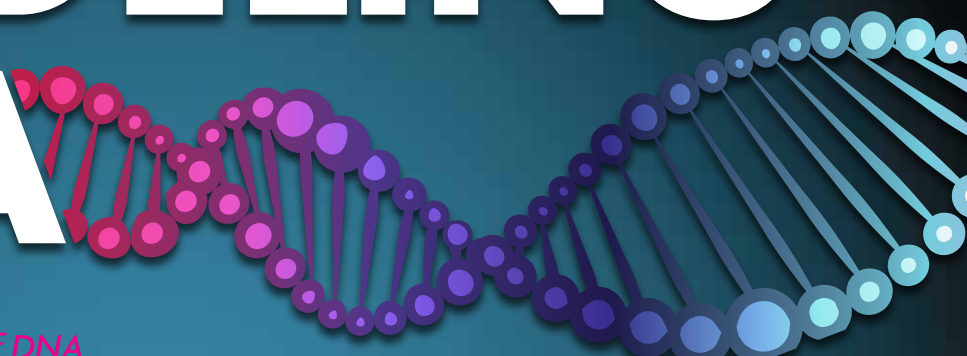


MODELING DNA



Understanding the structure of DNA through models and motion

Carol Robertson

Deoxyribonucleic acid (DNA) is life's most amazing molecule. It carries the genetic instructions that almost every organism needs to develop and reproduce. In the human genome alone, there are some three billion DNA base pairs. The most difficult part of teaching DNA structure, however, may be getting students to visualize something as small as a DNA molecule, which is only 2 billionths of a meter in diameter (much smaller than the human hair's 100,000 billionths of a meter diameter).

This article describes activities and models that introduce students to the components of DNA, including complementary base pairs and nucleotides, as well as the directionality of DNA—the fact that the two strands of DNA run in opposite directions to each other. In a kinesthetic activity, students position their bodies to create a DNA model and, in another activity, bend chenille stems (pipe cleaners) by hand to illustrate DNA structure and function. This helps students better understand growth and development of organisms, including inheritance and variation of traits (see box, p. 32, for connections to the *Next Generation Science Standards*). Students highly rate such simple classroom activities.



The "I Am a Nucleotide" DNA Body Modeling activity.

Using the 5E approach

A 5E approach (Bybee et al. 2006) allows teachers to guide students through a series of steps that build upon each other.

Engage

Pique student interest with a story about DNA, such as how DNA can help solve crimes or how minute changes in DNA may result in disorders such as sickle cell anemia. Then ask students, “What do you think DNA is made of? What does it look like?”

Explore

Next, have students perform DNA extraction—a laboratory activity to remove DNA from common substances such as strawberries or bananas. Step-by-step instructions are available online (see “On the web”).

If at first students find, disappointingly, that DNA simply looks like mucous, ask them to imagine what DNA would look like at the atomic level. Provide students with diagrams of DNA structure, or have them search online (see “On the web”) or in reference books or textbooks.

Through class discussion or by students researching the subject in teams of two to four, students should become familiar with the units that make up DNA: phosphate groups, deoxyribose sugars, and nitrogenous bases. Students must be able to distinguish between the four nitrogenous bases and to identify the components of a nucleotide, the basic building block of DNA.

Point out the complementary base pairs, and give students this tip about which goes with which: Straight letters of the alphabet go together (Adenine [A] always matches with Thymine [T]), and curved letters go together (Guanine [G] always matches with Cytosine [C]). To go into greater detail, you can discuss the differences between pyrimidines and purines—the nitrogenous bases of DNA respectively made up of a single and double carbon ring of carbon and nitrogen atoms—and between the number of hydrogen bonds for A–T (2) vs. G–C (3). The directionality of DNA (5′→3′) comes into play during DNA replication and protein synthesis and should be covered as well if your class goes into this level of detail. (Note: The two strands of DNA run in opposite directions to each other; one end of one strand is called the 5-prime [5′] end; the other end of that strand is the 3-prime [3′] end, a convention for identifying what other molecules, if any, are attached to the carbon atoms in the DNA’s sugar [deoxyribose] backbone. The 5′ end has a phosphate group attached to it, and the 3′ end does not.)

