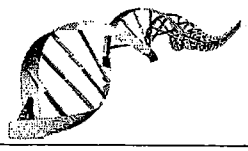
KEY

From Gene to Protein – Transcription and Translation[1]

How do genes influence our characteristics?

A **gene is a segment of DNA** that provides the **instructions for making a protein. Proteins** have many different functions that **influence our characteristics**. This chart shows an example.

Gene in DNA	→	Protein	→	Characteristic
	→		→	
One version of a gene provides instructions to make normal protein enzyme.	→	Normal enzyme makes the pigment molecule in skin and hair.	→	Normal skin and hair color
Another version of the gene provides instructions to make defective protein enzyme.	→	Defective enzyme does not make this pigment molecule.	→	Albinism (very pale skin and hair)

1. How can a gene determine whether a person has albinism? (Give a molecular explanation.)

gene codes for a defective enzyme which cannot make the pigment molecule

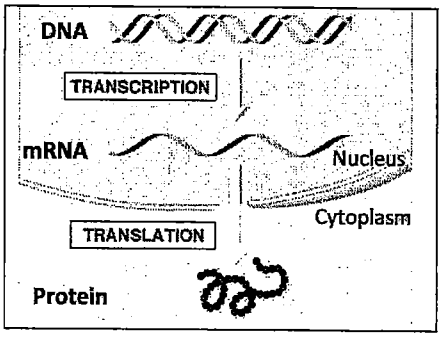
mutation → change in nucleotides

How does a gene provide the instructions for making a protein?

A two-step process:

The first step is **transcription** of the gene in the DNA.
Transcription produces **messenger RNA (mRNA)**.

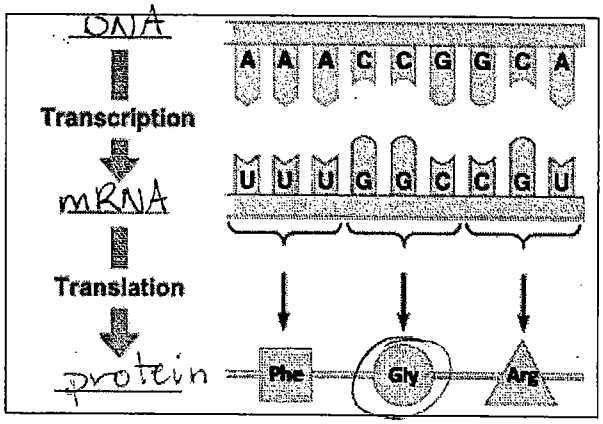
The second step is **translation** of the mRNA molecule.
Translation produces **proteins**.



2a. Fill in the blanks in this figure to label the DNA, mRNA and protein molecules.

2b. DNA and RNA are polymers of **nucleotides**. The four nucleotides in DNA are A, T, C, and G. The four nucleotides in RNA are A, U, C, and G.

2c. A protein is a polymer of **amino acids**. Draw a circle around the amino acid Gly (glycine) in the protein.



3a. During transcription, the sequence of nucleotides in a gene in the DNA is copied to a corresponding sequence of nucleotides in mRNA.

3b. During translation, the sequence of nucleotides in mRNA determines the sequence of amino acids in the protein. The sequence of amino acids determines the structure and function of the protein.

4a. Which process takes place in the nucleus? transcription ✓ translation ___

4b. Explain why this process must occur in the nucleus.

