A pipecleaner exercise to illustrate difficulties in DNA replication to students investigating the Meselson-Stahl experiment

Todd Nickle

Department of Chemical, Biological & Environmental Sciences,
Mount Royal College,
4825 Richard Road S.W.
Calgary, AB, Canada, T3E 6K6

Todd Nickle is a native Calgarian who had the luck to return to his home city after getting his Ph.D. at Oklahoma State University. When not teaching Biology, he chases his young son and daughter in a vain attempt to keep them out of mischief.

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Abstract

When teaching the Meselson-Stahl experiment investigating DNA synthesis, some students discount the conservative and dispersive methods of replication without considering that they indeed once were valid models to investigate. The double-helix structure of DNA is exceedingly awkward to unwind in order for semiconservative replication to be carried out successfully. With our current understanding of the enzymes involved in DNA replication, we know the topoisomerases assist unwinding by breaking the sugar-phosphate backbone to relieve torsion. In this exercise, students will model the DNA strand using pipecleaners and work in pairs to see the rapid buildup of torsion that occurs when trying to separate them into single-stranded pieces. This exercise is done during a normal lecture and provides a kinesthetic experience demonstrating a physical property of the double-helix structure.

Background and Exercise

As an instructor, I've tried to be cognizant of difficulties or misconceptions students bring with them or develop during instruction. I believe many are plagued by a desire to just focus on "what is known." As we work through the curriculum and revisit landmark work done by the scientific community, I find my students want to focus only on the results that show us "the truth" behind science questions. I believe that the *process* of science is important, and therefore I try to get the students to think *why* some of the wrong models were once considered acceptable.

In this demonstration, I have students construct "DNA models" by taking two pipecleaners, twisting their ends

together, and while holding them parallel and flat against a cylinder (for example, a fat sharpie marker or, less desirably, a pencil), wrap the wires into a spiral. At this point, I have the students adjust the sculpture so that the major groove and minor groove is seen, and point out the three-dimensional nature of their model. Though I haven't discussed transcription factors yet, I point out that proteins are involved in many ways for DNA maintenance and regulation of gene expression. These proteins typically must wrap along the major groove in order to identify the proper nucleotide sequences (much as a person looking up something from an index must see the page numbers in the book so that they can extract the information -- to do this, you need the proper-shaped tool, a finger, to turn the pages).

I next go over the conservative, semiconservative, and dispersive models of DNA replication. I point out that just after Watson & Crick published their initial paper, they only acknowledged that DNA molecular structure "suggests a possible copying mechanism" without going into details. Based simply on DNA structure, the three models could be constructed. Despite the simple elegance of the semiconservative model, it seems (to me, anyway) to be the most awkward. Have the students work in pairs, where one student holds the ends of the pipecleaner model. Next, the other student will pull the DNA strands apart while the first student holds the ends firmly. As the strands separate, torsion will rapidly build up and prevent the strands from easily parting. To allow the semiconservative model to work, a host of enzymes are required (helicases & topoisomerases). Natural selection has accommodated this limitation nicely, and the enzymes, after being predicted through thought-experiments, were later identified.

I believe this exercise provides a small break in lecture, which helps me communicate the scientific process to students in a more tangible way.

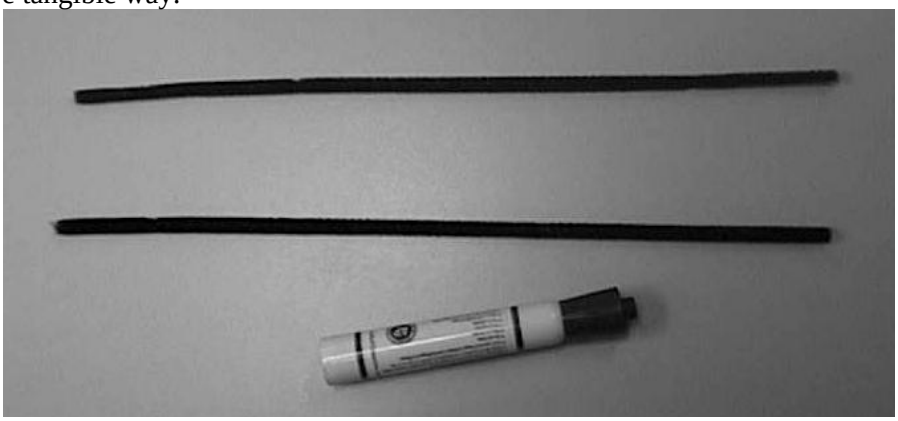

Figure 1. Supplies needed: two pipecleaners (of different colors if you wish to also point out differences between the pieces, such as the antiparallel nature of DNA). Any kind of cylinder, such as a highlighter, can guide you as you wrap the pipecleaners into a helix.

