Protein Synthesis and Biotechnology

Frameworksheet

Standards: 1d; 4a-e; 5a-c

1. d. *Students know* the central dogma of molecular biology outlines the flow of information from transcription of ribonucleic acid (RNA) in the nucleus to translation of proteins on ribosomes in the cytoplasm.

DNA, which is found in the nucleus of eukaryotes, contains the genetic information for encoding proteins. The DNA sequence specifying a specific protein is copied (transcribed) into messenger RNA (mRNA), which then carries this message out of the nucleus to the ribosomes located in the cytoplasm. The mRNA message is then translated, or converted, into the protein originally coded for by the DNA. © 2004 California Department of Education

Questions for Standard 1.d.

1. **What is the "central dogma of molecular biology"?**
2. **Describe the process of transcription.**
3. **Describe the process of translation.**

4. a. *Students know* the general pathway by which ribosomes synthesize proteins, using tRNAs to translate genetic information in mRNA.

DNA does not leave the cell nucleus, but messenger RNA (mRNA), complementary to DNA, carries encoded information from DNA to the ribosomes (transcription) in the cytoplasm. (The *ribosomes* translate mRNAs to make protein.) Freely floating amino acids within the cytoplasm are bonded to specific transfer RNAs (tRNAs) that then transport the amino acid to the mRNA now located on the ribosome. As a ribosome moves along the mRNA strand, each mRNA codon, or sequence of three nucleotides specifying the insertion of a particular amino acid, is paired in sequence with the anticodon of the tRNA that recognizes the sequence. Each amino acid is added, in turn, to the growing polypeptide at the specified position.

After learning about transcription and translation through careful study of expository texts, students can simulate the processes on paper or with representative models. Computer software and commercial videos are available that illustrate animated sequences of transcription and translation. © 2004 California Department of Education

Questions for Standard 4.a.

4. **Describe the general pathway by which ribosomes synthesize proteins, using tRNAs to translate genetic information in mRNA.**
5. **Draw and label a picture that describes the pathway of protein synthesis that includes the terms *DNA, mRNA, nucleus, ribosomes, cytoplasm, transcription, translation, tRNAs, amino acids, mRNA codon, anticodon, polypeptide.***
6. **How is information carried from DNA out of the nucleus to the ribosomes?**
7. **What is the role of tRNA in translation?**
8. **How are codons and anticodons important in translation?**

4. b. *Students know* how to apply the genetic coding rules to predict the sequence of amino acids from a sequence of codons in RNA.

The sequence of amino acids in protein is provided by the genetic information found in DNA. In prokaryotes, mRNA transcripts of a coding sequence are copied from the DNA as a single contiguous sequence. In eukaryotes, the initial RNA transcript, while in the nucleus, is composed of *exons,* sequences of nucleotides that carry useful information for protein synthesis, and *introns,* sequences that do not. Before leaving the nucleus, the initial transcript is processed to remove introns and splice exons together. The processed transcript, then properly called mRNA and carrying the appropriate codon sequence for a protein, is transported from the nucleus to the ribosome for translation.

Each mRNA has sequences, called *codons,* that are decoded three nucleotides at a time. Each codon specifies the addition of a single amino acid to a growing polypeptide chain. A *start codon* signals the beginning of the sequence of codons to be translated, and a *stop codon* ends the sequence to be translated into protein. Students can

write out mRNA sequences with start and stop codons from a given DNA sequence and use a table of the genetic code to predict the primary sequences of proteins.

Questions for Standard 4.b.

9. **What is the difference in the way that prokaryotes and eukaryotes transcribe mRNA strands during transcription?**
10. **What are exons and introns?**
11. **In eukaryotes, the proper mRNA is transported from the _____ to the _____ for translation.**
12. **What are codons on mRNA sequences? How many nucleotides are in a codon? How many amino acids does a single codon "code" for? How many nucleotides "code" for a single amino acid?**
13. **Why are start codons and stop codons important?**

4. c. *Students know* how mutations in the DNA sequence of a gene may or may not affect the expression of the gene or the sequence of amino acids in the encoded protein.