DNA is located here

Transcription

5. Why does a cell need to carry out transcription in order to make a protein?

DNA is too big to leave the nucleus, so mRNA must be made in order to fit through a nuclear pore and reach the ribosome

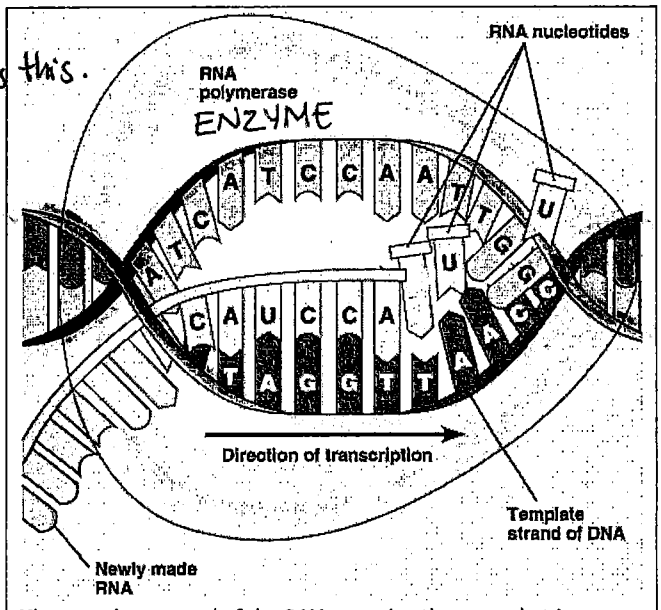
6. In this activity, you will model how a cell carries out transcription and translation to make the beginning of the hemoglobin molecule. What type of molecule is hemoglobin?

a protein

During transcription, the enzyme **RNA polymerase**:

- separates the two strands of a DNA double helix incorrect: DNA helicase does this.
- uses a gene in one DNA strand as a guide to make an mRNA molecule.

7. In the figure:
- Write enzyme next to the name of the enzyme.
- Trace the outlines of the DNA molecule.



The template strand of the DNA contains the gene that is being transcribed. **A** = adenine; **C** = cytosine; **G** = guanine; **T** (in DNA) = thymine; **U** (in RNA) = uracil

RNA polymerase adds one nucleotide at a time to the growing mRNA molecule. Each DNA nucleotide in the gene is matched with a **complementary RNA nucleotide** which has a matching shape and charge distribution.

The **base-pairing rules** summarize which nucleotides are complementary. The base-pairing rules for transcription are similar to the base-pairing rules in the DNA double helix.

8a. Use the information in the figure to complete this table.

Base-Pairing Rules for Complementary Nucleotides:	
between the two strands of a DNA double helix	**between DNA and RNA (during transcription)**
G pairs with **C**.	**G** pairs with C.
T pairs with **A**.	**T** in DNA pairs with A in RNA. **A** in DNA pairs with U in RNA.

8b. Which nucleotide will be the next nucleotide to be joined to the growing mRNA molecule in the figure? A

The base-pairing rules ensure that the nucleotide sequence in the gene in the DNA is copied into a corresponding nucleotide sequence in the mRNA molecule.

9. Why is RNA polymerase a good name for the enzyme that carries out transcription? Explain each part of the name: RNA, polymer and ase.

IGNORE!

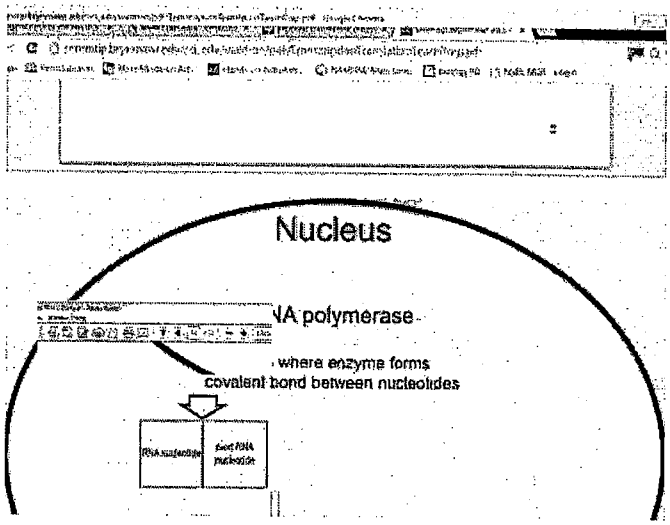
Transcription Modeling Procedure

Note: In this modeling activity, your goal is to learn how the cell actually makes mRNA. During transcription the enzyme RNA polymerase adds one nucleotide at a time to the growing mRNA molecule. You probably will be able to think of a faster way to make the mRNA, but you should follow this sequence of steps since they will simulate the actual molecular process of transcription.

