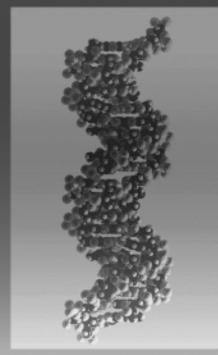
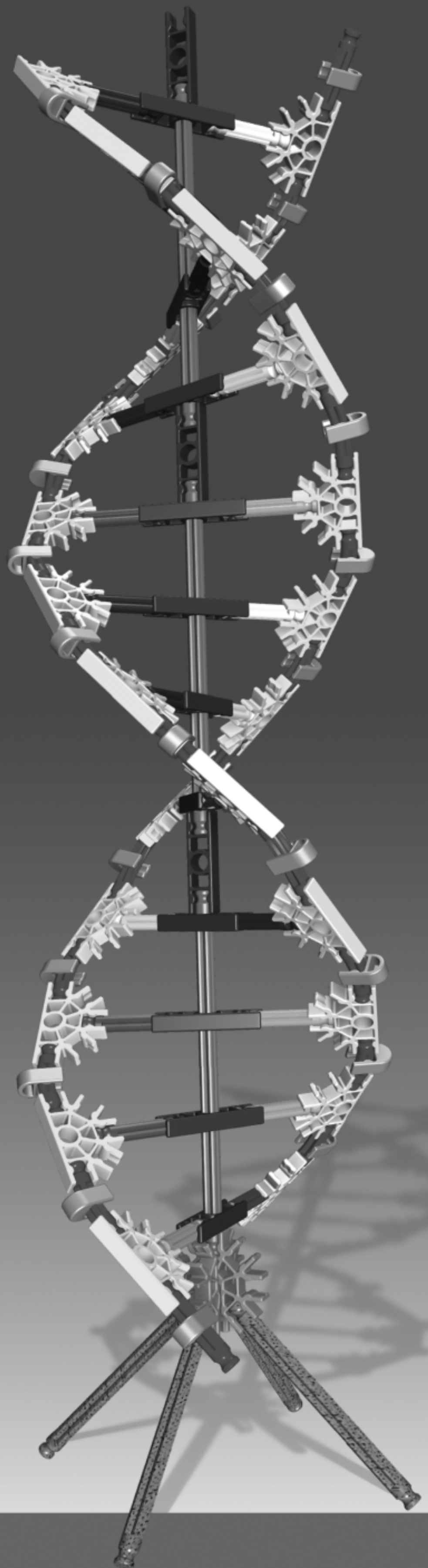
K'NEX® Education

