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DNA: Modeling Structure and Function

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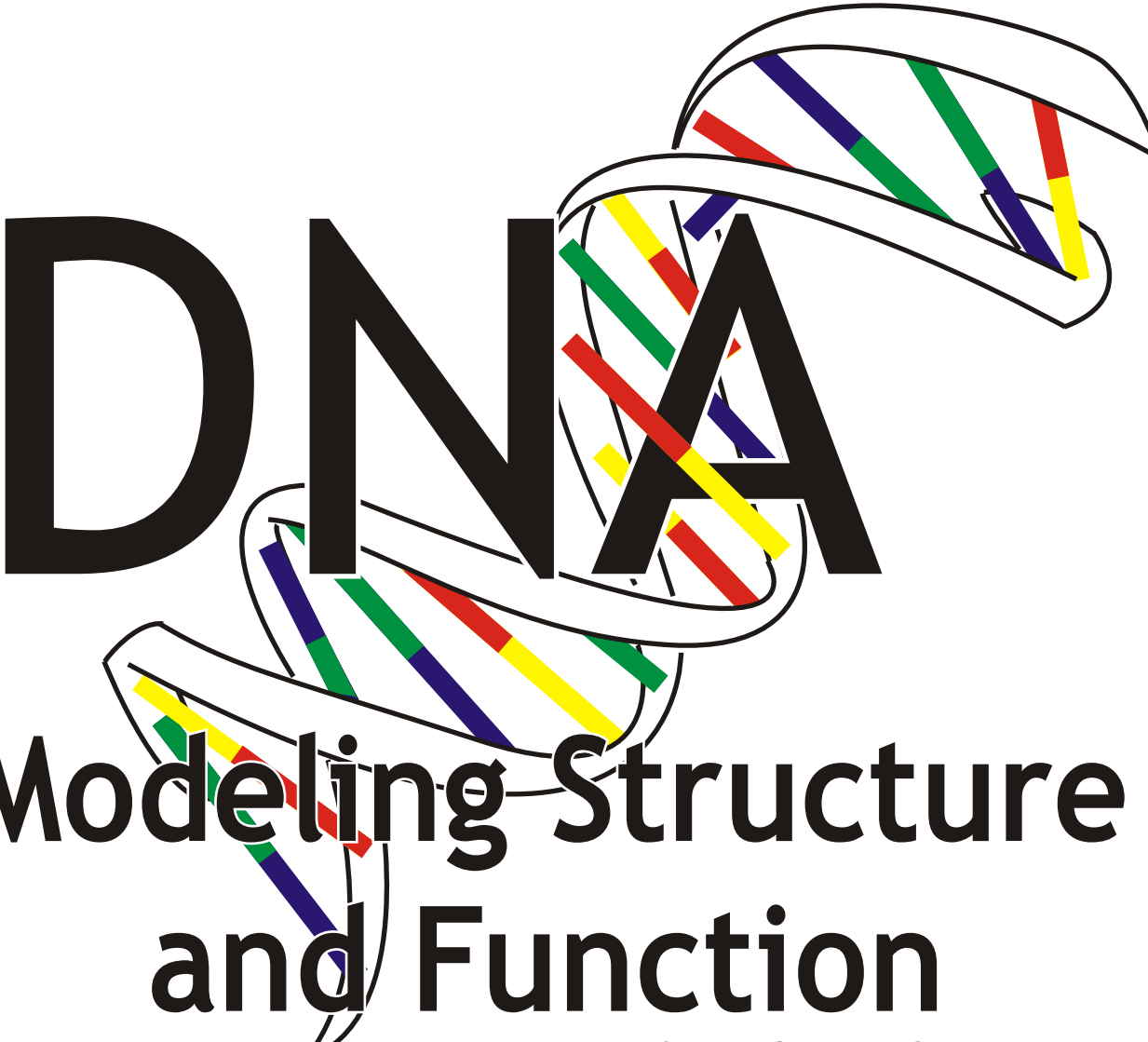
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DNA