- To model the process of transcription, your group will need a page showing an RNA polymerase molecule inside a nucleus, a paper strip showing a single strand of DNA labeled "Beginning of Hemoglobin Gene", RNA nucleotides and tape.
- One of you will be the RNA polymerase. Another group member will be the cytoplasm which surrounds the nucleus and supplies the nucleotides which are used to make the mRNA molecule.

- RNA polymerase: Insert the "Beginning of Hemoglobin Gene" DNA molecule through the slot in the RNA polymerase diagram so the first two nucleotides of the gene are on the dashes labeled DNA.

  Your RNA polymerase should look like this figure. (Note: A real RNA polymerase molecule and DNA and RNA nucleotides are much smaller than the nucleus.)



- Cytoplasm: Use the base-pairing rules to choose an RNA nucleotide that is complementary to the first DNA nucleotide. Give this nucleotide to the RNA polymerase person.
- RNA polymerase: Put the first RNA nucleotide in the box labeled RNA nucleotide.

- Cytoplasm: Give the next RNA nucleotide (complementary to the next DNA nucleotide) to the RNA polymerase person.
- RNA polymerase: Put this nucleotide in the box labeled "next RNA nucleotide". Join the two RNA nucleotides together with transparent tape; the tape represents the covalent bond between these two nucleotides in the growing mRNA molecule. Then, move the DNA molecule and the mRNA molecule one space to the left.

- Repeat these last two steps as often as needed to complete transcription of the beginning of the hemoglobin gene, adding one nucleotide at a time to the mRNA molecule.

What is the mRNA sequence you transcribed?
GUGCAUCUG

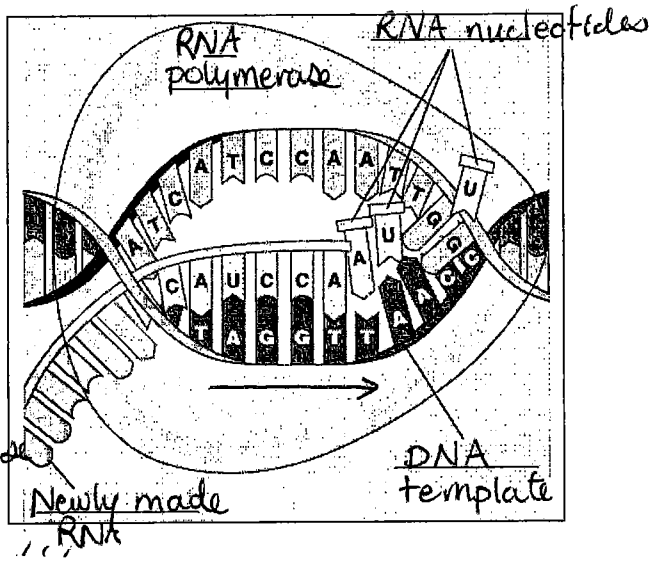
10. The first column of this table describes DNA replication. Fill in the blanks in the second column to summarize the differences between DNA replication and transcription.

DNA replication	Transcription
The whole chromosome is replicated.	1 gene is transcribed.
DNA is made. DNA is double-stranded.	mRNA is made. mRNA is single -stranded.
DNA polymerase is the enzyme which carries out DNA replication.	RNA polymerase is the enzyme which carries out transcription.
T = thymine is used in DNA, so **A** pairs with **T** in DNA.	**T** = thymine is replaced by ___ = uracil in RNA, so **A** in DNA pairs with ___ in mRNA.