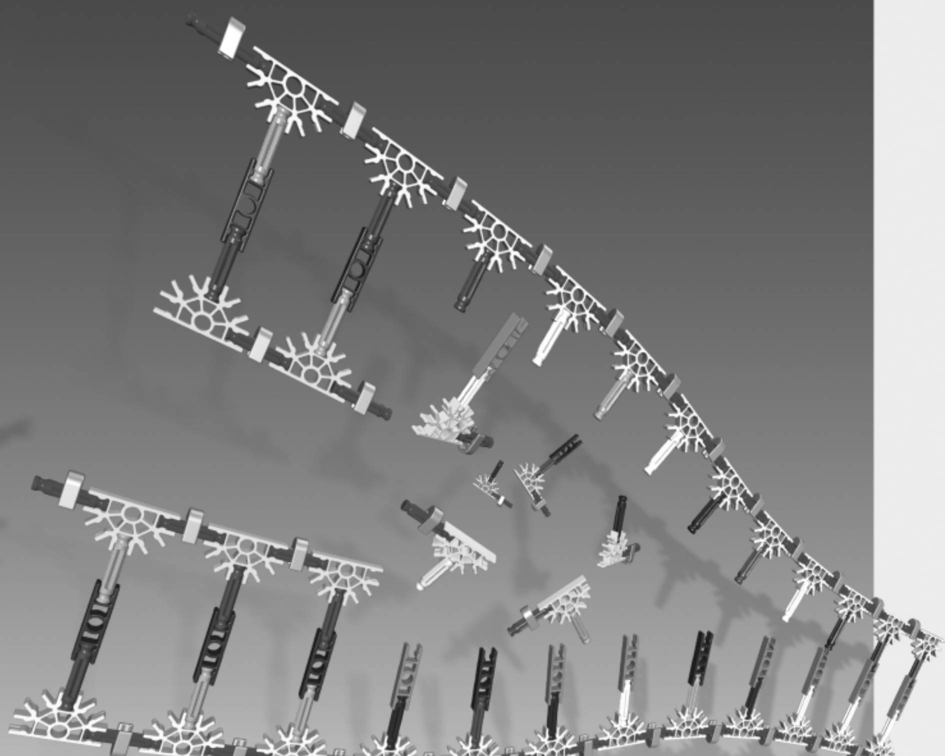
TEACHER'S GUIDE™

DNA, REPLICATION AND TRANSCRIPTION™



DNA MOLECULE





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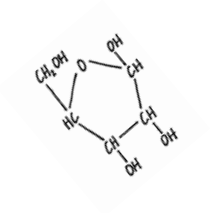
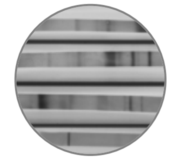
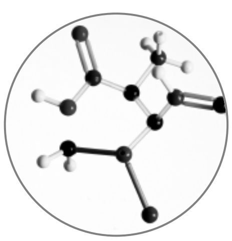
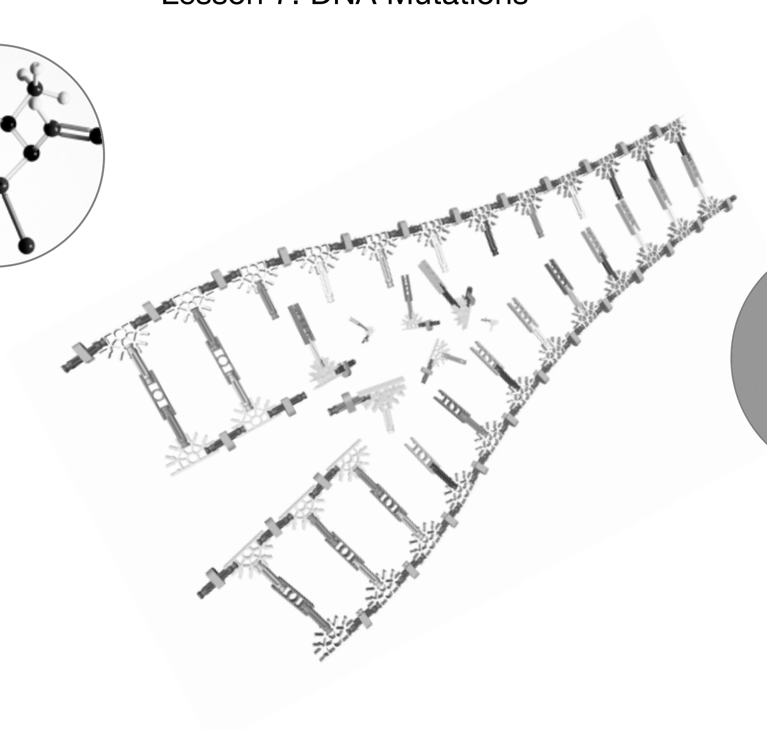
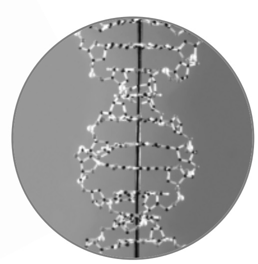
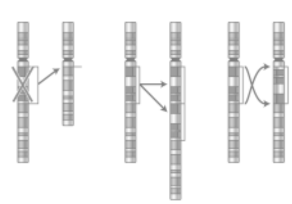
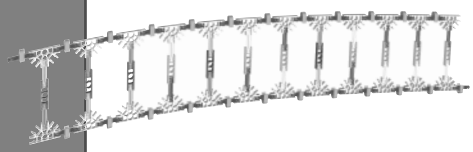



Courtesy of NHGRI



LESSON 1: Building the DNA Ladder

OBJECTIVES

Students will be able to:

1. Describe the DNA molecule.
2. Identify the component parts of the DNA molecule (bonds, nitrogen bases, deoxyribose sugar, phosphate).
3. Identify a nucleotide.
4. Understand the concept of base pairing in double-stranded DNA.

MATERIALS

Each student group should have the following:

- 1 **K'NEX DNA, Replication and Transcription kit** with building instructions booklet
- Student journals (1 per student)

PRELIMINARY ACTIVITY: Constructing the DNA Ladder

- Students should construct the DNA ladder-like structure by following the directions on Pages 2-5 in the **K'NEX DNA, Replication and Transcription kit** building instructions booklet. The flat DNA ladder that is constructed should be used as a reference for the following discussion.

