From Gene to Protein -- Transcription and Translation
Teacher Preparation Notes

By Dr. Ingrid Waldron and Dr. Jennifer Doherty, Department of Biology, University of Pennsylvania, Copyright, 2010[1]

Suggestions for Implementation

This activity is intended for students who have already learned about biological polymers (including the basic structure of proteins and DNA) and have been introduced to the concepts of chromosomes and genes. The questions on page 1 provide an opportunity to review some of the relevant concepts. We also assume that students have learned about the importance of the base-pairing rule in DNA structure and DNA replication (e.g. using the "DNA" activity on this website; see footnote).

If you have already introduced transcription and translation, your students probably can complete this activity in two 50-minute periods. However, if you would like to use this activity to introduce the topic, another possible sequence for four 50-minute periods is:

Period 1: Introduce the basic functions and processes of transcription and translation, and explain how transcription occurs (including the material on pages 1, 2 and the top of 3 of the student handout). Show an animation of transcription. We suggest the animation of transcription of the hemoglobin gene produced by the Howard Hughes Medical Institute and available at: http://www.hhmi.org/biointeractive/dna/animations.html#dna-transcription_vo1.

Period 2: Have students model transcription and answer the questions (pages 3, 4 and the top of 5). If you have time, explain how translation occurs (pages 5-6) and show an animation of translation http://www.hhmi.org/biointeractive/dna/animations.html#dna-translation_vo1.

Period 3: If you haven't finished explaining how translation occurs, explain translation. Have students model translation and answer the questions (pages 7-10).

Period 4: Discuss how different alleles affect phenotype, including sickle cell anemia, and have students answer the questions (pages 10-13). We also recommend showing and discussing the sickle cell anemia video available at http://www.hhmi.org/biointeractive/dna/animations.html

In order for students to learn the process of transcription through this modeling activity, it is important for them to add each nucleotide one at a time, mimicking the actual activity of RNA polymerase. Some students will want to lay out all the mRNA nucleotides and tape them together all at once, which is more efficient in getting the task done, but less effective in modeling and understanding the real biological process. Similarly, during translation, the students should insert one tRNA with amino acid at a time, similar to the actual function of the ribosome. Although the modeled process may seem rather long and tedious to some students, transcription and translation occur very rapidly in real cells. For example, RNA polymerase adds about 50 nucleotides per second to the growing mRNA molecule.

We find that, at each step, you have to be very explicit in your instructions in order to prevent students from racing ahead in ways that undermine the learning goals. For example, in the transcription activity students should not tape the RNA nucleotides to the DNA nucleotides, since these are not linked by covalent bonds. (You may want to provide masking tape or low stick painters' tape to represent the weaker hydrogen bonds between complementary nucleotides.) You may want to make a transparency of the RNA polymerase, ribosome, and relevant molecules and use these on an overhead projector to demonstrate the proper procedures.

If your students have particular difficulty learning vocabulary, you may want to precede question 3 on page 5 and question 1 on page 12 of the student handout with questions that ask for definitions of the terms listed (or perhaps a matching question in which you provide your preferred definitions for these terms). Alternatively, if you feel the current versions are too challenging for your students, you could use a fill-in-the-blank version of

---

[1] These Teacher Preparation Notes and the related Student Protocol are available at http://serendip.brynmawr.edu/sci_edu/waldron/.

these questions or you could provide a first sentence and the beginning of the second sentence to help the students get started.

If you want to emphasize learning how to use the standard chart of codons in mRNA and corresponding amino acids, you can substitute the chart from your textbook for the chart on the bottom of page 5 of the student handout. This would also provide the opportunity to discuss the function of the start and stop codons in initiating and terminating translation. Our preference is to use the simplified chart on page 5, so students can concentrate on understanding the process of translation, and then practice using the standard codon chart in a separate activity.

To request an answer key, write to iwaldron@sas.upenn.edu. If you would prefer to use two separate student handouts, one for the questions and one for the biology background and instructions for the activities, these are available at http://serendip.brynmawr.edu/exchange/waldron/gene.