11. Fill in the blanks to describe the similarities between transcription and DNA replication.

Both transcription and DNA replication produce nucleic acids which are polymers of nucleotides (C, G, A, and T or U). Both processes depend on a polymerase enzyme which adds one nucleotide at a time. To determine which nucleotide is added next, both transcription and DNA replication use the nucleotide sequence in a single strand and the base-pairing rules.

12a. Fill in the blanks to label each type of molecule in the figure.

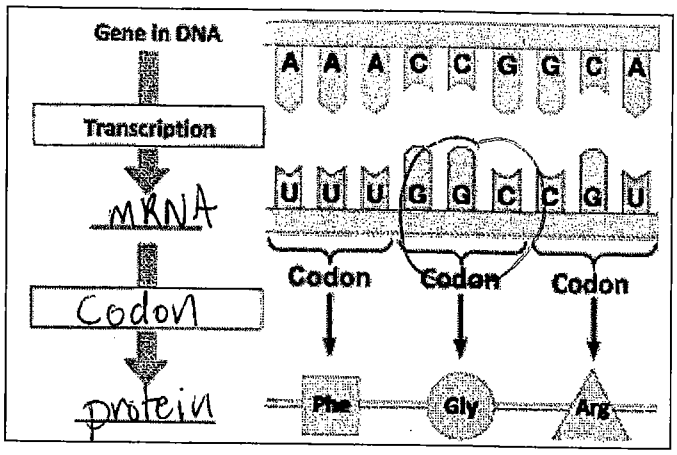


12b. Name the process shown in the figure and explain how this process occurs. Include in your answer each of the molecules shown and these words and phrases:
gene, base-pairing rules, one at a time.

Transcription is the process of converting a portion of DNA, a gene, into mRNA. DNA helicase unzips DNA and RNA polymerase uses 1 strand of DNA as a template for making mRNA. RNA polymerase follows the base-pairing rules to add one nucleotide at a time to make a new strand of mRNA.

Translation

13. To show how translation follows transcription, fill in the blanks and box in this figure.



How can four different types of nucleotide in mRNA provide a different code for each of the 20 different types of amino acids in proteins?

The answer is that the mRNA code for each type of amino acid is a sequence of three nucleotides called a **codon**.

14. In the figure, circle the mRNA codon that codes for the amino acid Gly (glycine).

Translation requires two types of RNA: mRNA and **transfer RNA** = **tRNA**. tRNA molecules bring the correct amino acid for each codon in the mRNA.

There are multiple different types of tRNA, each with a different **anticodon**. Each tRNA anticodon has three nucleotides that are matched by the base-pairing rules to the three nucleotides in the mRNA codon for a specific amino acid.

