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DNA Models for Non-Majors (and Majors!)

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Students build a model of DNA that is quite realistic in terms of the positioning of individual atoms. We refer to this as the big DNA model; it is the DNA Discovery Kit from 3D Molecular Designs. Student groups start with models of phosphate, deoxyribose, and two nitrogenous bases to assemble one nucleotide base pair. Then they assemble a sequence of 12 of these nucleotide pairs and study the molecular features that emerge. They copy the sequence of their big DNA model into a single strand Pop Bead model and lengthen it to 36 bases by adding randomly chosen bases. They compare the Pop Bead sequences produced by different groups. Then, assuming these nucleotide sequences are part of a gene, they convert them into amino acid sequences and consider how expectations differ when protein sequences reflect common ancestry rather than random generation. Several Group Activity Sheets drive the lab activity and the learning.

Keywords: DNA, molecular models, DNA Models

Introduction

All of us teaching today are comfortable with the basics of molecular biology. We've accumulated a more or less extensive understanding of nucleic acids and can talk in detail about the intricacies of protein synthesis. We have come to understand that life resulted long ago from interactions among nonliving chemicals. It is easy for us to forget what an exotic story we are dealing with.

Biology majors reach an understanding similar to ours before they graduate. Many of them have a good foundation from high school, and all of them are exposed to the story of DNA in virtually every biology class they take in college.

This is not the case for non-majors. If they take any biology, it is usually just one course. At the University of Delaware this will be a one-semester class that includes eleven lab meetings. How successful can we expect to be in conveying the "central dogma" of biology? What techniques can we use to maximize our success?

This workshop is about using models of DNA during those precious hours in lab. 3D Molecular Designs sells a remarkable model they call The DNA Discovery Kit. The detail and accuracy of this model can draw experienced biologists into happy moments of contemplation, and can help us show non-majors the features of DNA we want them to understand. Non-science students will not fully appreciate the sophistication of this model, and we should not expect them to, but they can enjoy assembling and studying it.

The DNA Discovery Kit supports our central lesson that DNA is the information molecule of biology, but it does not allow students to explore that function. For this, I turn to a simpler model using Pop Beads. These can be quickly and easily manipulated to put the focus on DNA's role in producing proteins, in the short term, and patterns of diversity, in the longer term.

Nucleic acids, protein synthesis, and evolutionary history are all topics that tend to "explode" into teacher-driven presentations that quickly overwhelm students. I think it is our responsibility to keep this from happening, so I plan in advance what I want students to do during lab, and use Group Activity Sheets to specify the tasks to be accomplished. This is certainly not an open-ended inquiry approach to lab teaching, though it can be thought of as guided inquiry.

I will use the DNA Discovery Kit, the Pop Beads, and the Group Activity Sheets during the workshop. There will be time at the end for workshop participants to discuss how they like to use lab time to teach this core biological material. Quite possibly we will be able to identify additions, modifications, and variations that will appeal to different faculty in different teaching situations.

Student Outline

Learning Objectives

When you have finished this lab, you should be able to do the following things:

1. Explain how an individual nucleotide is assembled from three components: phosphate, the sugar deoxyribose, and a nitrogenous base.
2. Explain how multiple nucleotides are connected to each other to give a DNA molecule its characteristic shape.
3. Explain where information is stored in a DNA molecule.
4. Compare the two ways we modeled DNA.
5. Discuss how the genetic code relates nucleotide sequences of DNA to amino acid sequences of proteins.
6. Discuss how this lab interconnects with other labs this semester.

Introduction

As all of you know, we live in the midst of a revolution in the way we handle information. Figuring out how to store information on a silica chip was the key event in getting this digital revolution started, and the World Wide Web is just one example of how we've changed the way we collect, store, and transmit information.

This digital age of ours is not the first information revolution on Earth. The first one enabled life, as we know it today, to exist. The key to that first revolution was an organic molecule we call DNA.

Watson and Crick published the structure of DNA (deoxyribonucleic acid) in 1953. This amazing molecule has become very famous in the years since. Here are some things you should understand about DNA.

- In the final analysis, DNA is what is passed from one generation to the next.
- The information for making proteins is stored in the sequence of nucleotide bases in DNA.
- If the DNA molecules in one of your cells were stretched out in a single line, it would be about six feet long. Each of your cells contains that much DNA.
- That much DNA contains about six billion pairs of nucleotides.
- Inside a eukaryote nucleus, one DNA molecule, highly coiled and wrapped around special proteins, is in each chromosome (so humans, with 46 chromosomes, have 46 DNA molecules in the nucleus of each cell).
- Every person has very similar DNA but the sequence of nucleotides in each person's DNA is unique to some extent.
- DNA differences among species are greater than differences among individuals within a species.