Modeling DNA

The “I Am a Nucleotide” DNA Body Modeling Activity (shown at left), which reinforces this information, should be done in an area with plenty of space for students to move around. Follow these instructions:

1. To represent the phosphate part of the DNA molecule, enlist a student helper to write the letter “P” on the back of each student’s left hand while the teacher writes one of the four nitrogenous bases in DNA on each student’s right hand. To keep the number of complementary base pairs equal, the teacher should rotate writing one of the four bases in this order: A, T, G, C. That way, if there

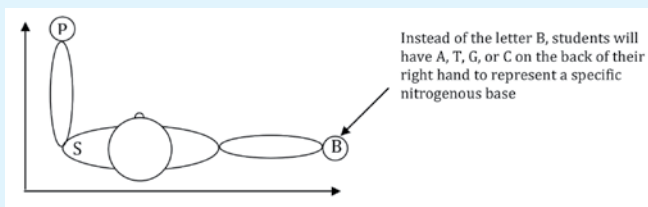
FIGURE 1

“I Am a Nucleotide” activity—script and diagram.

Script for teachers: To honor James Watson (an American) and Francis Crick (a Brit), who first described the double helix structure of DNA while collaborating in England’s University of Cambridge, use a British accent (just for fun) when leading students in this activity. Students should echo each statement in quotation marks aloud.

1. Start with arms down at your sides.
2. “I [students echo] am a nucleotide [students echo].”
3. “I have a *phosphate* on my *fi*st” [students echo]. As you say this, extend your left arm as shown and, while speaking, pat your left fist with your right hand at the italicized words. Your left hand should stay extended through step 6.
4. “I have *sugar* on my *sh*oulder” [students echo]. While speaking, pat your left shoulder with your right hand at the italicized words.
5. “And I have a nitrogenous *base*” [students echo]. Bring your right fist up to your right shoulder as you begin speaking. At the word *base*, punch your right arm to the side as if you were boxing, and hold that arm as shown below.
6. “I [students echo] am a nucleotide [students echo].”

Diagram: Aerial view of body orientation for the activity. Keep left and right arms perpendicular as shown and held parallel to the ground (allow frequent arm resting while students stand in place).



are an odd number of students (ending on A or G), the teacher can be the complementary base (T or C) to avoid having any unmatched nitrogenous bases as students link to each other to create the DNA. Safety note: Use water-based markers with the AP (approved product) label from the Arts and Creative Materials Institute (ACMI) and the phrase “conforms to ASTM D 4236.”

2. Facing the teacher, all students stand and spread out, echoing the teacher’s words and mimicking the teacher’s motions (Figure 1). Alliteration in the script helps students recall details of nucleotide composition.
3. Remind students that the nucleotide is the basic building block of DNA. Provide any other details you wish to include about nucleotides.
4. Recite the “I am a nucleotide” script (Figure 1) with students at least twice more.
5. Students should now use their bodies to create a model of an untwisted DNA molecule (opening page). First, remind students that complementary base pairs make up a “step” in the DNA ladder. Next, have students find their complementary base and form a hydrogen bond with each other by touching right fists, not holding hands, since this is a relatively weak hydrogen bond, while keeping their own arms perpendicular.
6. Ask students to connect *all* of the nucleotides to make the DNA ladder. The phosphate group (left hand) of one nucleotide must connect to the sugar (left shoulder, looking from behind) of the next nucleotide. Because this is a strong covalent (phosphodiester) bond, the left hand of one person should firmly hold on to the left shoulder of the person in front of them. Draw attention to students who figure out how to connect the DNA ladder and ask the rest of the class to add on to it (Figure 2).
7. You may modify this activity to show differences in the width of double ring purines vs. single ring pyrimidines. Students with A or G on their right hand must keep that arm fully extended, representing the wide, double-ringed structure of purines. Students with T or C on their right hand should bend that arm so the elbow points down to more accurately represent the narrower size of

FIGURE 2

Overhead view of student formation.

Below is an overhead view of students arranged to represent nucleotides. During the exercise, the instructor points out aspects of DNA structure, using this key: P: phosphate molecule; S: deoxyribose sugar; A: adenine; T: thymine; G: guanine; C: cytosine.

