Microbial Discovery Activity

Modeling Concepts of 5’, 3’, Antiparallel and Complimentary in DNA Structure

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Intended Audience

K-4
5-8
9-12 X

Activity Characteristics

Class room setting
Requires special equipment
Uses hands-on manipulatives
Requires mathematical skills
Can be performed individually
Requires group work X
Requires more than (45 min) class period
Appropriate for special needs student X
Introduction

Description
In this active learning activity, students build a DNA model focusing on the words: 5’, 3’, complementarity, and antiparallel using themselves as the nucleotides.

Abstract
Many students studying DNA structure do not understand or cannot fully visualize the concepts of complementarity, antiparallel, and the organization of the 5’ and 3’ ends of a nucleotide strand. Here, a method that works very well to get students actively involved in the process of describing a DNA molecule is described. Students themselves are used as the nucleotides in this activity.

Core Themes Addressed

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<th>General Microscopy Concepts</th>
<th>Microbial Cell Biology</th>
<th>Microbial Genetics</th>
<th>Microorganisms and Humans</th>
<th>Microorganisms and the Environment</th>
<th>Microbial Evolution and Diversity</th>
<th>Other -Common properties of life; Cellular components</th>
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</thead>
</table>

Keywords
DNA structure
Nucleotide
Purine
Pyrimidine
Antiparallel
Complementarity
5’ (five prime)
3’ (three prime)
Chargaff’s rules

Learning Objectives
At completion of this activity, the student will be able to:

- describe and diagram DNA structure using the following words: complementary and antiparallel.
- describe the components of a nucleotide,
- label a nucleotide’s 5’ and 3’ end,
- label the ends of a string diagram of DNA with 5’ and 3’, knowing one of the ends of one
- of the strands.
- diagram a complementary strand of DNA given the other strand.
National Science Education Standards Addressed

4. Life Science, Molecular Basis of Heredity. This activity covers the structural basis of DNA, focusing on the complementarity and antiparallel nature of DNA. This knowledge is required for students to understand the mechanisms of replication, transcription, and translation.
Teacher Handout

Modeling Concepts of 5', 3', Antiparallel and Complimentary in DNA Structure

Student Prior Knowledge
Students should have prior knowledge about DNA’s role as the genetic material and about the double-helical nature of the DNA molecule. General knowledge about the process of DNA replication, transcription, and translation is also helpful. Additionally, students should:

- be familiar with the structure of nucleotides in terms of their sugar, phosphates, and base.
- be able to identify the sugar, phosphates, and base of a nucleotide.
- understand why the carbons of organic molecules are numbered.
- be familiar with Chargaff’s rules.
- be able to explain hydrogen bonding and base pairing.

Teacher Background Information
Understanding DNA structure in terms of complementarity, directionality (5’ and 3’) and the antiparallel nature of the DNA molecule are foundational concepts for students to grasp before they can fully comprehend the mechanisms of replication, transcription, and translation. Nucleotides are made up of a pentose sugar, a nitrogenous base, and polyphosphate. The nitrogenous bases hydrogen bond according to Chargaff’s rules, and DNA structure is antiparallel in nature. The two strands run in opposite directions (noted antiparallel). Without understanding directionality and the antiparallel nature of the DNA double helix, students can visualize DNA replication, transcription, and translation. However, without understanding these concepts, students will not grasp the more nuanced and complex aspects of these mechanisms, such as movement of polymerases involved, the formation of Okazaki fragments, and the requirement for telomerase (usually not covered in general high school biology, but covered in AP Biology and freshman biology in college).

Class Time
This activity takes approximately 20-30 minutes. Students are actively engaged for most of that time.

Teacher Preparation Time
30 minutes or less. Teachers should prepare visual materials of nucleotide and DNA structure. They should also prepare student manipulatives of DNA structure.

Materials and Equipment
1. Nucleotide structure manipulatives, such as DNA Puzzle Kit (Carolina Biological Supply, NP-17-1050) or photocopies of nucleotide structures obtained from a textbook or the internet
2. DNA structure manipulatives, such as DNA Puzzle Kit (Carolina Biological Supply, NP-17-1050) or Pop Bead Kits (Ward's DNA Simulation Lab Activity, 36-W-1600, or Carolina DNA Simulation BioKit, NP-17-1033)
3. Visual materials of DNA and nucleotide structure (such as overheads of nucleotide and DNA structure)
4. Sheets of paper with nucleotide structure photocopied onto them, one per student, mixture of all DNA nucleotides
5. Adhesive tape
6. Pipe cleaners
7. Legos, pop beads, or post it notes

Methods
1. **Teacher describes nucleotide structure.**
   Students should be reminded of the structures of each nucleotide and how each nucleotide has a directionality, both 5’ and 3’. Students are given manipulatives of DNA nucleotide structure and follow the manufacturer guidelines for the manipulatives. Students are directed to analyze the structure of nucleotides, focusing on where the 5’ and 3’ of the sugar is located and where the phosphate is located (5’). Students discuss the structure of the nucleotides and how there is a directionality.