- Students should **not** proceed with twisting the ladder (Step 3 on Page 4 of the building instructions booklet) until this first lesson has been completed.

INTRODUCTION: The Structure of the DNA Ladder

DNA exists most commonly in nature as a double helical structure. The double helix of DNA resembles a twisted ladder. A closer inspection of the chemical structure of the DNA ladder reveals that the side rails are made of alternating sugar and phosphate molecules. The sugar of DNA, deoxyribose, is represented by the gray piece on the K'NEX DNA model. The phosphate molecule is the light blue Clip on the K'NEX DNA model. These two molecules are connected by the purple Rod (the phosphodiester bond) on the K'NEX model.

Notice that the starting end of the DNA molecule always has a free phosphate group hanging on the 5'-end. This is demonstrated by the light blue Clip and purple Rod extending beyond the deoxyribose, (gray piece,) on each opposite side of the K'NEX double-stranded DNA model.

> Δ The repeating sugar-phosphate groups making up a single strand of DNA are often referred to as the molecular backbone. The deoxyribose sugar (see Figure 1 below) has two connecting sites for the phosphate: the OH groups found on the 3'- and 5'- carbons (spoken "three-prime and five-prime carbons"). The reason these carbons are numbered with the prime system is because the attached nitrogen-containing bases are the starting point for the molecular numbering system. Carbons on attached molecules are numbered with the prime system.

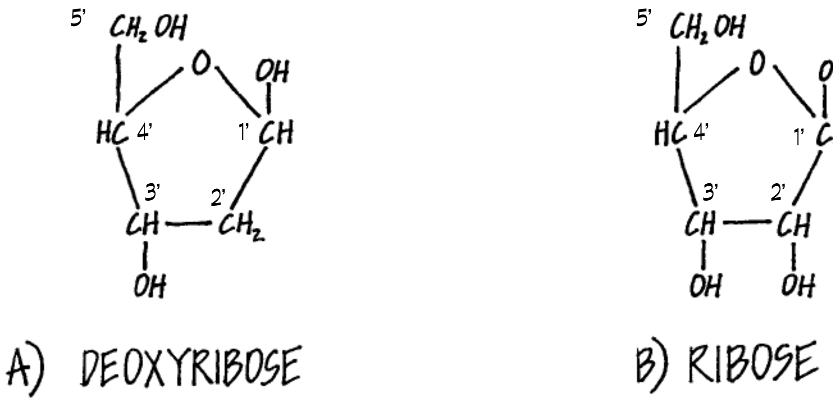
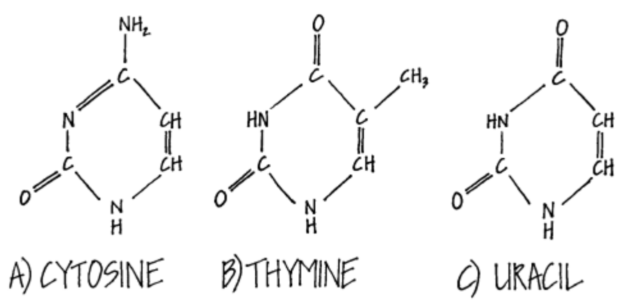


Figure 1 – Chemical structures and numbering systems for sugars found in DNA and RNA.

Δ Individual nucleotides are formed with the phosphate attached to the 5'- carbon. As new DNA strands are formed (see Module 2: Replication), new deoxyribose sugars with phosphates already attached to their 5'- carbons always connect to the growing strand by bonding to the OH of the 3'- carbon of the last sugar of the growing chain. To visualize this process, one can think of the phosphate on the 5'- carbon of the new nucleotide as a lasso that is used to grab the 3'- OH and attach the new unit to the growing chain. As a result, every strand of DNA has one free 5'- end with an unattached phosphate (the first unused lasso).

The "rungs" of the DNA ladder are composed of nitrogen-containing bases. There are four different nitrogen-containing bases in the DNA molecule: adenine (white Rod), thymine (black Rod), cytosine (teal Rod), and guanine (silver Rod). These nitrogen-containing bases pair in a very specific way to form the individual rungs of the ladder. Adenine always pairs with thymine, and cytosine always pairs with guanine. These pairs, adenine bonded to thymine and cytosine bonded to guanine, are called complementary base pairs. These pairings maintain the parallel sides of the DNA molecule because they have a common length. One larger purine base always pairs with one smaller pyrimidine base (see Figures 2 and 3 below).