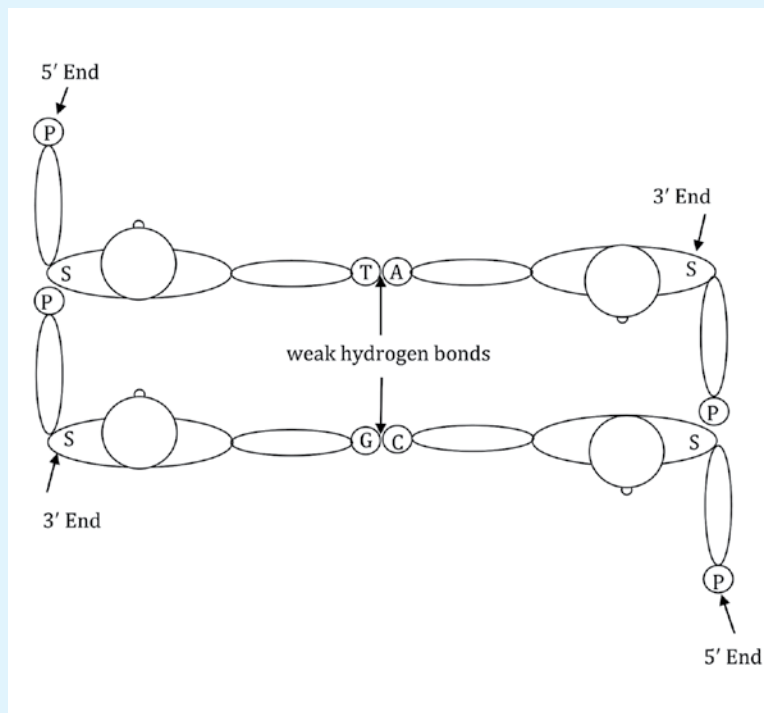


FIGURE 3

Supply list.

Supplies needed for one student to make the DNA chenille stem model, using 30 cm × 4 mm or 30 cm × 6 mm size chenille stems.

Color of chenille Stems:	How many you need:	Cut each piece into:	What they represent:
White	4	¼'s	Deoxyribose sugar
Red	2	DO NOT CUT	Phosphate molecules
Apricot (orange)	1	¼'s	Adenine
Turquoise (blue)	1	¼'s	Thymine
Green	1	¼'s	Guanine
Corn (yellow)	1	¼'s	Cytosine
Black	1	⅙'s	Hydrogen bonds

pyrimidines. A second modification can be made to show the number of hydrogen bonds between complementary base pairs. Students with G and C bases hold out three fingers to touch while students with A and T bases hold out two fingers to touch. Cheer when the class has correctly formed the DNA ladder. Students must remain standing in place for the DNA ladder, but allow them to rest their arms.