15. What is the tRNA anticodon for the amino acid Gly (glycine)? CCG

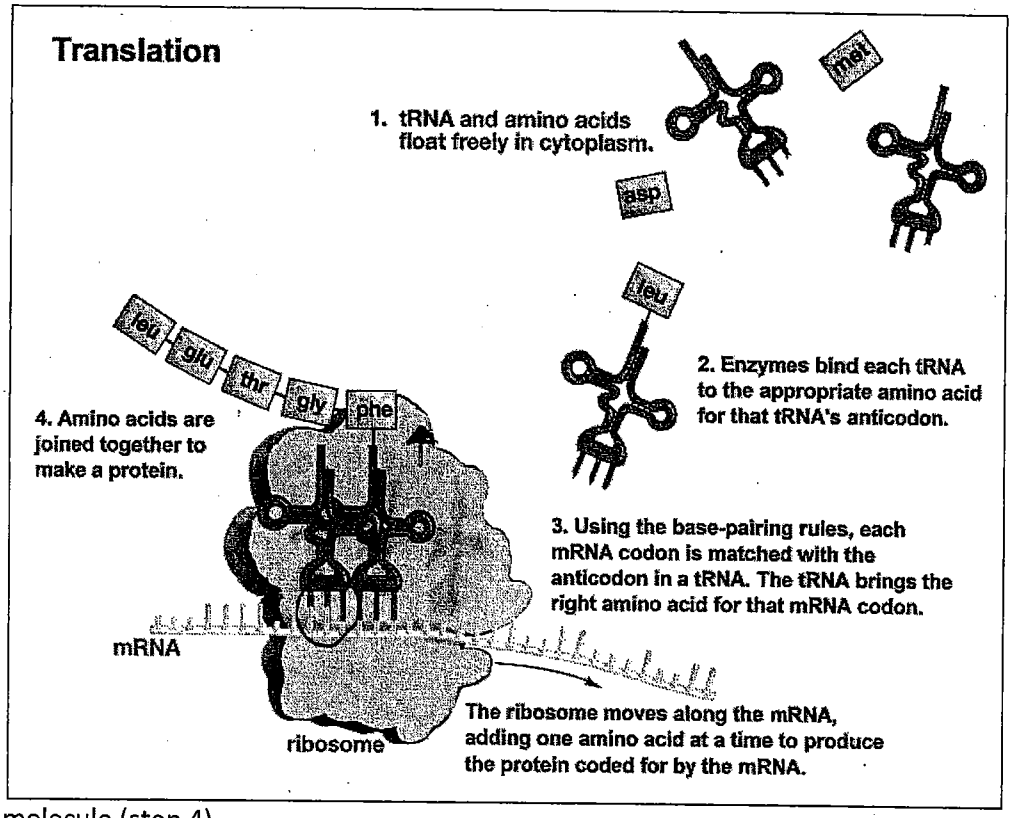
16. For each type of tRNA, there is a specific enzyme that attaches the correct amino acid for the anticodon in that tRNA. These enzymes are needed for step 2 (1/2/3/4) in the figure below.

Translation takes place in **ribosomes** (tiny structures inside cells).

Inside the ribosome, a codon in an mRNA molecule is matched by the base-pairing rules with an anticodon in a tRNA (step 3). This tRNA brings the next amino acid to be added to the growing protein molecule.

17. In the ribosome, circle a codon in the mRNA and the complementary anticodon in a tRNA molecule.

Each amino acid is joined to the previous amino acid in the growing protein molecule (step 4).



18. Use an arrow to show where the next amino acid will be added to the growing protein molecule.

19. What part of translation depends on the base-pairing rules?

mRNA codon matches tRNA anticodon

Translation Modeling Procedure

In this section you will simulate the steps in translation to produce the beginning of a hemoglobin protein.

- One of you will be the ribosome, and another will be the cytoplasm.

Preparation

- To model translation, you will need a page showing a ribosome, tRNA molecules, amino acids, the mRNA you made during your simulation of transcription, and a strip labeled "Second Part of mRNA".
- Cytoplasm: Tape the CUG end of the mRNA you made to the ACU end of the Second Part of mRNA strip.

20. For tRNA to do its job, each tRNA molecule must be attached to the correct amino acid that corresponds to the anticodon in that type of tRNA. To know which amino acid should be attached to each tRNA molecule, use the base-pairing rules to complete this table.

Amino acid	Threonine (Thr)	Histidine (His)	Proline (Pro)	Leucine (Leu)	Glutamic acid (Glu)	Valine (Val)
Anticodon in tRNA molecule that carries this amino acid	UGA	GUA	GGA	GAC	CUC	CAC
mRNA codon	ACU	CAU	CCU	CUG	GAG	GUG

- Cytoplasm: Use this table to match each model tRNA molecule with the correct amino acid for that type of tRNA. Tape the amino acid to the tRNA *very lightly*, because they will only be joined temporarily and will soon separate.

