Paper Transcription and Translation

Abstract

Using paper cut-outs, students follow the rules of complementary base pairing to build an mRNA molecule, then translate the codons in the mRNA to build a protein. At the end, they learn which of five actual proteins they've built. (DNA and amino acid sequences are abbreviated from real genes.)

Learning Objectives

- The arrangement of DNA building blocks in a gene specifies the order of amino acids in the protein it codes for.
- Amino acids are the building blocks of proteins.
- The sequence of amino acids in a protein determines its structure and function.
- Living things make proteins the same way.

Estimated time

- 60-90 minutes

Materials

- Per student or pair of students:
  - Copy of student instructions
  - Cut-outs (Page B, and one version of Page A), printed single-sided
  - Scissors
  - Clear tape
  - Paper clips
- Extra copies of protein and mRNA strips (in case students need to start over)
- Protein Pages: One page for each student or pair

Note: Rectangular and circular versions of the Amino Acid Codon Chart are provided. Though the activity uses the 1-letter abbreviations for amino acids, which are conventionally used in research, the Codon Charts also show the 3-letter abbreviations for amino acids, along with their full names.

Instructions

1. *Set up* – Prepare cut-outs according to the copy instructions in the cut-outs document.
2. Distribute materials and have students begin.
3. Place copies of the Protein Pages in a central location. As students finish their proteins, have them look at the Protein Pages and determine which protein they made. If their amino acid sequence does not match one of the proteins, have them go back through their work and find their error.

Common student problems to watch out for and correct

- Transcribing the wrong strand
- Transcribing in the wrong direction
- Misreading the Amino Acid Chart

Important note

When students make a transcription error while filling in their mRNA strip, THIS IS NOT A MUTATION! A mutation is a permanent base change in a DNA molecule. Mutations in a cell's DNA can be passed to daughter cells during cell division, and mutations in reproductive cells can be passed to offspring. But errors in transcription affect just one mRNA copy (out of hundreds or thousands) in just one cell (out of millions or billions), and they cannot be propagated. It's a similar concept—both are copying errors—but mutation is something very different.

Discuss

Each protein is from a very different organism, yet everyone followed the same instructions to make their proteins. Why do students think the same instructions worked for everyone? How does this relate to how organisms can read the information in one another's genes?

Use the Protein Pages as the basis of a discussion about protein structure and function. How might different amino acids give proteins different functions?

Supplemental Information

The following information might be useful as you talk about transcription and translation with your students.

Information about DNA

- The two strands of DNA are attached through complementary base pairing. A pairs with T, and C pairs with G.
- DNA has a polarity to it. Looking at the letters of a strand right-side-up, the left side is the 5′ (5-prime) end, and the right side is the 3′ (3-prime) end.
- The two strands of DNA have opposite orientations, which is why the "bottom" strand reads upside down and backwards.
- The machinery that builds DNA and RNA reads the DNA template strand from 3′ to 5′, and it builds the new strand from 5′ to 3′.

Details about Transcription

- Transcription begins at a specific DNA sequence called a transcription initiation site.
- An mRNA molecule commonly has multiple AUG sequences, but only the first one is considered the "start" codon. The ribosome attaches to the beginning of the mRNA molecule (the 5′ end), and it slides along until it finds the first AUG.
- RNA polymerase is a large complex made up of many different protein subunits. One of the

proteins (Gene 5) codes for a portion of this molecular machine—so this machine helps to build itself! (Another molecular machine that helps to build itself is the ribosome, which is made up of both RNA and proteins.)

- Multiple RNA polymerase complexes can transcribe the same gene all at once, lined up one behind the other. This allows the cell to make many mRNA copies of a single gene.

Details about Translation

- Amino acids are matched with the right tRNA molecules by protein enzymes called aminoacyl tRNA synthetases.
- A strand of mRNA has 3 possible reading frames, but only one of them is usually used to make a protein. (There are exceptions: some bacteria have overlapping reading frames, allowing one mRNA to code for multiple proteins.)
- Multiple ribosomes can be at work translating the same mRNA all at once, lined up one behind the other. With multiple ribosomes working on multiple mRNA copies, the cell can make many copies of the same protein at a time.
- In organisms that lack a nucleus, like bacteria and archaea, transcription and translation can happen at the same time. In cells with a nucleus, transcription happens in the nucleus, and the mRNA leaves the nucleus for translation.
- With a few exceptions, all organisms use the same genetic code for amino acids.
- There are just 20 amino acids (and stop), but there are 64 possible combinations of bases in 3-base codons (4 * 4 * 4). This means that most amino acids can be specified by multiple codons.
- Proteins that will stay in the cytoplasm are translated into the cytoplasm. Proteins that will be secreted to the outside of the cell, transported to a membrane-wrapped compartment (such as a lysosome), or inserted into a membrane are translated into the endoplasmic reticulum.

Information about proteins

- Each of the 20 amino acids has a different chemical composition. Different amino acids vary in size, charge, hydrophobicity, and more.
- As they are formed, proteins fold into distinct 3-dimensional shapes. The shape and function of each protein is influenced by the size and chemical properties of the amino acids it is made of.

Resources

RCSB PDB-101 [http://pdb101.rcsb.org] has a poster, free to download, featuring many of the molecules involved in transcription and translation. It is also available as a handout and as an online interactive.

References

Goodsell, David S. (2009). *The Machinery of Life* (2nd ed.). New York, NY: Springer Science+Business Media.

Circular amino acid codon chart based on figure 12-17 (p. 303) from Miller, K.R. & Levine, J. (2002). *Biology*. Upper Saddle River, NJ: Prentice Hall.

DNA and amino acid sequences were excerpted from the following sources:

- PCNA from corn – UniProtKB entry Q43266 (PCNA_MAIZE)
- DNA Polymerase 1 (PolA1) from mouse – NCBI Gene ID 18968
- RNA Polymerase 2, subunit B, from yeast (Note: 5′ and 3′ UTR are made up) – UniProtKB entry P08518 (RPB2_YEAST)
- Recombination Protein RadA from *Methanocaldococcus jannaschii* – UniProtKB entry Q49593 (RADA_METJA)
- Topoisomerase 1 from *E. coli* (Note: 5′ and 3′ UTR are made up) – UniProtKB entry P06612 (TOP1_ECOLI)

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