Figure 2 – Chemical structures for the pyrimidine class of nitrogen-containing bases found in DNA and RNA.



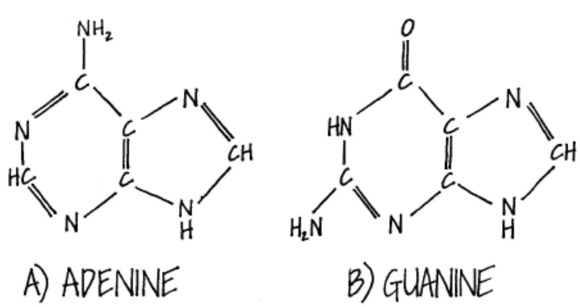


Figure 3 – Chemical structures for the purine class of nitrogen-containing bases found in DNA and RNA.

Adenine, thymine, cytosine, and guanine are usually referred to by one-letter codes, A, T, C, and G respectively, when recording their sequence in a single strand of DNA. When DNA forms a ladder or double-stranded structure, the sequence of one strand is always complementary to the other. For example, a strand with the sequence 5'-AACGGT-3' will bind to a strand with the complementary sequence 3'-TTGCCA-5'.

5'-AACGGT-3'
3'-TTGCCA-5'

The complementary base pairs forming each rung of the ladder are firmly held together by multiple hydrogen bonds. These are represented in the K'NEX model by brown Connectors (representing the three hydrogen bonds that hold together guanine and cytosine,) and orange Connectors (representing the two hydrogen bonds that hold together adenine and thymine.)

Important Note: The size of the Connectors representing the hydrogen bonds is not to scale. These bonding distances are actually a fraction of the length of the two nitrogen-containing bases being linked together (see Figure 4C).

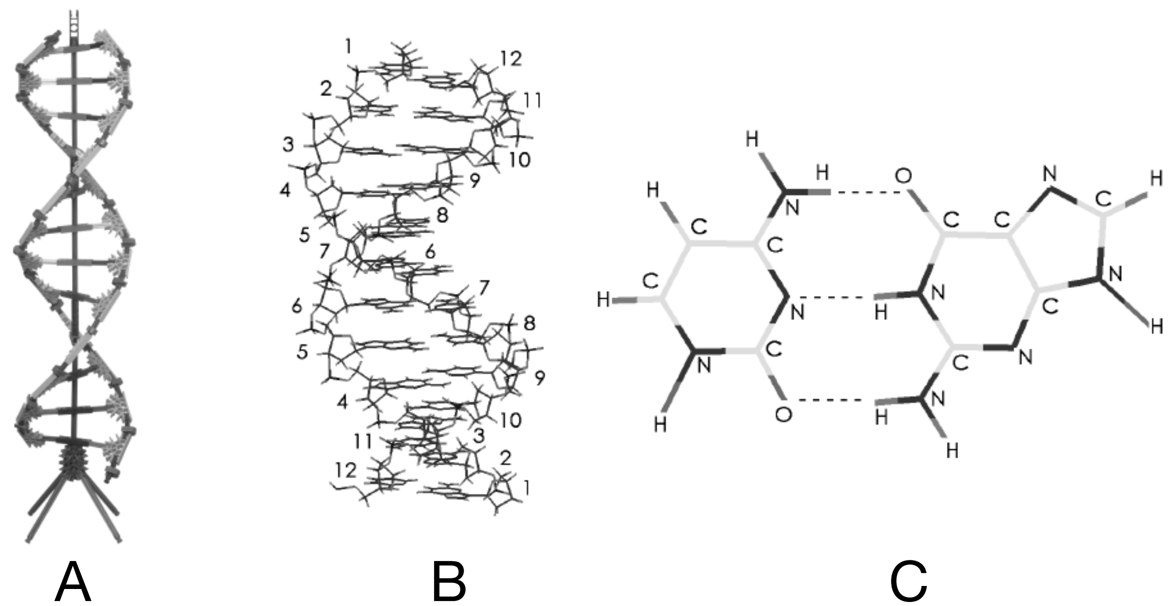


Figure 4 – (A) K'NEX double helix model; (B) corresponding computational representation of double-stranded DNA molecule with twelve base pairs; and (C) an individual cytosine-guanine base pair showing hydrogen bonds (dashed lines).

