conceivable life function:

- ▼ A structural protein called collagen helps make up cartilage and tendons. Another protein (keratin) is found in our hair and fingernails.
- ▼ Hemoglobin is a transport protein that carries oxygen through the body.
- ▼ Plant hormones such as auxins and gibberellins are proteins that enhance or regulate biochemical messages. Insulin stimulates our blood to remove sugar.
- ▼ Proteins that catalyze chemical reactions in organisms are called enzymes. Amylase helps us to digest starches, and RNA polymerase assists with the transcription process that you will learn about in this activity.
- ▼ Proteins also perform many other functions, serving as antibodies, nutrient and waste transporters, nutrient storers, receptors and contractile proteins for muscles.

Proteins have different functions, activities, shapes and chemical nature. Proteins are long, chainlike molecules that assume twisted 3-dimensional shapes. If we could see a typical protein, it might look like this:



Each link of a protein chain is a simple organic unit called an **amino acid**. There are 20 amino acids that are used to form protein chains. The proteins we eat are broken down and then rearranged into the proteins we need.

DNA, a type of nucleic acid, is a long, double-stranded molecule made up of units called **nucleotides**. One nucleotide consists of a deoxyribose sugar, a phosphate group and one nitrogenous base. The sequence of nucleotides contains information necessary for making a chain of amino acids – a protein chain. That sequence of nucleotides is called a **gene**. Sometimes several DNA sequences work together to make a protein; a gene is not always one continuous stretch of DNA.

Protein synthesis involves two basic processes, transcription and translation, that make use of another nucleic acid, RNA. RNA, like DNA, is made up of a chain of nucleotides. In transcription, enzymes catalyze the transfer of DNA's information to messenger RNA (mRNA) molecules. The mRNA molecules then move out of the nucleus to the ribosomes, where protein synthesis occurs.

Translation is the process of decoding the transcribed DNA message contained in mRNA. A second type of RNA, a cloverleaf shaped molecule called transfer RNA (tRNA) is involved. In the cytoplasm of the cell, specific tRNAs attach to their particular amino acid. At the base of each tRNA molecule is a sequence of three nucleotides (anticodon) that will recognize a complementary set of three nucleotides on the mRNA molecule (codon). The tRNAs, bonded to their amino acids, move to the ribosome where the mRNA is attached. The tRNA's and mRNA's bond together, as do the amino acids. The mRNA's and tRNA's release from each other, and the sequence of amino acids that is left is what defines the protein.

In this activity you will act out the steps of transcription and translation in protein synthesis.

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Activity Sheet

In this activity you will act out the steps of transcription and translation in protein synthesis.

Procedure

A. Setting the scene

- ▼ The classroom's floor, walls and ceiling are analogous to a cell membrane. The windows and doors represent the membrane's selectively permeable pores because they regulate the size of the objects that can enter or leave the "cell." (It would be hard for an elephant to come into the room!)
 - ▼ Designate one area of the class as the "nucleus," where **transcription** occurs. Enclose it with chairs and desks to represent the nuclear membrane. Spaces between chairs and desks simulate nuclear pores that regulate the movement of mRNA in and out of the nucleus.
 - ▼ All other non-nucleus areas in the room are "cytoplasm."
 - ▼ In the cytoplasmic region designate an area of the class as the "ribosome," where **translation** occurs.
1. The teacher will distribute the DNA sequences and their complementary mRNA codes to two groups of students. The cards are arranged in groups of three letters because the nitrogenous bases of the *genetic code* function as triplet-base units. The large letters on the cards refer to first letter of the nucleotide bases (A=adenine, C=cytosine, G=guanine, T=thymine and U=uracil). The nucleotide base "thymine" found in DNA is replaced by the base "uracil" in all RNA molecules. Do not distribute the tRNA and amino acids cards until step #8.
 2. Review DNA structure and the concept of complementary base-pairing. Recall that the informational part of DNA is within the sequence of nitrogenous bases. Protein synthesis, just like DNA replication, does not begin until a stretch of DNA gets the signal to "unzip" and expose the nitrogenous bases.

B. TRANSCRIPTION: The DNA message is *transcribed* into mRNA by the enzyme RNA polymerase.

1. Assume that a strand of DNA has unzipped, exposing DNA's bases. In reality, one of the two strands is "active," while the other acts as a "dummy." You will be working with the active strand in this activity.
2. Students with DNA cards should line up in the classroom area designated "nucleus." The student with the DNA card labeled "TAC" (the start sequence) should be on the left as the class sees him/her, and the "ATC" (the stop sequence) card should be on the right. All other DNA cards can be arranged in any order.
3. RNA polymerase catalyzes the pairing of DNA's exposed bases with complementary RNA bases. (Remember, only one of the two DNA strands is active.) Students with the RNA cards should match their 3-letter sequence with the 3-letter sequence of the DNA cards. The 3-base mRNA sequence is called a codon.
 - ▼RNA cytosine always pairs with DNA guanine.
 - ▼RNA uracil (Remember: "U" substitutes for "T") always pairs with DNA adenine.
 - ▼RNA adenine always pairs with DNA thymine.
 - ▼RNA guanine always pairs with DNA cytosine.
4. After everyone matches up their cards, use the following table to check the DNA/RNA pairs. Notice that of the nine pairs, the stop and start pairs are the only ones that must be in a certain position.