Explain

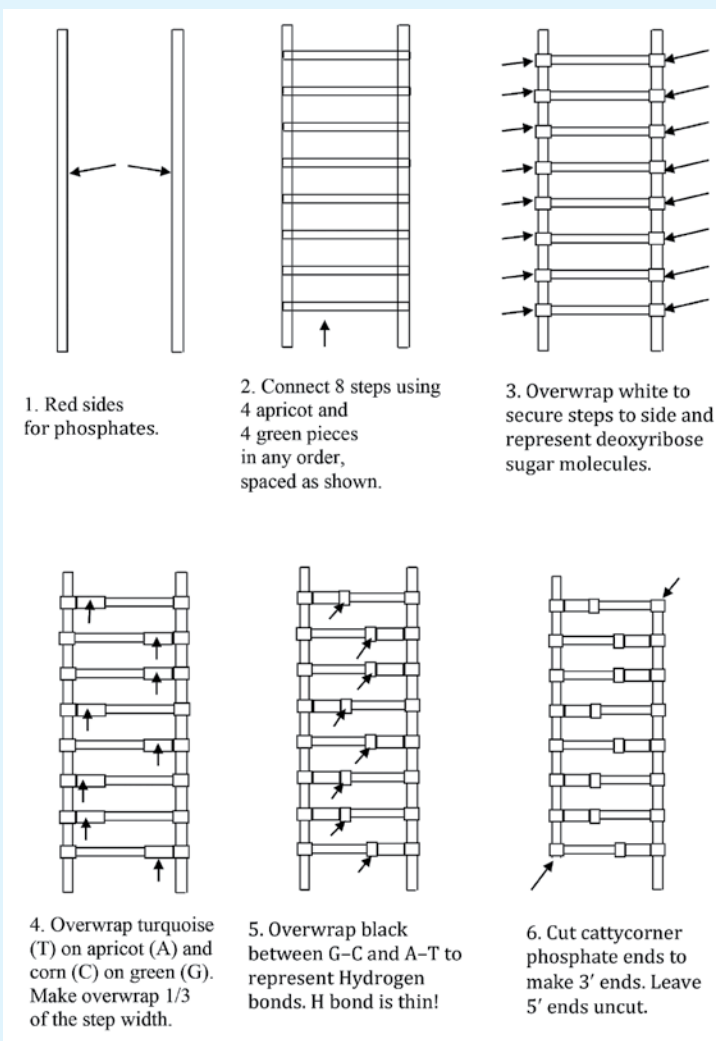
Partner students with their complementary base pair and have them compare the DNA body model with the diagrams they have studied so far. If necessary, students may need to re-make the DNA ladder. While they are in the ladder, help them identify deoxyribose sugar, phosphate groups, nitrogenous bases (A, T, G, C), nucleotides, complementary base pairs, antiparallel orientation, purines vs. pyrimidines, 5' ends and 3' ends, and weak hydrogen bonds. Have students see how the deoxyribose sugar molecules alternate with phosphate groups on the side of the ladder while the steps are made of complementary base pairs. (I usually walk down the side of the student DNA model and touch the left hands and left shoulders of students while saying, "Phosphate, sugar, phosphate, sugar..."). To illustrate weak hydrogen bonds, walk through the middle of the students' DNA and gently part the complementary base pairs (students' fists), saying: "weak hydrogen bond."

Next, introduce students to the directionality of DNA by reassembling the DNA molecule and asking what they notice about the direction they are facing. Students will see that the two sides of the DNA ladder are in opposite directions, just as the orientation of DNA is antiparallel. Stand at one end of the student ladder, facing the 5' end of one DNA strand, and explain that the front of the line for that side of DNA is the 5' end, represented by the student whose left arm is not connected to anyone else's. Ask students, "Where is the end of the line for this side of the DNA?" The 3' end is located on the deoxyribose sugar (left shoulder) of the last person who does not have anyone behind her or him. Reinforce the antiparallel orientation of DNA by pointing out that on the other strand of the DNA molecule, the 5' and 3' ends are oriented in the opposite direction.

Next, students return to their diagrams and notes to determine which parts of the DNA molecule are represented by their own bodies and to identify the structures that are in

FIGURE 4

Making the DNA chenille stem model.



the activity. Projecting the diagrams in front of the class and having students take turns coming up to the projected image to circle all the nucleotides will help students make the connection with the kinesthetic activity.

Elaborate

Students make a durable model with chenille stems (pipe cleaners), which are inexpensive when bought in bulk. Connecting the stems as shown in Figure 4 will help students learn about and remember DNA structure.

Student helpers hand out the appropriate number of chenille stems (Figure 3). Students use scissors or utility shears to cut the stems (Figure 6, p. 30) **Safety note:** Cut ends may poke students, so warn them to be careful and to use safety

FIGURE 5

How 10th-grade biology students rated various teaching methods (percentages) (n=42).

Teaching Method	1 Not helpful	2 Somewhat helpful	3 Helpful	4 Very helpful	5 Extremely helpful
DNA body modeling	0.0	7.1	14.3	19.1	59.5
Chenille stem model	2.4	0.0	11.9	28.6	57.1
Coloring diagrams	0.0	11.9	40.5	21.4	26.2
Taking notes	9.5	14.3	38.1	28.6	9.5
Reading the textbook	40.4	33.3	19.0	7.1	0.0

glasses. Students should assemble their models during class, when the teacher can reinforce the correct way to assemble the pieces. Because students typically make the overwrap for the pyrimidines (thymine and cytosine) too wide, remind them to keep this overwrap 1/3 the width of the step to accurately reflect the relative sizes of pyrimidines and purines. The overwrap for hydrogen bonds must also be very thin so that the appearance of the purine molecules is wider than pyrimidines. All overwraps should be done tightly to create a more stable model overall (Figure 7).