Supplies needed

Use the templates shown, beginning on page 5, to make for each pair of students a page labeled Nucleus, a page labeled Ribosome, and a packet containing the following:

- DNA molecule on colored paper (cut the template in strips)
- Second Part of mRNA strip and 9 RNA nucleotides on a different color paper (each packet should have 1A, 2C, 3 G, and 3U)
- 6 tRNA molecules on same color paper as RNA nucleotides (cut each tRNA rectangle to include the three nucleotides and the words "amino acid" directly above these nucleotides; one of each type of tRNA per packet)
- 6 amino acids on a different color paper (one of each amino acid per packet)

Each pair of students will also need transparent tape.

Key Concepts for Students to Learn:

-- understand process of transcription

and comparison of transcription vs. replication

-- similarities: base-pairing rule crucial for both; monomers added one at a time and joined by covalent bonds; carried out by a polymerase enzyme

-- differences (see table on page 4 of student protocol)

-- understand process of translation, including roles of mRNA, tRNA and ribosomes

-- understand function of mRNA and tRNA

-- mRNA carries genetic message from nucleus to ribosomes; each mRNA codes for the sequence of amino acids in a protein and each triplet codon in the mRNA codes for a specific amino acid in the protein

-- tRNA needed for translation -- different types of tRNA bring the right amino acid for each position in the polypeptide; tRNA anti-codon has three nucleotides which are complementary to the three nucleotides in an mRNA codon; the other end of each tRNA molecule binds to the amino acid specified by that mRNA codon

-- explain how proteins are synthesized using genetic information from DNA

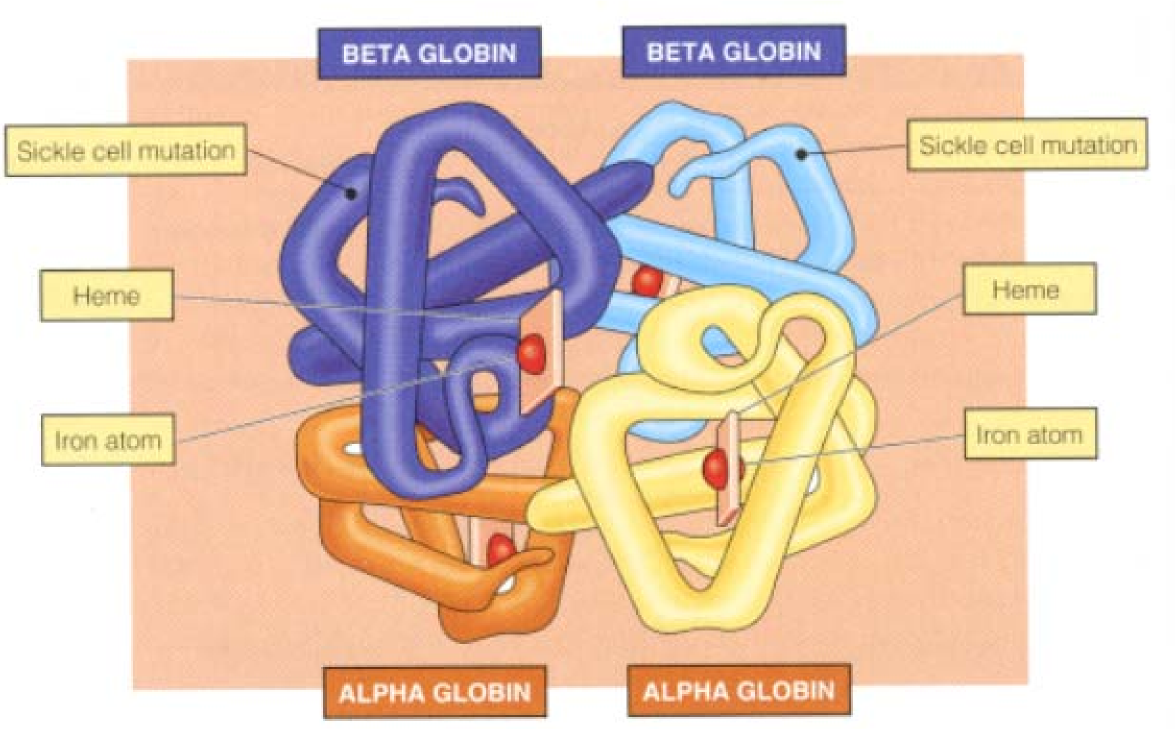
-- incorporate understanding of transcription and translation