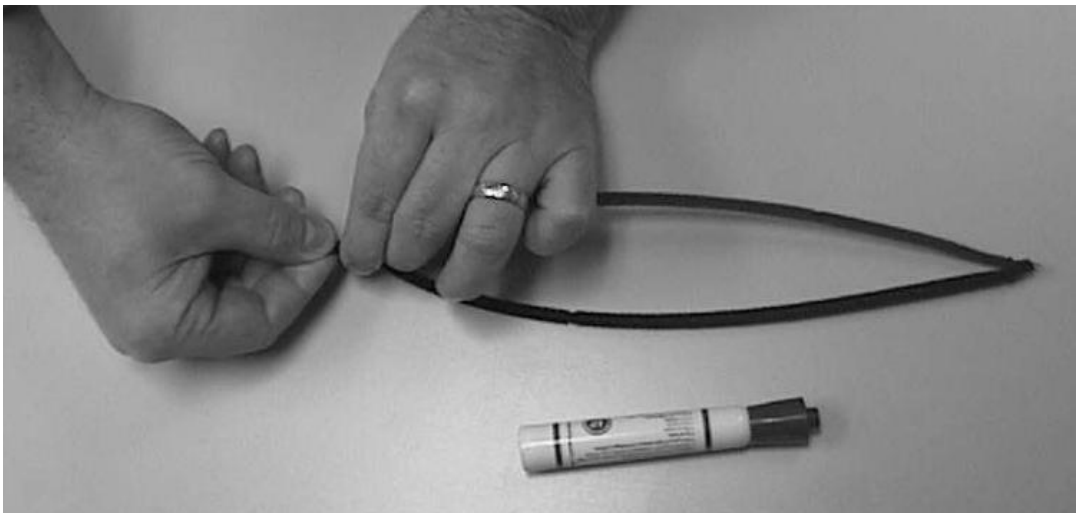

Figure 2. Twist the ends of the pipecleaners to anchor them.

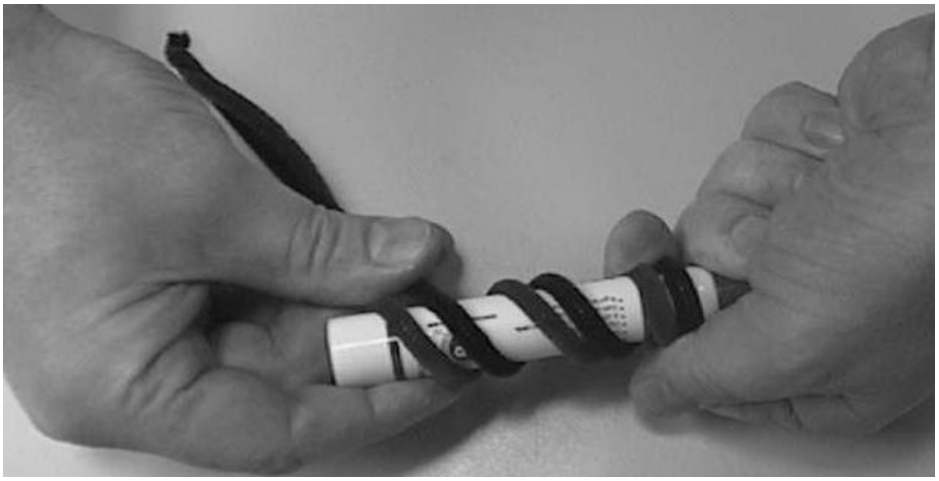

Figure 3. Wrap the pipecleaners around a highlighter or other wide cylinder, making sure the wires don't cross. Students can visualize that these are parallel lines -- in fact, they're *anti*parallel if you take into account the polarity of DNA.

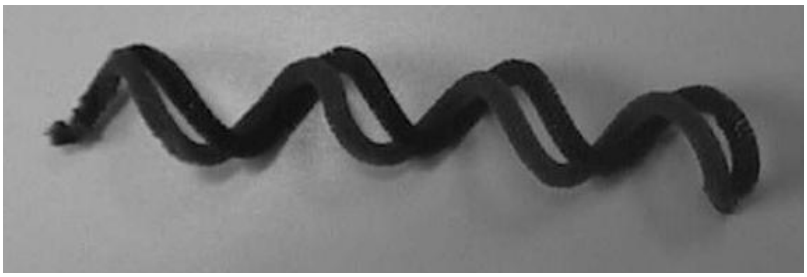

Figure 4. The finished "double helix". Note that the major grooves and minor grooves are quite evident.

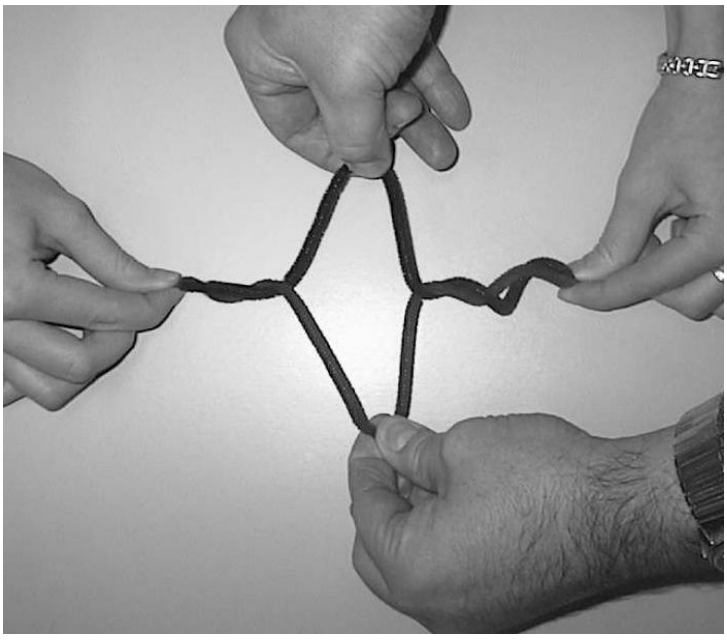

Figure 5. Have one student hold the ends and another try to untwist the DNA by pulling on each DNA molecule. Torsion builds up rapidly in front of the "replication forks" (left and right) which bracket the "replication bubble" (center). Point out that their tiny "DNA molecule", if made to scale, would be much longer than a typical college building and have them consider the kinds of stresses the forks will experience in an actual DNA molecule.