Δ Adenine and guanine belong to a class of compounds called purines, all of which have a common 9-atom, double-ring structure. Thymine and cytosine belong to the class of compounds called pyrimidines, which are based on a common 6-atom, single ring structure. Advanced students having studied chemistry may be able to identify which atoms participate in the two hydrogen bonds between adenine and thymine and the three hydrogen bonds between cytosine and guanine. The difference in bonding energies required to form two versus three hydrogen bonds account for the increased amount of heat required to separate the two strands of a double-stranded DNA molecule when G-C combinations are found more frequently than A-T combinations.

In summary, there are three key concepts students should understand:

1) DNA is made up of sequences of nucleotides. In molecular terms, a DNA nucleotide consists of a phosphate group, a deoxyribose sugar molecule, and a nitrogen-containing base. Nucleotides are represented in the K'NEX model by the following pieces: 1 light blue Clip, 1 purple Rod, 1 gray Connector, and one of the Rods (silver, teal, white or black). Nucleotides are covalently bonded together in DNA by phosphodiester linkages (modeled by the purple Rod in the K'NEX model) to form the backbone of the molecules containing specific nucleotide sequences.

2) To create the ladder structure of the double-stranded DNA molecule, two single strands of DNA are held together by hydrogen bonds that form between complementary nitrogen-containing bases. Adenine complements thymine, and guanine complements cytosine.

3) The backbones of the two DNA strands making up the double-stranded molecule (ladder) are antiparallel. This means that one side rail lies in a 5' to 3' direction and the other lies in a 3' to 5' direction when they are linked together. Consequently, the free 5'-phosphate group (purple Rod with blue Clip) that is found on the starting end of every single-stranded DNA molecule appears on opposite ends of the two strands forming the ladder structure. A full understanding of this concept requires chemical background that is usually limited to advanced high school students (see AP notes above), but it is important for all students to note that 5' and 3' ends exist on the ladder if lessons on replication and transcription will be used.

Create/Assess

- Using the K'NEX DNA model, students should disconnect their previously built DNA molecule into nucleotide pieces and, in turn, create a single-stranded DNA molecule with the following sequence of twelve nucleotides:

5' - CACTCAGAAGGT - 3'

If several K'NEX kits are available in the classroom, each group may be given a different sequence to produce. In order to most accurately model and understand the cellular method of DNA synthesis, students should be encouraged to assemble DNA strands by first assembling the necessary nucleotides (with nitrogen-containing bases attached) prior to assembling the long backbone of repeating deoxyribose sugars and phosphate groups.

- Students should record in their journals the nucleotide sequence that they are assembling along with important notes about its construction. The following are key concepts that students should be asked:
  1. What components make up the strand?
  2. How many purines does your strand contain?
  3. How many pyrimidines does your strand contain?
  4. What clue indicates this is a DNA strand?

Students should now create a strand that is complementary to the single strand that was just completed and connect the two with the appropriate hydrogen bond pieces. The complementary strand sequence should be written in the student journals, showing the complementary base-pairing as follows:

5' - CACTCAGAAGGT - 3'
3' - GTGAGTCTTCCA - 5'

Student notes should also include hypotheses about why specific nucleotide sequences and complementary base-pairing are important to the function and structure of the DNA molecule.

Comment: Specific sequences of nitrogen-containing bases code for specific proteins. Complementary base-pairing maintains the parallel nature of the molecule. Notes about Chargaff's research could also be given or inquiry-based projects assigned at this time.

Students should record hypotheses in their journals about what consequences may occur if sequences of nucleotides in the DNA are altered.

APPLY

Questions/Activities for students:

- When the gray Connector is snapped together with the light blue Clip and the purple Rod, what bond is being simulated? (*The phosphodiester bond*)

- Explain complementary base pairing and how it affects the DNA molecule structure.

- Draw a picture of what the DNA ladder would look like if purines matched with purines and pyrimidines matched with pyrimidines.

- What type of bond is the phosphodiester bond? (*A covalent bond*)

- Δ - Draw the complementary nitrogen-containing base pairs and show the hydrogen bonding sites. There should be three hydrogen bonds for a G-C pair and two for an A-T pair.

