Becoming DNA

Introduction

Knowledge of the structure and function of DNA is key to an understanding of molecular biology and cellular genetics. In this dramatic simulation, each student in your class will be a nucleotide in a giant DNA model. A simulated restriction enzyme will cut the giant DNA model, and the resulting DNA fragments will travel through an obstacle course mimicking an electrophoresis gel.

Concepts

- DNA structure
- Gel electrophoresis
- Nucleotide (base) pairing rules
- Restriction enzymes

Background

The chemical characteristics of DNA, deoxyribonucleic acid, enable it to carry the information needed to control the activities of a cell as well as to create new cells. The human genome contains 3 billion *nucleotides*. Each nucleotide is made up of a five-carbon sugar called deoxyribose, a phosphate group, and one of four nitrogenous bases—adenine (A), guanine (G), cytosine (C), and thymine (T). See Figure 1. Each deoxyribose molecule is bonded to a phosphate group and one nitrogenous base. The nucleotides combine to form a chain, with the phosphate group of one nucleotide bonding to the deoxyribose molecule of another nucleotide. However, DNA typically occurs as a double strand with each of the nitrogenous bases in the center of the strand hydrogen bonded to another base on the opposite strand to form a double helix. The bases bond together in a specific manner. The base pairing rules are universal for all DNA: adenine (A) always pairs with thymine (T), and cytosine (C) always pairs with guanine (G).

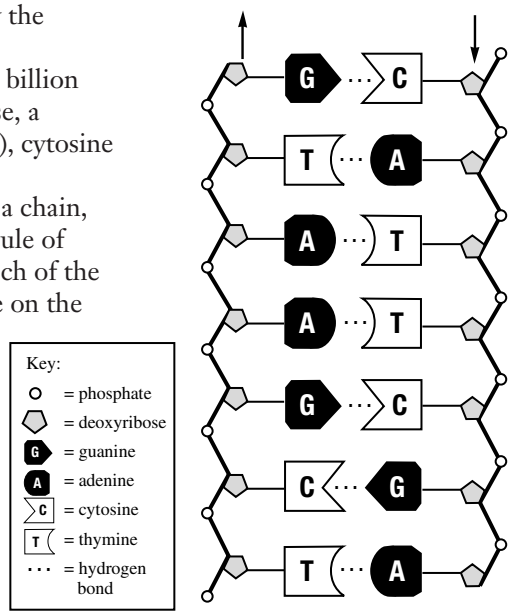


Figure 1. Short DNA sequence.

Certain bacteria are able to take advantage of the universal code to protect themselves. The bacteria produce enzymes that recognize and bind to DNA at specific base sequences and cut the DNA at or near the so-called recognition site. These enzymes are called *restriction enzymes* or *restriction endonucleases*. Hundreds of restriction enzymes have been identified and isolated by scientists. When restriction enzymes are added to a sample containing DNA, the enzyme will cut the strand of DNA wherever it finds its recognition site. These cuts produce fragments of DNA of various lengths. The fragments can be separated and stained to produce a DNA fragment pattern that is specific for the individual organism that supplied the DNA used in the experiment. Scientists use DNA fragment patterns to determine the exact DNA sequence for an organism. Forensic scientists use DNA fragment patterns to determine the origin or source of a DNA sample found at a crime scene.

Materials

Index cards, 15
Marker
Scissors
Stopwatch or clock with a second hand

Safety Precautions

Although this activity is considered nonhazardous, some students will be walking backwards during the simulation. Do not have unusually dangerous items in the students' pathway. Follow all laboratory safety guidelines.

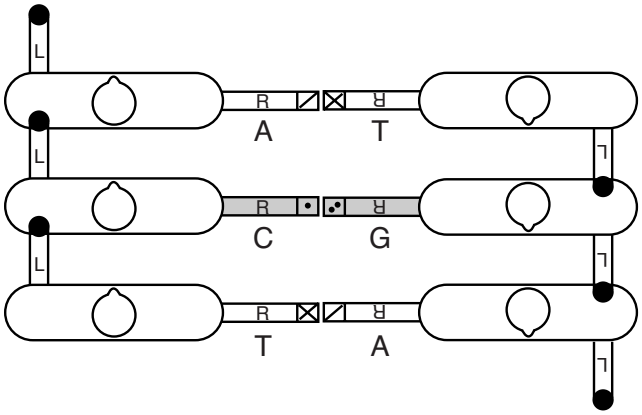
Procedure

1. Write either A and T or C and G on the two ends of an index card. Create one index card for every pair of students.

Publication No. 10883
061616

Note: If there are an odd number of students in the class, have one student serve as the restriction enzyme.