Modeling Structure and Function

by Jennifer A. R. Smith and Cynthia J. Martin

ABSTRACT: This article presents a developmentally appropriate approach to introduce high school biology students to the structure of DNA and illustrate how its structure and function are related. We address the importance of beginning instruction with a concrete representation of DNA, and using it to scaffold to several important biological concepts. We also make clear the teacher's crucial role in this scaffolding process. *This article promotes National Science Education Content Standards C and G, and Iowa Teaching Standards 1,2,3,4, and 7.*

Understanding cells and the molecular basis of heredity are part of the National Science Education Standards for high school students (NRC, 1996). These content standards require that students understand the structure and function of DNA. The structure of DNA is often introduced via lecture along with two-dimensional media or pictures, reinforced with textbook reading, and then followed by having students construct a short three-dimensional model of the molecule. Many students struggle through such lectures and readings because they have significant difficulty visualizing what their teacher and textbook are attempting to describe. Difficulties visualizing the structure of DNA interfere in understanding how its function is linked to the structure. Thus, students resort to memorization.

High school students are able to understand and apply a wide variety of abstract science concepts, but often need assistance in forming and using those concepts. Two-dimensional representations portrayed by pictures, television, or computers may help, but students must still translate them into a three-dimensional structure. Hands-on materials, models, and careful scaffolding are necessary for students to grasp abstract concepts (Woolfolk, 2001). What this means is that learning is enhanced by beginning with concrete experiences, so that students can refer to back to those encounters when they are presented information and look at pictures.

This activity has been designed to facilitate students' learning by first providing a model to explore before discussing the structure of DNA. Beginning with a three dimensional DNA model provides students with a concrete object they can then refer back to as they work to visualize abstract ideas that follow. When introducing the structure and function of DNA, teachers can direct students' attention back to the models and use them to illustrate abstract ideas. This promotes increased mental engagement that results in a better understanding of the material and increased interest among students. This approach more effectively promotes a variety of National Science Education Standards, including the K-12 unifying concept of form and function as well as the unifying concept of understanding evidence, models, and explanation.

Building DNA Models

The idea for the construction of these models came from the University of Northern Iowa's BIOMES project. Models are made of everyday materials familiar to students such as plastic gutter guard cut into approximately one-inch wide strips, male and female electrical disconnects (yellow, size 12-10), duct tape, needle nose pliers, and red, blue, and green spray paint (Figure 1).

Electrical connectors that contain a lip in the end that prevents them from pulling through the gutter guard work best (Figure 2).

Before constructing models, first spray paint the electrical connectors so that you have equal numbers of red female to yellow male and green female to blue male connectors. After the paint has completely

dried, insert a connector in every other hole in the center of the gutter guard strip (Figure 3). On a second strip of gutter guard insert the matching connector (red to yellow or blue to green) in every other hole. Use duct tape to cover the back of the gutter guard



Figure 1. Construction materials to build DNA models.



Figure 2. Electrical connector with lip.

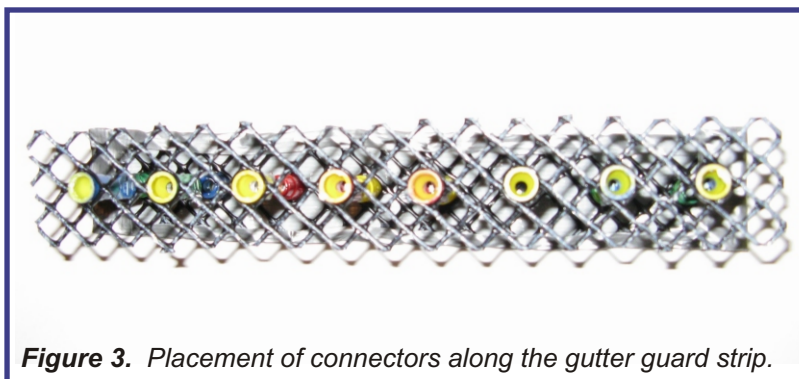


Figure 3. Placement of connectors along the gutter guard strip.

and to keep the connectors in place when pushing them together (Figure 4). Push the matching connectors together and squeeze shut with pliers. Vary the lengths of different models and the pattern of colors running down the center of each to represent different base pair sequences that exist in DNA molecules of different organisms.