Figure 1. Sugars in DNA and RNA, note 5’ and 3’ directionality

![Sugars in RNA and DNA](http://www.microbelibrary.org)
2. **Teacher describes DNA structure.**
   The teacher should use visual aids to describe DNA structure and the concepts of antiparallel and complementarity. The teacher then demonstrates how the 3' end of one nucleotide links up with the 5' end of the next nucleotide in the structure of DNA and during DNA and RNA synthesis. Students are directed to study the nucleotide structure, and model the hydrogen bonding between...
complementary bases. Students are to note that in order to form the correct hydrogen bonds between bases, one base needs to be “upside down” or antiparallel to the other nucleotide. Students then link up nucleotide manipulatives to make a short DNA chain. Students then makes the complementary and antiparallel chain as well. Students are directed to note where the 5’ and 3’ ends of each chain are located (upside down or antiparallel). Students discuss the structure of the nucleotides. Students discuss what they are doing, using keywords like Chargaff’s rules, purine, pyrimidine, antiparallel, and complementary.

Figure 4. Repeating Structure of DNA, note 5’ is on top and 3’ is on bottom

Figure 5. Single Strand of DNA, note 5' phosphate and 3'


Figure 6. Complementary base pairing

3. **Teacher uses analogy to describe nucleotide.**
   A person’s body is compared to a nucleotide, where the left hand is the 5’ end and the right hand is the 3’ end. The left hand has the phosphate and the right hand has the hydroxyl group. Students discuss how each of them has a direction.

4. **Each student and the instructor then become a nucleotide.**
   Students are assigned one of the 4 nucleotides and are given a piece of paper with the nucleotide structure on the paper to use as their label, which the student tapes to her/his shirt. Student hold in their right hand a pipecleaner to symbolize the 3’ hydroxyl group. Students hold in their left hand three legos stacked together, three popbeads connected, three post-it notes stacked one on top of the other, or some other item in a collection of three to simulate the 5’ triphosphate. The instructor reminds the students that the left and right hand are different (5’ triphosphate and 3’ hydroxyl). Students discuss how their left and right hands are now different.

5. **One half of the class forms a DNA strand.**
   The instructor and a group of students stand hand in hand in front of the class to show how each right hand (3’) in turn is connected to the next left hand (5’). The first student stands with his/her RIGHT hand extended, and the next student attaches their LEFT hand at the RIGHT hand of the first student. The initial student drops their pipecleaner, and the second student loses 2 of the three legos/pop beads/post it notes (to symbolize that the nucleotide becomes monophosphate). Then students come in one by one to form the DNA strand. Students discuss the nature of bonds and why three legos (pop beads, post it notes) become one.

6. **The other half of the class forms the complementary, antiparallel strand.**
   Then another line of students, complementary to the first, comes in one by one to face the first line (organized as above).

7. **The teacher points out several key features of this structure.**
   First, the teacher reminds the class what complementary and antiparallel mean. Then students can now see how the antiparallel nature of DNA has the 3’ of one nucleotide facing the 5’ of the complementary strand (left hand of one person is across from the right hand of the person facing them). The students are now antiparallel to each other. This activity also demonstrates how one strand ends with a 3’ (right hand), and thus the complementary, antiparallel strand ends with a 5’ phosphate (lego, pop bead, post it note). Students discuss their structure as it relates to the key words complementary and antiparallel.

**Extension**
This activity could also be used to demonstrate how RNA synthesized from a DNA template is also complementary and antiparallel, substituting RNA for DNA in the complementary student chain. The mRNA made above could even be translated by a ribosome, focusing again on how mRNA is read 5’ to 3’, and if instead it were read 3’ to 5’, a nonfunctional polypeptide would be formed.

Another extension includes drawing the nucleotides (from a textbook) on the board or in an acetate transparency for the students to visualize their structure. Then have students draw them out on
sheets of paper. The act of each student drawing out the structure will help the students to learn the shape, sequence, and layout of the molecular structure.

Suggestions for Assessment
Students should be probed as to their understanding of DNA structure after this activity. Sample questions are listed below.

1. In thinking about the DNA structure, what does complementary refer to?
2. In describing DNA structure, what does antiparallel refer to?
3. What did your left hand represent?
4. What did your right hand represent?
5. Why was your right hand bonded to your neighbor’s left (and not right) hand?
6. Describe the person who stood in front of you. Where was their left hand? Their right hand? What word is used to describe this type of structure?
7. What nucleotide were you? What was the nucleotide across from you? Why can you predict every time what nucleotide is across from (hydrogen bonded to) a nucleotide you already know?
8. What did the pipcleaner represent?
9. What did the legos, popbeads, or post it notes represent?
10. Why can’t you just turn around have your left hand bond to someone else’s left hand?