2. Use scissors to cut between the base letters. Cut a triangle shape between the G and C's and a curve between the A and T's. Separate each half into a separate pile. See Figure 1 on page 1.
3. Set up an obstacle course to simulate the electrophoresis gel. The design need not involve much more than moving lab tables or desks and chairs so that they are not all in a straight line. The large fragments will have some difficulty moving fast even without many obstacles. A few restricted areas will slow the fragments down.
4. Create a chart on the chalkboard with columns for DNA fragment size and time in seconds.
5. Explain to the class that each student represents a single nucleotide. Have students extend their left arms straight out in front of them. (This is the phosphate group.) Next, ask students to extend their right arms out to the side to make a 90° angle with their left arm. (This is one of the nitrogen bases.) The body itself represents the deoxyribose. See Figure 2. Discuss the key DNA elements and characteristics as the molecule is assembled.



Student's left arm = Phosphate group
Student's body = Deoxyribose sugar
Student's right arm = Nitrogen base

Figure 2. DNA Student Simulation

6. Randomly distribute the bases from one pile to half of the students. Build one strand of the double-stranded DNA in the classroom. Each student should place his left hand on the left shoulder of the student in front of him.
7. Shuffle and pass out the second pile of bases. Allow the second half of students to complete the DNA double-stranded structure. The students will quickly realize that in order for the components of the model to be used consistently, the two lines must be facing in opposite directions (the antiparallel structure of DNA) and the bases must be matched following the base-pairing rules.
8. When the double-stranded DNA molecule is completely assembled, the "restriction enzyme" (either student or teacher) should move into the DNA structure at a recognition site and move down the middle of the molecule until the end of the restriction site is found. The restriction enzyme breaks the phosphate–sugar bond, some base connections, and then another phosphate–sugar bond before it exits the DNA and moves to the next restriction site.
9. Once the DNA has been cut in this manner, the fragments need to be loaded into a well (the classroom door is a good "well" simulator).
10. Each DNA fragment will "run" the length of the obstacle course gel by itself. The rules for the run are that the DNA fragment must stay intact (hands on shoulders, base pairs hooked, etc.) while moving as quickly as possible through the obstacle course. (Remember some students will be walking backwards. Caution students to be careful.) All students making up the fragment must cross the "finish" line or get to the end of the gel before stopping the timer.
11. Record the DNA fragment size and the time needed to traverse the "gel" on a chart on the classroom chalkboard.
12. After all DNA fragments have crossed the line, compare times, and discuss the simulation and the results in detail.

Disposal

All components may be stored and reused.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Form and function

Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard C: Life Science, structure and function in living systems, reproduction and heredity

Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard C: Life Science, molecular basis of heredity

Tips

- The basic structure of DNA should be taught prior to this demonstration. Discuss and review the basic DNA structure concepts as the gel electrophoresis simulation is being conducted.
- Small DNA fragments will move more quickly and thus travel further in a gel compared to larger fragments, which will move more slowly and thus travel a shorter distance. The analogy for the speed of molecular fragments passing through an obstacle course is very helpful for students in visualizing why fragments separate in an electrophoresis gel. Given the same "running time," different size fragments will end in different locations in the gel.
- If possible, set up the obstacle course in a gymnasium or outside rather than creating the course in a small or crowded classroom.
- Create a DNA strand that includes several recognition sequences for specific restriction enzymes. For example, EcoRI recognizes the DNA sequence GAATTC. It cuts the DNA between the deoxyribose of the guanine and the phosphate group of the adenine. The cut continues between the base pairs until it reaches the A and G of the complementary strand. Have the students reform the same DNA strand and cut the strand at a second restriction enzyme recognition site. Discuss how scientists will cut the same DNA with many restriction enzymes to determine the DNA sequence.
- The same materials can be used to simulate DNA replication.
- Extend the activity to simulate transcription and translation.
- The DNA and Electrophoresis Kit available from Flinn Scientific (Catalog No. FB1228) uses wooden, colored sticks to simulate the nitrogenous bases.
- Another representation of the deoxyribose sugar in the human chain uses the following pattern—the student's head represents the oxygen, the right shoulder is the 1′ carbon, the right hip is the 2′ carbon, left hip is the 3′ carbon, left shoulder is the 4′ carbon, the left elbow is the 5′ carbon, and the left hand is the phosphate group. The phosphate group (left hand) bonds with the 3′ carbon (left hip).

Acknowledgment

Special thanks to Sue Whitsett, Fond du Lac High School, Fond du Lac, WI, for providing the idea and instruction for this activity to Flinn Scientific.

An activity kit of *Becoming DNA* called *DNA and Electrophoresis Simulation* is available from Flinn Scientific, Inc.

Catalog No.	Description
FB1228	DNA and Electrophoresis Simulation— Biological Demonstration Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.