EXTENSION ACTIVITIES

- Students may write a position paper concerning important issues and questions relating to DNA. Topics may include moral, ethical, and societal issues related to genetic engineering, genetically-modified organisms (GMOs), and the struggles of women and minority scientists (e.g., Rosalind Franklin and George Washington Caver). An excellent reading to accompany this assignment would be *The Double Helix: A Personal Account of the Discovery of DNA* by James Watson.[2] K'NEX models should be built to demonstrate points made in these papers.

Δ EXTENSION ACTIVITIES

- Students who are more advanced in their DNA structure knowledge should be presented with this lesson as a discovery lesson. The **K'NEX DNA, Replication and Transcription kit** instruction booklet may be withheld and only K'NEX piece identifications should be given to the students. Students should attempt to build the DNA model using their knowledge of nucleotide structure. The most advanced students may use the Internet to look up sections of specific known nucleotide sequences for proteins and create a corresponding DNA segment with their model (see web sites 2, 3, and 4 at the end of this lesson). This activity could serve as a lab practicum format for assessment.

- Students may enjoy researching Rosalind Franklin and her X-ray crystallography studies that helped to determine the structure of the DNA double helix. A short essay may be written describing how Watson and Crick made their conclusions on the structure of DNA using her research and her pictures of the molecule. Examples of how the molecule is not structured (based on earlier proposals by Watson and Crick) should be constructed using the **K'NEX DNA, Replication and Transcription kit.** An excellent resource is James Watson's autobiographical account of the discovery of the double helix, The Double Helix: A Personal Account of the Discovery of DNA[2], which is listed in the references at the end of this lesson.

- Essay/Research: Students may study and research PCR (polymerase chain reaction). The steps of PCR may be detailed and practical uses of PCR discussed. **K'NEX DNA, Replication and Transcription kits** could be used to demonstrate the steps of PCR.

- Students may use HyperChem® or other computational programs to make a computer model of DNA and compare the exact chemical structure and dimensions to their K'NEX model. A free trial version of HyperChem® may be downloaded at the Hypercube, Inc. web site. Alternatively, students may find Chime/Protein Explorer graphical representations of DNA molecules on the Internet for exploration and comparison with the K'NEX models. (These activities may use web sites 6, 7, or 8 at the end of this lesson.)

Useful Related Web Sites

1. **http://knexeducation.com//** - *K'NEX Education Homepage*
2. **http://knex.com//** - *K'NEX homepage*
3. **http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=Genome&itool=toolbar** – *Entrez Genome NCBI Search Site (U.S. National Institutes of Health search site)*
4. **http://www.ebi.ac.uk/embl/** - *EMBL (European Bioinformatics Institute) Nucleotide Sequence Database*
5. **http://www.doegenomes.org/** - *Human Genome Program official web site.*
6. **http://www.rcsb.org/** - *Molecular Structure Databank*
7. **http://www.hyper.com//** - *Hypercube homepage*
8. **http://www.umass.edu/microbio/chime/whatis_c.htm** - *What is Chime?*
9. **http://www.proteinexplorer.org** - *1 Hour QuickTour for Protein Explorer*

References

[1]National Research Council, National Science Education Standards. National Academy Press, Washington, DC. 1996.

[2]Watson, James, The Double Helix: A Personal Account of the Discovery of DNA. New York, Atheneum, 1968.

NSES Content Standards Alignments

National Science Education Standards (Grades 5 - 8) *Students will develop an understanding of:*
UNIFYING CONCEPTS AND PROCESSES
• *Evidence, models, and explanation*
SCIENCE AS INQUIRY
• *Abilities necessary to do scientific inquiry*
• *Understanding about scientific inquiry*
LIFE SCIENCE
• *Structure and function of living systems*
• *Reproduction and heredity*
• *Diversity and adaptations of organisms*
SCIENCE AND TECHNOLOGY
• *Understanding about science and technology*
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES
• *Personal health*
• *Science and technology in society*
National Science Education Standards (Grades 9 - 12) *Students will develop an understanding of:*
UNIFYING CONCEPTS AND PROCESSES
• *Evidence, models, and explanation*
SCIENCE AS INQUIRY
• *Abilities necessary to do scientific inquiry*
• *Understanding about scientific inquiry*
LIFE SCIENCE
• *Molecular basis of heredity*
• *Biological evolution*
SCIENCE AND TECHNOLOGY
• *Understanding about science and technology*
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES
• *Personal and community health*
• *Science and technology in local, national, and global challenges*