Answers to assessment questions
1. Student should describe A-T G-C relationship.
2. Student should describe how 5’ on one end of strand, 3’ on other end, and two strands hydrogen bond, where 5’ is on one strand 3’ in on other.
3. 5’ or 5’ phosphate
4. 3’ or 3’ hydroxyl
5. Because the 3’ of one nucleotide is covalently attached to the 5’ of the next nucleotide
6. The student should identify that the “partner” was antiparallel to them. The student’s left hand (5’) faced the partner’s right (3’) hand. The two complementary nucleotides were also antiparallel.
7. Student should identify themselves and the complementary nucleotide. Student should discuss complementary nature of nucleotide structure.
8. 3’ hydroxyl
9. 5’ polyphosphate
10. Phosphate must bond to the sugar not to another phosphate

Answer Key to Student Follow Up/Homework:
1. 3’-GCCTAGCTAGCTAGTAGAGTA-5’

2. 5’----------------------------------- 3’
3. 3’-----------------------------------5’
Student Handout

Modeling Concepts of 5', 3', Antiparallel and Complimentary in DNA Structure

Introduction
In order to fully understand the mechanisms of DNA replication, transcription, and translation, one must understand the structure of DNA and RNA. Each nucleotide has a directionality based upon its chemical structure (commonly referred to as the 5' and 3' end), and this directionality is essential for forming DNA and RNA strands. This directionality is also critical for the processes of replication, transcription, and translation. Nucleotides are composed of a five carbon pentose sugar (ribose in RNA and deoxyribose in DNA), a 5' triphosphate, a 3' hydroxyl, and a base.

Student Background Knowledge
You should be familiar with DNA structure prior to this activity by reading the portion in your textbook, or can visit many websites such as:
http://seqcore.brcf.med.umich.edu/doc/educ/dnapr/pg1.html

Vocabulary
Nucleotide - repeating unit of DNA and RNA, has a pentose sugar, base, and phosphate
Purine - double ringed base structure, A and G
Pyrimidine - a single ringed base structure, T and C,
Antiparallel - the structure of DNA in which one strand is running one direction while the other strand is running in the opposite direction
Complementarity - the structure of DNA in which A in one strand is hydrogen bonded to T in the other strand and C is hydrogen bonded to G
Five prime 5'- the end of the sugar in DNA or RNA to which the phosphate is bonded
Three prime 3'- the end of the sugar in DNA or RNA that has a hydroxyl group
Chargaff's rules - A hydrogen bonds to T, C hydrogen bonds to C, U in RNA bonds to A
Hydrogen bonded – a weak interaction between two hydrogen atoms, occurs between complementary base pairs
Covalently bonded – a strong chemical bond in which electrons are shared, occurs between two nucleotides in the same DNA chain

Materials check list (Per group)

<table>
<thead>
<tr>
<th>Nucleotide and DNA manipulatives (provided by your teacher)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nucleotide structures</td>
</tr>
<tr>
<td>Pipe cleaners</td>
</tr>
<tr>
<td>Legos, popbeads, or post it notes</td>
</tr>
</tbody>
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Procedure for Participants

1. Look at the nucleotide models your teacher has provided.
2. Draw all four DNA nucleotide structures.
3. Use the models to demonstrate how nucleotides hydrogen bond in DNA.
4. Draw how nucleotides hydrogen bond in DNA. Where are the 5’ and 3’ ends of the DNA?
5. Describe how nucleotides hydrogen bond using the words complementary, antiparallel, purine, pyrimidine, adenine, thymine, cytosine, and guanine.
7. Form the DNA double helical structure, as directed by your teacher.
Student Worksheet
Modeling Concepts of 5', 3', Antiparallel and Complimentary in DNA Structure

Student’s name ___________________________ Date ____________

1. Draw the structure your class made. Label each nucleotide, its base, 5’, and 3’ end.

2. What does the pipe cleaner represents?

3. What did the legos, pop beads or post it notes symbolize?

4. How did you attach to each of your neighboring nucleotides?

5. Why did you go from three phosphate groups to one when you covalently bonded to your neighboring nucleotide?

6. Why did you drop the pipe cleaner when you bonded with the next nucleotide?

7. Describe the structure your class made. Use all of the vocabulary words.
Follow Up Questions/Homework:

1. What is the other strand of DNA for the following sequence?
   5’-CGGATCGATCGATCATCTGAT-3’
   (Don’t forget to label your 5’ and 3’ ends).

2. Label the following diagram with the 5’ and 3’ ends of the DNA strands:

   5’------------------------------------------?
   ?------------------------------------------?
   ?------------------------------------------?