It is time to learn more about the DNA molecule.

Nucleotides – What Are They?

DNA is made of units called nucleotides. One molecule of DNA can have a really huge number of these units. The Y chromosome, for instance, which is well known because its presence leads an individual to develop into a male instead of a female, contains a relatively short piece of DNA that has about 57 million pairs of nucleotides.

A single nucleotide is made of three smaller parts: 1) a phosphate molecule; 2) a sugar molecule; 3) a molecule called a nitrogenous base. We will look at each of these in turn.

As you will see, the phosphate and sugar are identical in all nucleotides, but there are four different nitrogenous bases and this little bit of variation is what makes it possible for DNA to store information.

Phosphate

A simple two-dimensional model of phosphate looks like this:

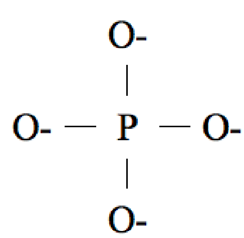

Figure 1. A model of a phosphate group.

It has one phosphorus atom and four oxygen atoms. In the illustration three of the oxygen atoms have a negative charge, i.e., each one has an extra electron. Those negative charges means phosphate will move strongly in an electric field.

You have a three-dimensional model of phosphate in the tray your lab instructor gave you. Its single phosphorous atom is yellow. Its four oxygen atoms are red. Two of the oxygen atoms are not smooth and round like the other two are, because they have a tab or a magnet you will use to attach the phosphate to the rest of the DNA model.

Sugar

Find the piece that represents the sugar deoxyribose. It has a ring shape that includes one red oxygen atom and four gray carbon atoms. A fifth carbon sticks up almost at a right angle from the ring.

Molecular biologists have given specific numbers to the carbon atoms. Compare the model piece to this two-dimensional illustration and figure out the numbering of the carbons.

Carbons #1, #3, and #5 have an –OH group attached. Carbon #4 has just an O because it is sharing that oxygen with carbon #1, to close the ring. Deoxyribose gets its name from the fact that its carbon #2 has no –OH group. None of these H's and OH's are included in the physical model.

Carbon #5 of the model has a slot to receive the tab on the phosphate group. Join the two of them together and set them aside.

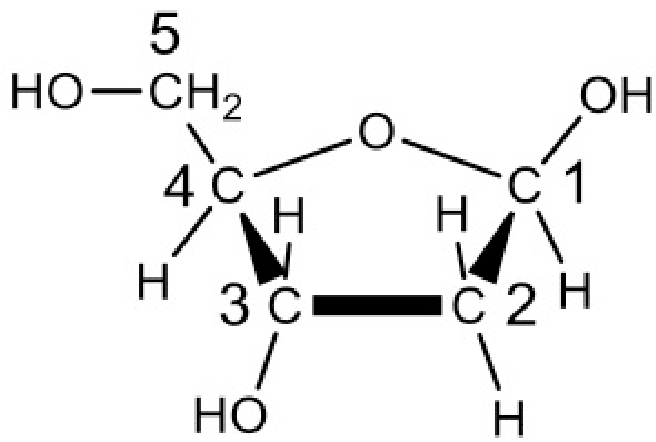

Figure 2. Numbering the carbon atoms in the deoxyribose sugar.

Nitrogenous Bases

Look at what you have left:

- There are atoms colored blue; these are nitrogen.
- There are atoms colored white; these are hydrogen.
- Some of the white atoms are distinctively barrel-shaped; these are hydrogen bonds.
- There is one ring by itself and a pair of rings fused together.
- The model piece is flat.

Flex the model at the hydrogen bonds so it separates into two pieces. Each half is a nitrogenous base; what you started with was a pair held together by hydrogen bonds. (A hydrogen bond is a hydrogen atom being shared between two other atoms.)

DNA bases always pair up so that one with a double ring pairs with one with a single ring: A with T and G with C.

The AT and GC are easy to tell apart because AT pairs have two hydrogen bonds and GC pairs have three. All this is summarized in Table 1, which also names the four bases.

Table 1. The nitrogenous bases of DNA.

		Ring	
		Double	Single
Hydrogen	2	Adenine (A)	Thymine (T)
bonds	3	Guanine (G)	Cytosine (C)

[1] Another sugar, ribose, does have an –OH group on carbon #2. Ribose is part of RNA the way deoxyribose is part of DNA.

Join each nitrogenous base piece to a sugar-phosphate piece so you have two complete nucleotides.

Assemble DNA

Each group can assemble a dozen nucleotide pairs on a special stand. Look at the cover of the lab manual to see what the assembled model looks like.