Mutations are permanent changes in the sequence of nitrogen-containing bases in DNA (see Standard 5.a in this section for details on DNA structure and nitrogen bases). Mutations occur when base pairs are incorrectly matched (e.g., *A* bonded to *C* rather than *A* bonded to *T*) and can, but usually do not, improve the product coded by the gene. Inserting or deleting base pairs in an existing gene can cause a mutation by changing the codon reading frame used by a ribosome. Mutations that occur in somatic, or nongerm, cells are often not detected because they cannot be passed on to offspring. They may, however, give rise to cancer or other undesirable cellular changes. Mutations in the germline can produce functionally different proteins that cause such genetic diseases as Tay-Sachs, sickle cell anemia, and Duchenne muscular dystrophy.

Questions for Standard 4.c.

14. **What are DNA mutations?**
15. **How can inserting or deleting a nitrogen base pair affect the expression of a gene?**
16. **Why are mutations in somatic, or nongerm cells (i.e. not sperm or egg cells), not passed on to offspring?**
    a. **What disease can mutations in somatic, or nongerm cells (i.e. not sperm or egg cells), cause?**
17. **Why can mutations in the germline (i.e. sperm or egg cells) be passed on to offspring?**
    a. **What diseases can somatic, or nongerm cell (i.e. not sperm or egg cells), mutations cause?**

4. d. *Students know* specialization of cells in multicellular organisms is usually due to different patterns of gene expression rather than to differences of the genes themselves.

Gene expression is a process in which a gene codes for a product, usually a protein, through transcription and translation. Nearly all cells in an organism contain the same DNA, but each cell transcribes only that portion of DNA containing the genetic information for proteins required at that specific time by that specific cell. The remainder of the DNA is not expressed. Specific types of cells may produce specific proteins unique to that type of cell.

Questions for Standard 4.d.

18. **What is gene expression?**
19. **Do most body (somatic) cells contain the same DNA? Explain.**
20. **If brain cells have the same DNA as muscle cells, what accounts for the difference in the proteins each cell makes?**

4. e. *Students know* proteins can differ from one another in the number and sequence of amino acids.

Protein molecules vary from about 50 to 3,000 amino acids in length. The types, sequences, and numbers of amino acids used determine the type of protein produced.

Questions for Standard 4.e.

21. **The hemoglobin protein is 144 amino acids long. This protein is a(n) _____ (small, large, average) sized protein.**
22. **What 3 factors determine the type of protein produced by a cell?**
23. **Protein A has 2,560 amino acids and protein B has 2,560 amino acids. These two proteins may not be the same protein because _____.**

5. a. The genetic composition of cells can be altered by incorporation of exogenous DNA into the cells. As a basis for understanding this concept: a. *Students know* the general structures and functions of DNA, RNA, and protein.

Nucleic acids are polymers composed of monomers called *nucleotides.* Each nucleotide consists of three subunits: a five-carbon pentose sugar, a phosphoric acid group, and one of four nitrogen bases. (For DNA these nitrogen bases are adenine, guanine, cytosine, or thymine.) DNA and RNA differ in a number of major ways. A DNA nucleotide contains a deoxyribose sugar, but RNA contains ribose sugar.

The nitrogen bases in RNA are the same as those in DNA except that thymine is replaced by uracil. RNA consists of only one strand of nucleotides instead of two as in DNA.

The DNA molecule consists of two strands twisted around each other into a double helix resembling a ladder twisted around its long axis. The outside, or uprights, of the ladder are formed by the two sugar-phosphate backbones. The rungs of the ladder are composed of pairs of nitrogen bases, one extending from each upright. In DNA these nitrogen bases always pair so that *T* pairs with *A,* and *G* pairs with *C.* This pairing is the reason DNA acts as a template for its own replication. RNA exists in many structural forms, many of which play different roles in protein synthesis. The mRNA form serves as a template during protein synthesis, and its codons are recognized by aminoacylated tRNAs. Protein and rRNA make up the structure of the ribosome.

Proteins are polymers composed of amino acid monomers. Different types of proteins function as enzymes and transport molecules, hormones, structural components of cells, and antibodies that fight infection. Most cells in an individual organism carry the same set of DNA instructions but do not use the entire DNA set all the time. Only a small amount of the DNA appropriate to the function of that cell is expressed. Genes are, therefore, turned on or turned off as needed by the cell, and the products coded by these genes are produced only when required.

Questions for Standard 5.a.