  Note: Each model tRNA molecule only shows the three nucleotides of the anticodon and the binding site for the amino acid. A real tRNA molecule has many more nucleotides. Similarly, a real mRNA molecule has many more nucleotides than your strip has.

Skip this and give them the codon chart.

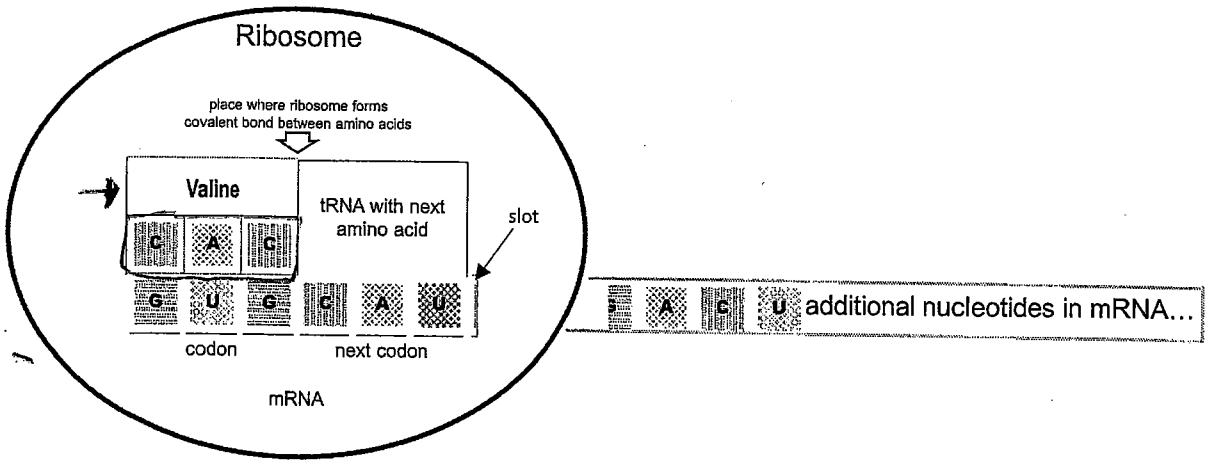
21. Your partner wants to move ahead quickly, so he uses the mRNA strip and the table above to arrange the amino acids in the correct sequence; then he tapes together all six amino acids. Explain why this would *not* be a good simulation of the actual sequence of steps used to carry out translation. (Hint: See page 5.)

Valine - Histidine - Leucine - Threonine - Proline - Glutamic Aci'd.

Modeling the Steps in Translation

- Ribosome: Insert the mRNA through the slot in the model ribosome, with the first three nucleotides of the mRNA in the "codon" position and the next three nucleotides in the "next codon" position.
- Cytoplasm: Use the base-pairing rules to supply the tRNA that has the correct anticodon to match the first codon in the mRNA.
- Ribosome: Place this tRNA with its amino acid in position.

Your model ribosome should look like this:



22. In the above diagram, put a rectangle around the anticodon in the tRNA. Use an arrow to indicate the amino acid.

- Cytoplasm: Supply the tRNA that has the correct anticodon to match the codon in the "next codon" position.
- Ribosome: Place the tRNA in position. Tape the two amino acids together to represent the covalent bond between these two amino acids. Detach the amino acid on the left from its tRNA.
- Ribosome: Move the mRNA and matching tRNAs with amino acids one codon to the left. Release the tRNA on the left to the cytoplasm.

- Repeat these three steps until you have attached all six amino acids to form the beginning portion of the hemoglobin protein.

23. Why does a cell need tRNA to make a protein? Explain the function of tRNA and how tRNA and mRNA work together to put the right amino acids in the right sequence as the protein is made.

What is the sequence of amino acids at the beginning of it brings the correct amino acid to the mRNA. Which tRNA is needed depends upon the mRNA codon.