Using the Models to Develop a Deep Conceptual Understanding of DNA

Begin the activity by placing students into groups of two. Show students the models without telling them what they represent. Some students may know the name for the models, but that doesn't mean they understand its structure and function. Demonstrate to the class that the models can be twisted, while emphasizing that handling of the models and twisting should be done gently. After providing each pair of students with a model, direct them to closely observe it and look for any regularities they feel may exist in the structure. Walk around observing what students do and listen to how they describe their models. Encourage students to write down what they observe by asking, "How will you remember your observations and interpretations when you no longer have the models?" When you feel students have sufficiently completed this task, direct them to switch models with another group, and observe it. As you walk around and notice that students have made many observations of their first and second models, ask questions such as "What similarities and differences exist between the two models?" When you decide students have thoroughly completed this task, have them exchange models for a third time with a new group. Continue as before, and have students summarize their observations and interpretations of all three observed models on a white board or butcher paper. Providing colored markers similar to the colors used in the models is important.



Figure 4. Placement of duct tape around the gutter guard strip. One side shows the alignment of the duct tape prior to folding it over.

After students have finished observing their third DNA model, begin a discussion with the entire class. Have students use their white boards or butcher paper to share their observations of what was similar and different between the models they observed. Similarities regarding the models typically include:

- the overall shape is similar to a ladder,
- the structure can be twisted,
- the structures' two sides are similar to that of a ladder,
- four different colored pieces appear in the center of the structure,
- each rung in the center of the structure is composed of two colored pieces, and
- the colored pieces always pair up in a specific order (blue with green, red with yellow).

However, students also note that the lengths of the models differ and that, while blue is always matched with green and red with yellow, the order of these colored pieces is different as you move down the ladder. These two points are essential, because they represent the only two differences between DNA molecules of any organism; the structure of DNA molecules of all organisms are the

same except for the number of base pairs (length of molecule) and the order of the base pairs.

If students have not already recognized that this is a model of DNA, this is the time to make this clear. Ask them “What do you now know about DNA after having observed models of its structure?”

Point out to your students that they have recognized some very important details about the structure of DNA, and one of those details is that DNA is a ladder shaped molecule that can coil and uncoil. Have them twist their models and tell them that this shape is referred to as a double helix. Some students may not be familiar with the term helix so be prepared to provide additional concrete examples of helices such as screws or the type of staircase you would find in a lighthouse (Figure 5).

After sharing this information with students, have them look at their twisted models once again and ask, “Why might the shape of DNA be called a double helix?” By relating this content to objects they find more familiar, students are more likely to understand and remember the terminology.

As students come to understand the structure of DNA, relating that structure to its function is important. Ask questions to spark in students the idea that a twisted structure takes up less room in the small nucleus of the cell. This can be accomplished by asking students what differences there are between the twisted and untwisted models. Additional appropriate questions include, “Why is it beneficial for the DNA to take up less space?”, “Where is DNA located?”, and “How big are most cells?”

Remind students of another important detail they noticed about their DNA, that the four parts making up the center of the structure were always paired red with yellow and green with blue. A series of questions is needed to lead students to the understanding that the matching process is essential to DNA's ability to replicate. For example, create one model of DNA that can easily be pulled apart. Take this model and, after having pulled it apart, ask “What would attach to this yellow part?”, “What would attach to this blue piece?” Continue this along each open strand and at the appropriate time ask, “As this continues along each open strand, what will be produced?” Students see that two copies of DNA are being made. Ask them to compare these two new DNA structures. You may have to orient the two structures in a way to help students come to the conclusion that the two structures are identical.



Figure 5. A spiral staircase is a recognizable example of an object with a helical structure. Photo courtesy of Jim Craig (see photo usage rights at the end of the article)

You should repeat this concrete demonstration as often as you deem necessary to build the concrete foundation necessary to scaffold to the inner workings of DNA in cells. Remember that cognitive development at this age varies considerably from one student to the next. Some students will quickly understand the structure of DNA and its significance. These students often readily volunteer to answer questions from the teacher, but this should not be taken to imply that all students have made the necessary connections to relate the form of DNA to its function.