Make sure your bases are all correctly paired: A – T and G – C.

When you add a pair, the central post goes between the two hydrogen bonds of AT pairs and at the point where the hydrogen bonds change orientation in GC pairs.

Each time you add a new piece, rotate it around the post until its magnets click together with the magnets of the nucleotide pair below it (making new sugar-phosphate bonds).

Every fourth pair rests on a circular ledge that is part of the central post.

Answer questions #1 and #2 on the first Group Activity Sheet.

Compare DNA Molecules

Compare your model with one built by another group. How are they similar?

Can you find yours again if they are mixed up? Describe the problems you encounter.

Answer question #3 on the first Group Activity Sheet. You will dismantle your model as you do this (just to the level of nucleotide pairs – please do not break it down to the level of phosphates and deoxyriboses).

Answer question #4 on the first Group Activity Sheet.

A Simpler Model of DNA

We can look at the information storage function of DNA by building a simpler physical model. This time we leave out the sugar/phosphate chains since deoxyribose and phosphate are the same in every nucleotide.

All we need are the nitrogenous bases, and to make things even simpler, we only have to specify one base of each pair because of the AT and GC pairing rules.

Procedure

1. Locate:

• Pop Beads of four colors
• Eight-sided die with A/T/G/C faces
• Two Pop Beads of a different color

2. The four colors of Pop Beads represent the four bases of DNA this way:

Harvesting Cheek Cells

Either: use a sterile stick (wooden end of the swab) to scrape cells from the inside of your cheek. Transfer the cells to a tube of sterile saline. Alternatively, swish 5 ml of sterile saline around your mouth for 1-2 minutes, and then transfer it to a clean cup.

Table 2. Pop bead colors that represent the four DNA bases.

Base	Pop Bead color	Also called
A	**A**lba	White
T	**T**angerine	Orange
G	**G**reen	
C	**C**herry	Red

3. Use Pop Beads to re-make the 12 base sequence of your first DNA model.

4. Increase the length to 36 bases. Use the eight-sided die to pick each new base. Add this information to Table A on the second Group Activity Sheet.

5. You have two Pop Beads of a different color. Add one to each end of your model. These are not part of the DNA. They are markers so you can keep track of which one is yours.

6. Line up your model alongside another group's, to compare the two sequences. How many of the DNA bases are matches? Enter this, as a percentage, into Table B in the second Group Activity Sheet.

7. Do a "two-sequence alignment" between your model and each of the four remaining models and complete Table B. Answer questions #1 and #2 below Table B.

Proteins

DNA provides a cell with the information it uses to make its proteins. Suppose your 36 bases in Table B are part of a **gene** that codes for a protein. Let's see what amino acid sequence you get from your randomly generated DNA sequence.

Procedure

1. Rewrite your bases as triplets (in Table A).

2. Get a copy of the genetic code from your lab instructor and use it to look up each triplet. Write the first letter of its amino acid in column four.

3. Put your results in the appropriate places in the table your lab instructor puts on the blackboard.

4. When all the groups have entered their data, fill out Table C.

5. Answer questions #3 and #4 below Table C.

6. Answer question #1 on the third Group Activity Sheet.

More Questions

What if DNA sequences are not randomly generated? Answer questions #2, #3, and #4 on the third Group Activity Sheet.

Answer question #5 on the third Group Activity Sheet.

DNA Models: Group Activity Sheet 1

Names: **Lab Section:**

1. Describe two features of DNA that show up only when the model is fully assembled.

2. Can you measure something about each of those features? Make the measurements and record the results here.

3. Copy down the sequence of nucleotide bases. The one at the top, with its phosphate projecting up, is #1, etc. Remove the pairs from the stand as you go. Return them to the tray, but do not take phosphate or sugar groups off.

Table 3. Table for recording nucleotide base sequence.

1
2
3
4
5
6
7
8
9
10
11
12

Transfer this sequence into Table A on Group Activity Sheet 2.

4. Notice how the phosphate/sugar chains form a double helix surrounding the nucleotide base pairs. This protects the bases from reacting with other chemicals in the nucleus. Haphazard chemical changes to the bases would destroy their information content.

DNA tells a cell how to make its proteins. This is amazing, really, and it poses an interesting problem. Proteins are chains of amino acids: AA1 – AA2 – AA3 – AA4 – AA5 – AA6 – etc. There are 20 different amino acids in proteins, yet there are only four kinds of nucleotide bases. Discuss how four DNA bases specify twenty amino acids.

[2]"Double helix" has become a nickname for DNA.

DNA Models: Group Activity Sheet 2

Names: **Lab Section:**

Table 4. Details of simple pop bead model.