24. Explain why it makes sense to use the word translation to describe protein synthesis and why it would *not* make sense to use the word translation to describe mRNA synthesis.

same language → transcription - uses DNA nucleotides to write in tRNA nucleotides

different language → translation - translates from RNA nucleotides to amino acids

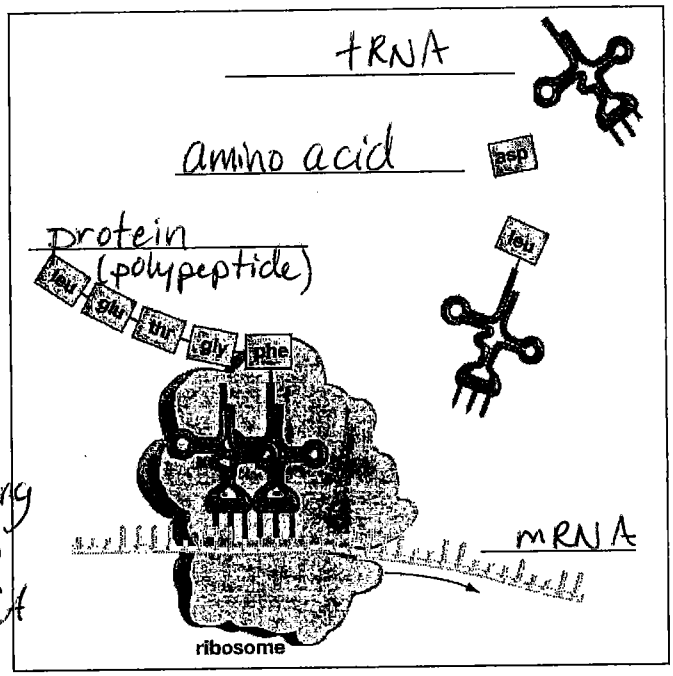
25. Why does a cell need to carry out transcription before translation?

So that the code can reach the ribosome where proteins are made.

26a. Fill in the blanks to label each type of molecule in this figure.

26b. Name the process shown in the figure and explain each step in this process. Include in your answer each of the molecules shown and these words and phrases:

anticodon, base-pairing rules, codon, ribosome, sequence of amino acids.



Translation - at the ribosome the mRNA codons are matched with the corresponding tRNA anticodon according to base-pairing rules. The tRNA brings the correct amino acid to the ribosome and attaches them together to make a polypeptide (protein)

Understanding How the Gene for Sickle Cell Hemoglobin Results in Sickle Cell Anemia

Different versions of the same gene are called different **alleles**. These different alleles share the same general sequence of nucleotides, but they differ in at least one nucleotide in the sequence.

27a. Complete this flowchart to show how different alleles can result in different characteristics.

In the DNA, different alleles of a gene have a different sequence of nucleotides

↓ transcription

different sequence of nucleotides in mRNA

↓ translation

different sequence of amino acids in a protein

↓

different structure and function of the protein

↓

different characteristics

27b. Label the arrow that represents transcription and the arrow that represents translation.

Next, you will analyze how different alleles of the hemoglobin gene can result in sickle cell anemia vs. normal health.

28. Using the table below, compare the nucleotide sequence in the "Beginning of Normal Hemoglobin Gene" vs. the "Beginning of Sickle Cell Hemoglobin Gene". What is the only difference?

Normal - T
Sickle Cell - A

Beginning of **Normal** Hemoglobin **Gene**	**CACGTAGACTGAGGACTC**					
Transcription *produces:*	codon1	codon 2	codon 3	codon 4	codon 5	codon 6
Beginning of **Normal** Hemoglobin **mRNA**	GUG	CAU	CUG	ACU	CCU	GAG
Translation *produces:*	amino acid 1	amino acid 2	amino acid 3	amino acid 4	amino acid 5	amino acid 6
Beginning of **Normal** Hemoglobin **Protein**	Valine	histidine	leucine	Threonine	Proline	Glutamic Acid
Beginning of **Sickle Cell** Hemoglobin **Gene**	**CACGTAGACTGAGGACAC**					
Transcription *produces:*	codon 1	codon 2	codon 3	codon 4	codon 5	codon 6
Beginning of **Sickle Cell** Hemoglobin **mRNA**	GUG	CAU	CUG	ACU	CCU	GUG
Translation *produces:*	amino acid 1	amino acid 2	amino acid 3	amino acid 4	amino acid 5	amino acid 6
Beginning of **Sickle Cell** Hemoglobin **Protein**	valine	histidine	leucine	Threonine	Proline	valine.