Now begin the careful scaffolding to the function of DNA in the cell. Ask questions such as, “Where

do new cells come from?”, “When a cell divides, what must happen to the DNA?”, “Why is it important that DNA is copied before the cell divides?”, and “If DNA must be copied, how could the matching of bases be helpful?” Ask students to consider this last question as they unzip the connectors in the top half of their model. Then have students work in pairs and use white boards to diagram how the matching of bases could be used for DNA replication. Following discussion, students should come to realize that the matching of bases is essential to DNA replication and allows each side of the DNA molecule to work as a template.

Understanding the Nature of Science

The National Science Education Standards emphasize understanding of the nature and history of science, and the role of evidence, models, and explanation in science. Students should be aware of both the usefulness and limits of models. The remainder of this activity can be used to address these standards.

At this point in the lesson, hold up one of the DNA models for the class to see. Ask the students, “How is this model similar and different from DNA found in cells?” Typically students will likely respond that DNA is much smaller and is not made of plastic, duct tape, paint, or electrical connectors. Follow this with a question such as, “How are these models still useful for understanding DNA?” Next, show students an even more detailed model of DNA that includes representation of the deoxyribose sugars and phosphates, and ask students, “How is this model similar to and different from the first model?” While students should not be expected to understand the details of the more complex model, this important scaffold helps demystify it. Moreover, students come to understand that scientists build models to help us understand natural phenomena.

However, a crucial question remains! Ask students, “How did scientists come to understand the structure of DNA?” They likely will not know, but their answers often indicate their belief that scientists have a powerful magnifying device that permits them to directly observe DNA. You might choose to perform a DNA extraction from fruit and display it to the class. Place it under the highest magnification device you have in the classroom and have students peer at it. Now show them a picture of DNA taken with an electron microscope. Tell students that this is the highest magnification of DNA that is possible. This helps students understand that scientists have not seen the precise structure of DNA, and they are ready for activities and discussions about the history of science and how the structure of DNA was pieced together from a variety of data sources.

Many materials exist addressing this important scientific puzzle and the many individuals involved. One suggestion for conveying the difficulty scientists experienced in coming to understand the structure of DNA is to have the class watch and discuss the Nova program *The Secret of Photo 51*. Be sure to preview the entire program so that you can stop and ask questions or make comments at appropriate places. From class discussion, students should gain the understanding that science is

Additional resources for *The Secret of Photo 51* can be found on the PBS web site at: www.pbs.org/wgbh/nova/photo51/

a human endeavor involving creativity, collaboration, and competition. Students should also understand that data gathered did not tell scientists the structure of DNA; instead many forms

of data had to be analyzed and interpreted by scientists. Following lessons on the history of the discovery of DNA's structure, teachers should discuss the structure of DNA and the process of DNA replication in more detail. At this time the students' prior experiences with the models will serve as a concrete experience students can link to the more abstract content.

The Teacher's Key Role

Students will not come to the desired understanding of DNA and the nature of science simply by manipulating models. Clough (2002) writes that “without a teacher's perceptive questioning and

responding that plays off of students' observations, actions, and thinking, they would rarely accurately put together intended ideas." The questions interspersed throughout this article are only examples of what teachers must be ready to ask to help students make the desired links. However, for these questions to be effective, they must be appropriately scaffolded, be followed with appropriate encouraging non-verbal behaviors, and wait-time. Wait-time 1 (a 3+ second pause provided after a question is asked) provides students time to contemplate the question and develop an answer. Wait time 2 (an additional pause provided following a student response) encourages more student responses and elaboration of previously offered ideas. The initial discomfort felt by students and teachers during wait time is often necessary to draw out student responses and ideas, and is essential to the discussion process.

During wait time teachers must use positive non-verbal behaviors to encourage student responses and draw out additional responses. Teachers should also be non-judgmental when accepting answers from students. If students perceive their ideas will be judged by the teacher, they are less likely to respond, thus limiting the information gained about their thinking processes (Rowe, 1986; Penick, Crow & Bonnestetter, 1996). The models described here provide a needed concrete foundation for learning, but how teachers engage learners with these models and help them scaffold to desired understandings will determine the success of the activity.

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