Evaluate

Students must complete an oral quiz, during which they name and point to all components or aspects of DNA represented in their chenille stem model. For instance, students may simply point to a deoxyribose sugar by touching that part of the model as they name it. However, the model must be twisted to demonstrate the double helix (photo, p. 31). To show antiparallel orientation, students must indicate 5' and 3' ends on each side and then use directional motions to show how each side is oriented from the 5' end to the 3' end.

To enhance student learning, my sophomore biology students practice with each other, using my classroom set of cameras to video their oral quizzes until they reach a mastery level of 90% (Figure 8).

I grade my sophomore biology students' videos outside of class, whereas I allow my upper-level honors genetics students to grade each other, so that they can gain valuable experience. Although I allow my sophomore biology students to refer to my list of required DNA structures (see "On the web") while taking the quiz, upper-level students are not afforded the same advantage.

After the oral quiz, I administer a 10-question multiple-choice written test that also asks students to draw and label the parts of a DNA molecule. I allow students to color code this model with the same colors used on the chenille stem model. Because I require 90% proficiency on the written quiz, retakes may be necessary for some students. Multiple approaches for evaluation ensure student mastery of DNA structure.

FIGURE 6

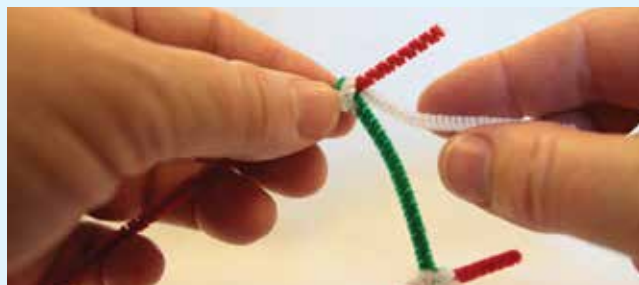
Chenille stems cut and ready to assemble.



FIGURE 7

Overwrapping.

Anchor each step to the side by overwrapping with white pieces. Wrap around this intersection from several different directions to ensure a tight connection and to fully cover it with white.



Conclusion

Surveys show that students believe the activities and models described in this article help them learn the structure of DNA (Figure 5). Using body modeling and incorporating DNA chenille stem models to teach DNA structure can provide students with a strong knowledge base that will serve them well as they go on to learn about DNA replication, protein synthesis, and inheritance and variation. ■

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On the web

DNA extraction: <http://bit.ly/1o99oRH>;

Extract DNA from a strawberry: <http://1.usa.gov/1nJZvWi>

Online DNA video module: <http://bcove.me/m3newyri>

List of required DNA structures for the quiz: www.nsta.org/highschool/connections.aspx