29. Complete the above table. ~~(Use the table on page 6 to help with translation.)~~ Use your codon chart to

30. Compare the amino acid sequence for the beginning of sickle cell hemoglobin vs. the beginning of normal hemoglobin. What difference do you observe?

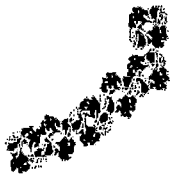
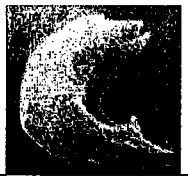
1 amino acid difference

Sickle cell hemoglobin and normal hemoglobin differ in only a single amino acid out of more than 100 amino acids in the complete hemoglobin protein. This difference in a single amino acid results in the different properties of sickle cell hemoglobin compared to normal hemoglobin.

Hemoglobin is carried inside red blood cells. Normal hemoglobin dissolves in the watery cytosol of red blood cells. Sickle cell hemoglobin is less soluble in the cytosol because:

- Valine (Val) is much less water-soluble than glutamic acid (Glu).
- Amino acid 6 is in a crucial location on the outer surface of the hemoglobin protein.

The chart on the next page shows how the lower solubility of sickle cell hemoglobin results in the symptoms of sickle cell anemia.

Genes in DNA	→	Protein	→	Characteristics
2 copies of the allele that codes for normal hemoglobin (SS)	→	Normal hemoglobin dissolves in the cytosol of red blood cells. 	→	Disk-shaped red blood cells can squeeze through the smallest blood vessels → normal health  A
2 copies of the allele that codes for sickle cell hemoglobin (ss)	→	Sickle cell hemoglobin can clump in long rods in red blood cells.  B	→	If sickle cell hemoglobin clumps in long rods → sickle-shaped red blood cells → clogged small blood vessels + fragile red blood cells → pain, damage to body organs + anemia = sickle cell anemia  C

31a. Circle the arrows in the chart that represent transcription + translation.

31b. Use the letter for each of the following statements to label the box or boxes in the flowchart that illustrate this statement.

A. Normal hemoglobin dissolves in the watery cytosol of red blood cells. The disk-shaped red blood cells can squeeze through the smallest blood vessels so blood flow is normal.

B. If a person inherits two copies of the sickle cell hemoglobin allele and produces only sickle cell hemoglobin, then the sickle cell hemoglobin molecules tend to clump together in long rods inside red blood cells.

C. These hemoglobin rods can result in sickle-shaped red blood cells which can block blood flow in small blood vessels; this causes pain and damage to body organs. Sickle-shaped red blood cells don't last as long as normal red blood cells; when the body can't produce enough replacement red blood cells, this results in anemia.

32. Considering that we are all made up of the same 4 nucleotides in our DNA, the same 4 nucleotides in our RNA, and the same 20 amino acids in our proteins, why are we so different from each other? For example, why do some people have sickle cell anemia and others don't?

differences in nucleotides.

[1] By Drs. Ingrid Waldron and Jennifer Doherty, Department of Biology, University of Pennsylvania, Copyright, 2017. Teachers are encouraged to copy this Student Handout for classroom use. A Word file (which can be used to prepare a modified version if desired) and Teacher Preparation Notes with instructional suggestions and background biology are available at http://serendipstudio.org/sci_edu/waldron/#trans .