24. Define the following:
- **a. Nucleic acid –**
- **b. Nucleotide –**
- **c. Nitrogen base –**

25. What are the 3 subunits that make up a nucleotide?

26. What are the four nitrogen bases in DNA? What are the four nitrogen bases in RNA?

27. Describe 3 ways that DNA different that RNA.

28. Describe the structure of DNA.

29. What are DNA backbones made of?

30. How do nitrogen bases pair in DNA? Why is the pairing of nitrogen bases important?

31. Describe the <u>functions</u> of the following:
- **a. DNA –**
- **b. mRNA –**
- **c. tRNA –**
- **d. rRNA –**
- **e. Proteins –**

32. Do most cells in an organism have the same DNA?

33. What is a gene? Why do cells turn off or turn on genes?

5. b. *Students know* how to apply base-pairing rules to explain precise copying of DNA during semiconservative replication and transcription of information from DNA into mRNA.

Enzymes initiate DNA replication by unzipping, or unwinding, the double helix to separate the two parental strands. Each strand acts as a template to form a complementary daughter strand of DNA. The new daughter strands are formed when complementary new nucleotides are added to the bases of the nucleotides on the parental strands. The nucleotide sequence of the parental strand dictates the order of the nucleotides in the daughter strands. One parental strand is conserved and joins a newly synthesized complementary strand to form the new double helix; this process is called *semiconservative replication.*

DNA replication is usually initiated by the separation of DNA strands in a small region to make a "replication bubble" in which DNA synthesis is primed. The DNA strands progressively unwind and are replicated as the replication bubble expands, and the two forks of replication move in opposite directions along the chromosome. At each of the diverging replication forks, the strand that is conserved remains a single, continuous "leading" strand, and the other

"lagging" complementary strand is made as a series of short fragments that are subsequently repaired and ligated together.

Students may visualize DNA by constructing models, and they can simulate semiconservative replication by tracing the synthesis of the leading and lagging strands. The critical principles to teach with this activity are that two double-stranded DNA strands are the product of synthesis, that the process is semiconservative, that the antiparallel orientation of the strands requires repeated reinitiation on the lagging strand, and that the only information used during synthesis is specified by the base-pairing rules.

RNA is produced from DNA when a section of DNA (containing the nucleotide sequence required for the production of a specific protein) is transcribed. Only the template side of the DNA is copied. RNA then leaves the nucleus and travels to the cytoplasm, where protein synthesis takes place.

Questions for Standard 5.b.

34. **Describe the steps in semiconservative replication.**
35. **Why is DNA replication called "semiconservative"?**
36. **What is the purpose of the 'replication bubble' in DNA synthesis?**
37. **What are the "leading" and "lagging" strands in DNA replication?**
38. **How is RNA produced from DNA? What is the process called?**

5. c. *Students know* how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products.

Recombinant DNA contains DNA from two or more different sources. Bacterial plasmids and viruses are the two most common vectors, or carriers, by which recombinant DNA is introduced into a host cell. Restriction enzymes provide the means by which researchers cut DNA at desired locations to provide DNA fragments with "sticky ends." Genes, once identified, can be amplified either by cloning or by polymerase chain reactions, both of which produce large numbers of copies. The recombinant cells are then grown in large fermentation vessels, and their products are extracted from the cells (or from the medium if the products are secreted) and purified. Genes for human insulin, human growth hormone, blood clotting factors, and many other products have been identified and introduced into bacteria or other microorganisms that are then cultured for commercial production. Some agricultural applications of this technology are the identification and insertion of genes to increase the productivity of food crops and animals and to promote resistance to certain pests and herbicides, robustness in the face of harsh environmental conditions, and resistance to various viruses.

Students can model the recombinant DNA process by using paper models to represent eukaryotic complementary DNA (cDNA), the activity of different restriction enzymes, and ligation into plasmid DNA containing an antibiotic resistance gene and origin of DNA replication. To manipulate the modeled DNA sequences, students can use scissors (representing the activity of restriction enzymes) and tape (representing DNA ligase). If both strands are modeled on a paper tape, students can visualize how, in many cases, restriction enzymes make staggered cuts that generate "sticky ends" and how the ends must be matched during ligation.

Questions for Standard 5.c.

39. **What is recombinant DNA?**
40. **What is a vector? What are the most common vectors?**
41. **How are restriction enzymes used in genetic engineering?**
42. **What types of genetic products have been identified and introduced into bacteria to be cultured for commercial use?**