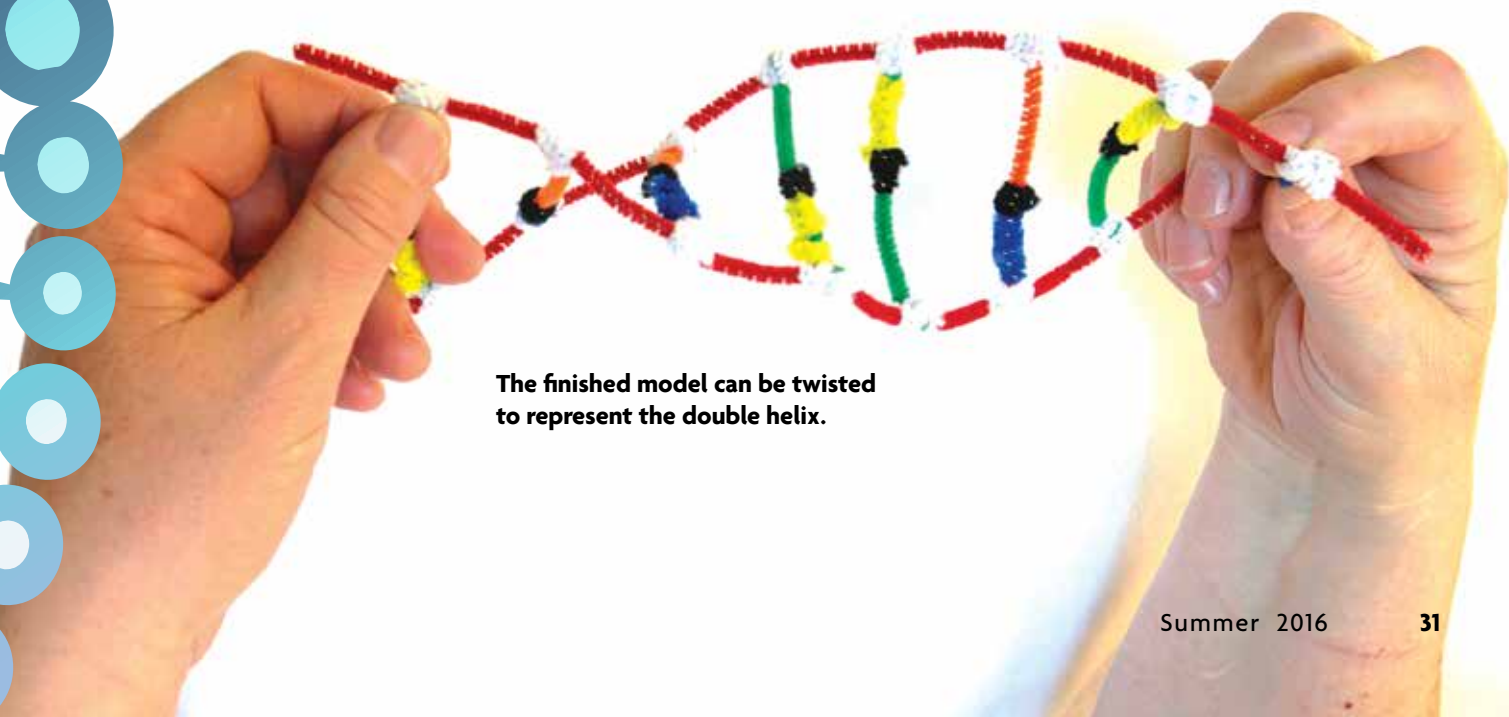
References

- Bybee, R.W., J.A. Taylor, A. Gardner, P. Van Scotter, J.C. Powell, A. Westbrook, and N. Landes. 2006. *The BSCS 5E instructional model: Origins and effectiveness*. Colorado Springs, CO: BSCS. <http://bit.ly/1UWoPtj>
- NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

FIGURE 8

Oral quiz.

One team member videos a fellow student taking the oral quiz over DNA structure. Students may review the video to check for accuracy and must redo the quiz if their scores do not meet the required level of mastery.



The finished model can be twisted to represent the double helix.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

Standards		
HS-LS1 From Molecules to Organisms: Structures and Processes HS-LS3 Heredity: Inheritance and Variation of Traits		
Performance Expectations		
<p>The chart below makes one set of connections between the instruction outlined in this article and the NGSS. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectations listed below.</p> <p>HS-LS1-1 Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.</p> <p>HS-LS3-1 Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.</p>		
Dimension	Name and NGSS code/citation	Specific Connections to Classroom Activity
Science and Engineering Practices	Developing and Using Models <ul style="list-style-type: none"> Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions – including energy, matter, and information flows – within and between systems at different scales. 	Students create a model of DNA using kinesthetic activities where they “become” a nucleotide and combine with other students to create a section of unwound DNA. Students also create a chenille stem DNA model that correlates with teacher-provided diagrams and the kinesthetic activities. Using these activities, students become proficient in knowing the basic structure of DNA.
	Constructing Explanations and Designing Solutions <ul style="list-style-type: none"> Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students’ own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS1-1) 	
Disciplinary Core Ideas	LS1.A: Structure and Function <ul style="list-style-type: none"> All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins. 	Students create a model of DNA with their bodies while using the kinesthetic activity and also by using chenille stems. Teachers use these modeling activities in helping students build their knowledge of basic DNA structure.
	LS3.A: Inheritance of Traits <ul style="list-style-type: none"> Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species’ characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. (HS-LS3-1) 	
Crosscutting Concepts	Cause and Effect <ul style="list-style-type: none"> Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-1) 	Students learn how covalent bonds and hydrogen bonds contribute to the chemical characteristics of DNA.
	Scale, Proportion, and Quantity <ul style="list-style-type: none"> Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. 	