Position	Base	Triplet	Amino Acid	AA Position
1				1
2				
3				
4				2
5				
6				
7				3
8				
9				
10				4
11				
12				
13				5
14				
15				
16				6
17				
18				
19				7
20				
21				
22				8
23				
24				
25				9
26				
27				
28				10
29				
30				
31				11
32				
33				
34				12
35				
36				

Table 5. Percent identity of randomly generated DNA chains.

Group	1	2	3	4	5	6
1	---					
2		---				
3			---			
4				---		
5					---	
6						---

1. On average, how many bases are identical between pairs of the DNA chains?

2. Can you explain why we expect any two strands of DNA, no matter where they come from, to be about 25% similar?

Table 6. Amino acid sequences produced by randomly generated sequences of DNA.

	Amino Acid Position											
Group	1	2	3	4	5	6	7	8	9	10	11	12
1												
2												
3												
4												
5												
6												

3. How similar are these sequences of amino acids?

4. Does this surprise you?

DNA Models: Group Activity Sheet 3

Names: **Lab Section:**

1. Suppose we take a small sample of your blood and isolate white blood cells from it. We extract DNA. Then we pick two random sections out of the total DNA and compare their sequences. How similar do you expect those sequences to be?

2. Now suppose we collect some of your cheek cells and isolate the DNA of a particular gene from them. We also isolate the DNA of the same gene from your white blood cells and then determine the sequence of DNA bases in these two samples. How similar are the two sequences of DNA going to be?

3. Suppose we isolate the DNA for one specific gene from a dachshund and from a Great Dane. We compare sequences of nucleotide bases in these two samples. How similar do you expect them to be?

[3]White blood cells are part of the immune system. They respond rapidly to an infection by proliferating (cell division) and by producing proteins. White blood cells have nuclei and DNA, unlike red blood cells, which lose their nuclei when they mature.

4. Suppose we isolate and sequence the DNA of the same gene from you, a chimpanzee, an alligator, a crocodile, and two whales – a beluga and a blue whale. How similar do you expect these sequences to be?

5. If you built a big DNA model of the human Y chromosome, you'd need about 57 million nucleotide pairs. How long would the finished model be?

DNA Models: Pre-Lab Questions

Name: **Lab Section:**

The cover of the lab manual shows a model of DNA.

1. List three details you notice about the model (or the molecule).

a.

b.

c.

DNA Models: Homework Assignment

Name: **Lab Section:**

1. Play the role of reporter.

Interview two friends or relatives (anyone not currently taking this class). Ask each one to tell you what they understand about DNA. After the interview, summarize their understanding. (1 pt each.)

2. Play the role of teacher.

Get one (or both!) to agree to let you teach them about other aspects of DNA – things you learned in lab that they don’t already know.

Describe your experience. What aspects were the most challenging to teach? What did you do to get those ideas across? (3 pts.)

The assignment is worth 5 points. It will be evaluated on the basis of the accuracy of what you taught your friends about DNA and the readability and clarity of your presentation.

Materials

DNA Discovery Kit, one per group.
Rulers
Containers to facilitate distribution of the model pieces to students
Copies of Activity Sheets, one per group
Pop Bead set
Genetic Code table, one per student or one per group

Notes for the Instructor

The DNA Discovery Kit

The DNA Discovery Kit can be purchased from 3D Molecular Designs for $252. The model is sturdy but it can be damaged by someone who attempts to disassemble it as her/his first interaction with it. For this reason we have students assemble, but not disassemble, the nucleotides. We give each group of students two small trays, one containing the pieces of a GC pair and the other containing the pieces of an AT pair. This requires the instructor to pull the phosphates and the deoxyriboses off each nitrogenous base before handing them out, about a 10-minute job for 6 groups.

Pop Beads

We buy our Pop Beads from Ward's. We find we have to discard 10-20% of each new batch of beads because the holes are too large. It is important to test new beads so you can find the bad ones and discard them before they get mixed in with beads that have already been tested.

Genetic Code

We are not delving into transcription and translation in this lab, so we avoid those terms. We find that the common way to present the code, with each letter on a different side of a look up table, is difficult for students, so we use a table with several columns.

Randomizer

The dice with A/T/G/C sides were custom made and are not on the market yet. A different way of creating random base sequences will be needed. A bag of labeled poker chips is one method.

About the Authors

Robert Ketcham is Laboratory Coordinator in the Biology Department at the University of Delaware.

Appendix
Suppliers

3D Molecular Designs
1050 Market Street
Suite CC130A
Milwaukee WI 53202
414 774-6562

Ward's Science
5100 West Henrietta Road
PO Box 92912
Rochester, NY 14692-9012
800-962-2660
wardsci.com

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