-- understand how genes influence phenotype by determining amino acid sequence in proteins

-- examples: albinism and sickle cell anemia

Background Biology and Suggestions for Discussion

To stimulate student interest, you may want to begin with the question "How can differences in the tiny DNA molecule change a person's appearance or health?" The examples discussed in this activity are the genes for albinism and sickle cell anemia, but the same principles apply to the effects of many other genes. A view of the human side of sickle cell anemia (including singer/actress Tionne T-boz Watkins) and an introduction to some current research on treatment of sickle cell anemia is available at http://videos.howstuffworks.com/hsw/18705-your-body-your-health-sickle-cell-disease-video.htm



This activity discusses transcription and translation of the beginning of the gene for the beta globin polypeptide in the hemoglobin tetramer and ignores the gene for the alpha globin polypeptide. The alpha globin gene and polypeptides are unchanged in sickle cell hemoglobin. You may want to relate the tendency of sickle cell hemoglobin to clump together in long rods to the lower solubility of nonpolar valine in the watery cytosol of the red blood cell, compared to the high solubility of ionic glutamic acid. This difference in the solubility of amino acid 6 is crucial because amino acid 6 is on the outside of hemoglobin molecule.

This activity summarizes the effects of the homozygous sickle cell allele, resulting in sickle cell anemia. Even in a person who has severe sickle cell anemia, most red blood cells are not sickled. The amount of clumping of the sickle cell hemoglobin, sickling of red blood cells, and symptoms are influenced by multiple factors, including oxygen levels in the blood, dehydration, and multiple genetic factors. A very good summary of the medical aspects of sickle cell anemia, including symptoms, diagnosis and treatment is available at http://www.mayoclinic.com/health/sickle-cell-anemia/DS00324.

An individual who is heterozygous for the sickle cell allele (sickle cell trait) almost always has no symptoms because each red blood cell contains both normal and sickle cell hemoglobin and the normal hemoglobin generally prevents clumping of the sickle cell hemoglobin. Athletic associations recommend testing for sickle cell trait and taking appropriate precautions to prevent extreme exertion and dehydration in order to reduce the small but significant risk of exercise-related sudden death. Harmful health effects of sickle cell trait are rare, and life expectancy is not detectable reduced. Individuals with sickle cell trait have less serious malaria infections because the malaria parasite doesn't grow as well in their red blood cells.

The DNA strand we provide is the template strand for the beta globin polypeptide; this is the DNA strand which is transcribed for a given gene. The template strand is also called the antisense strand. The other strand of the DNA double helix is called the sense strand; it has the same nucleotide sequence as the RNA produced by transcription. If your students ask how the RNA polymerase is directed to transcribe the right strand of the DNA double helix, you can explain the role of the promoter in initiating transcription.

The modeling procedures for transcription and translation demonstrate the basic biological processes, but we have omitted many points and you may want to include some of these if your students already have a good grasp of the basic processes. For example, multiple different nucleotides enter and leave the RNA polymerase, but, for each DNA nucleotide only the complementary RNA nucleotide that can form hydrogen bonds with that specific DNA nucleotide will remain in place to be covalently bonded to the preceding RNA nucleotide.

Some students have difficulty understanding the function of the tRNA molecule. An analogy that may help them understand is as follows. Suppose a group of American tourists goes into a restaurant in China and each one wants to order his or her favorite Chinese dish. Suppose the tourists only speak English, and the cook only speaks Chinese. It will be very helpful to have a waiter who understands English and can speak Chinese, so he can serve as a translator. The tourists are equivalent to the mRNA which specifies which amino acids should be incorporated in the growing protein molecule, and the cook is equivalent to the cytoplasm which provides lots of different types of amino acids. The waiter is equivalent to the tRNA molecules which bring the right amino acids to the right locations.