DNA	TAC	GGC	TTA	CAG	CTC	GAT	AGG	CCG	ATC	
mRNA	AUG	CCG	AAU	GUC	GAG	CUA	UCC	GGC	UAG	<i>Transcription</i>
	<u>start</u>								<u>stop</u>	

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5. Students with the DNA cards can sit down, leaving a chain of RNA sequences. You have simulated the process of **transcription** as it happens in protein synthesis. Notice you have made a very short (shorter than in real life) **complementary** section of RNA that almost reflects the exact opposite of the DNA code.

C. TRANSLATION: The mRNA message is *translated* into a chain of amino acids called a protein via enzymes and tRNA.

Notice that the tRNA cards are also arranged in groups of three letters. The three-base sequence of tRNA is called an *anticodon*. In addition, each tRNA card has a 3-letter abbreviation (in the "arrow" part of the card) for one of the 20 amino acids. This activity includes only seven of the 20 protein-building blocks called amino acids.

- If there are enough students, distribute the tRNA and amino acid cards to two new groups of students. Students with either type of card should be randomly scattered in the "cytoplasm."
- Students with the tRNA cards should find their specific amino acids. For example, the tRNA anticodon card "GGC" with the letters PRO should find the amino acid PROLINE. Simultaneously, students with mRNA cards should walk out the "nucleus" through the rows of desks/chairs that represent the nuclear pores and stop in the area designated "ribosome."
- After the tRNA students find the students with amino acid cards, *both students* should proceed over to the mRNA card that matches the tRNA card. Use the rules of complementary base-pairing:
 - ▼ RNA cytosine always pairs with RNA guanine.
 - ▼ RNA uracil always pairs with RNA adenine.
 - ▼ RNA adenine always pairs with RNA uracil.
 - ▼ RNA guanine always pairs with RNA cytosine.
- Messenger RNA and tRNA anticodon sequences are given below based on the original DNA sequence given in step #7. Except for the start and stop cards, student cards will not necessarily be in this order across the row, but they should match up vertically (e.g., mRNA's "CCG" will pair with tRNA's "GGC"). Use the following table to check the mRNA/tRNA pairs:

mRNA	AUG	CCG	AAU	GUC	GAG	CUA	UCC	GGC	UAG	
tRNA and amino acid	UAC met	GGC pro	UUA asn	CAG val	CUC glu	GAU leu	AGG ser	CCG gly	AUC <u>stop</u>	<i>Translation</i>

5. As each tRNA anticodon finds its corresponding codon on the mRNA strand, the tRNAs detach from their amino acids. The amino acids remain at the ribosome and form a peptide bond with the amino acid brought by the previous tRNA. Two or more amino acids linked in this way are called polypeptides. *Translation* is complete when a sequence of mRNA information translates into a polypeptide. A protein is one or more polypeptide chains linked together.

Do the circled questions.

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STUDENT PAGE 4



Questions

1. Name five types of proteins and describe their functional roles.

- a.
- b.
- c.
- d.
- e.

2. Compare and contrast:

▼ mutations, selective breeding and genetic engineering

▼ DNA replication and protein synthesis

▼ transcription and translation

3a. What is the difference between a DNA sequence of codons and an RNA sequence of codons?

b. Why do we say that DNA determines the structural arrangement of proteins?

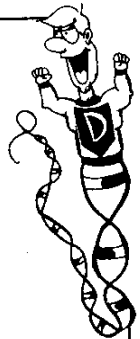
4. Suppose an individual has a nutrient deficiency due to poor diet and is missing a particular amino acid. Which process of protein synthesis would be more affected? Why?

5a. What is the relationship of the "active" and "dummy" strands of DNA? What do they look like?

b. Would there be a problem if the dummy strand were used to make a protein? Why?

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STUDENT PAGE 5



6a. Given below are some tRNA anticodons/amino acid relationships and a stretch of imaginary DNA. Fill in the missing boxes in the chart below by writing the correct mRNA codons, tRNA anticodons and amino acids.

Use the following tRNA/amino acid relationships:

		GGC pro	UUA asn	CAG val	CUC glu	GAU leu	AGG ser	CCG gly					
DNA:	TAC	AGG	GGC	CTC	TTA	CAG	CTC	GAT	AGG	CCG	GAT	ATC	
mRNA													
tRNA													
Amino Acid	met start												stop

b. What are the similarities between the DNA sequence and the tRNA sequence?

7. A new and exciting branch of biotechnology is called protein engineering. To engineer proteins, molecular biologists work backward through the protein synthesis process. They first determine the exact sequence of the polypeptides they want, and then create a DNA sequence to produce it. Use the rules of transcription and translation to "engineer" the peptide sequence below. Fill in the rows for tRNA anticodons, mRNA codons and DNA.

Use the following tRNA/amino acid relationships:

		GGC pro	UUA asn	CAG val	CUC glu	GAU leu	AGG ser	CCG gly					
DNA													
mRNA													
tRNA													
Amino Acid	met start	leu	val	pro	gly	asn	ser	glu	glu	pro	val		stop